Mesoamerican Reef Alliance
ICRAN-MAR Project

FINAL REPORT TO USAID

Report of Project Activities and Results
as of November 2, 2006[1]

Contact: Liza Agudelo, Project Coordinator
lagudelo@icran.org

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[1] Project activities to be completed by June 30, 2007.

UNITED NATIONS ENVIRONMENT PROGRAMME

Caribbean Regional Coordinating Unit

CARIBBEAN ENVIRONMENT PROGRAMME

FINAL REPORT TO USAID

BACKGROUND INFORMATION.

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ACRONYMS AND ABBREVIATIONS

AVHRR	Advanced Very High Resolution Radiometer
APESCA	Asociación Pesquera del Caribe
BERDS	Biodiversity & Environmental Resource Data System of Belize clearinghouse
BMP	Better Management Practice
BFCA	Belize Fishermen Cooperative Association
BTIA	Belize Tourism Industry Association
CAFTA	Central America Free Trade Agreement
CCAD	Comisión Centroamericana de Ambiente y Desarrollo
CELB	The Center for Environmental Leadership in Business
CI	Conservation International
CIAT	Centro de Investigación Agrícola Tropical
CLUE-S	Conversion of Land Use and its Effects
CONANP	Comisión Nacional de Áreas Naturales Protegidas, México
CONAP	Consejo Nacional de Áreas Protegidas, Guatemala
CORAL	Coral Reef Alliance
CST	Certification for Sustainable Tourism
CTO	Caribbean Tourism Organisation
CZMAI	Coastal Zone Management Authority Institute, Belize
FAO	Food and Agriculture Organization of the United Nations
FGDC	Federal Geographic Data Committee
G-CAP	Guatemala – Central American Programs Mission, USAID
GCRMN	Global Coral Reef Monitoring Network
GDA	Global Development Alliance (USAID)
GEF	Global Environment Facility
GEMS-GLORI	Global Registration of Land-Ocean River Inputs
ICRAN	International Coral Reef Action Network
ICRI	International Coral Reef Initiative
IGBP	International Geosphere / Biosphere Program
INEGI	Instituto Nacional de Estadística, Geografía e Informática, México
LOICZ	Land-Ocean Interactions in the Coastal Zone
MAR	Mesoamerican Reef
MBRS	Mesoamerican Barrier Reef System
MODIS	Moderate Resolution Imaging Spectroradiometer
MPA	Marine Protected Area
MSC	Marine Stewardship Council
N-SPECT	Non-point Source Pollution and Erosion Comparison Tool
OSPESCA	Organización del Sector Pesquero y Acuícola Del Istmo Centroamericano
PROARCA	Programa Ambiental Regional Para Centroamérica (de USAID)
RA	Rainforest Alliance
RC	Reef Check
SOSC	Strategic Objective Steering Committee
SRTM	Shuttle Radar Topography Mission
TNC	The Nature Conservancy
TOC	Technical Oversight Committee
UNEP	United Nations Environment Programme
UNEP-CAR/RCU	UNEP Caribbean Regional Coordinating Unit
UNEP/DTIE	UNEP Division of Technology, Industry, and Economics
UNEP-WCMC	UNEP-World Conservation Monitoring Centre
UNF	United Nations Foundation
USAID	United States Agency for International Development
WCS	Wildlife Conservation Society
WIDECAST	Wider Caribbean Sea Turtle Conservation Network
WRI	World Resources Institute
WMW	ICRAN-MAR Watershed Management Workshop
WWF	World Wildlife Fund

INTRODUCTION

The current report is submitted to USAID to meet final reporting requirements as indicated in the contractual agreement between USAID and UNF in support of the ICRAN Mesoamerican Reef Alliance (ICRAN-MAR), which expired as of November 2, 2006. While this is the final report to USAID, it is important to mention that project activities are scheduled to finalize by June 30, 2007 and further development and results are expected in the coming months. A terminal project report of the ICRAN Mesoamerican Reef Alliance will be submitted to the donors as of August 30, 2007.

Beginning with an executive summary that describes overall status of project components – including summarizing tables of project statistics and project indicators– the report moves on to describing detailed aspects of project implementation by component (please refer to Section II); these sections contain lessons learned and expected results as of June 30, 2007. Section III presents the financial status of the project as of November 2, 2006. A final table of relevant annexes is presented at the end of the document.

EXECUTIVE SUMMARY

In recognition of the ecological and socio-economic richness and importance of the Mesoamerican Barrier Reef region (MAR), the ICRAN Mesoamerican Reef Alliance (ICRAN-MAR) project was designed in 2003 to contribute to the many local, national and regional-level resource conservation and sustainable development projects that had been initiated in the MAR region since 1990. Discussions among ICRAN representatives and conservation leaders in the MAR region had established that there were opportunities where ICRAN could, and should, become engaged.

As a result, ICRAN partners developed a 3-year initiative to address threats to the MAR under three components known for their potential to strongly impact the coastal and marine ecosystems: watershed management, sustainable fishing, and sustainable tourism. With the generous support of the United States Agency for International Development (USAID) and the United Nations Foundation (UNF), the ICRAN-MAR partners would conduct a set of inter-linked, complementary activities to enable the proliferation of good practices for coral reef management and conservation. The strategy of this Alliance would combine a conservation and sustainable management approach with the creation of partnerships with the private sector to leverage resources and talents to find long-term solutions.

Project implementing partners are the World Resources Institute (WRI), UNEP-World Conservation Monitoring Centre (WCMC), World Wildlife Fund (WWF), the Coral Reef Alliance (CORAL), UNEP-Division of Technology Industry and Economics (DTIE), and Reef Check. As of November 2, 2006, approximately 29 months after beginning project implementation, partners have achieved significant results, some of which have exceeded original expectations. A lead organization within ICRAN, UNEP-CAR/RCU manages project execution.

PROJECT IMPLEMENTATION

The project has evolved since its original inceptions and over the course of the implementation phase. Earlier stages required significant investments to set up the necessary mechanisms to undertake planned activities and achieve project goals. This included, among others, gathering information and building relationships with local counterparts. Initial results provided a good platform not only to leverage further support from governments and the private sector but also to inform and influence decision makers in the region. During these years of implementation,

ICRAN-MAR partners have capitalized on lessons learned and strengthened channels of communication with project partners and other initiatives in the region.

As already indicated in previous progress reports, while the three components of the project are closely interlinked and designed to pursue the overall goal of contributing to the sustainable management and use of the Mesoamerican Reef, each component is independent and as such, each one has had particular characteristics and different levels of complexity. The high dynamism of the project activities and the challenges they have produced, have called for adopting an adaptive approach to allow addressing changes in the implementation mechanisms as appropriate. Under the supervision of the Project's Coordinator and the guidance of UNEP-CAR/RCU this approach has facilitated the reorientation of investments —consequent with the project's objectives— as necessary.

The spirit of creating alliances and consolidating societies with the private sector for the benefit of coral reefs in the Mesoamerican region has been the fundamental objective of the ICRAN-MAR Project. The positive results obtained by the project to date demonstrate that alliances are an effective mechanism that can bring great benefits for the handling of Marine resources. Nevertheless, coordinating efforts is not a simple task and requires commitment and joint work to identify the best strategies that involves relevant stakeholders and especially the local partners.

Please refer to Section II of the present report for more detailed information.

Watershed Management

This component is integrated by two complementary sub-components:

a) On one end, WWF has focused its efforts identifying sources of pollution and sediment from agricultural activities that have a negative impact on the marine environment, as well as on-the-ground activities with agricultural businesses to adopt a suite of "better management practices". This work was designed to be carried out in three years, has produced concrete results over the past 2 years, and it is still ongoing.

b) On the other end, WRI and UNEP-WCMC have produced information and GIS tools for examining the potential impact of different land use and development options in the region and the associated impacts on water quality on the MAR. These hydrologic models and diagnostic tools help educate and encourage key stakeholders to implement better management practices to reduce impacts on the coastal and marine resources. This work was designed to be carried out during the first two years of the project. It is now almost complete, with only some further follow-up capacity building efforts to fulfill.

Under the leadership of WWF, the project has produced significant results following an innovative approach that has praised the importance of adopting better management practices (BMPs) in the agricultural sector, and highlighted the relevance of partnership building with the private sector for conservation efforts and better management. Aiming to achieve the project goal of identifying agricultural threats WWF managed to set up a bioaccumulation monitoring program, design a monitoring protocol, and leverage significant results from the private sector (e.g. Croplife) and other donors in the region (e.g. Summit Foundation) that help consolidate project results in the long-term. MoUs signed with major agricultural companies in the region (e.g. Chiquita, Dole) are now promoting the implementation of BMPs and speak of the industry's willingness to participate in actions that can lower their impact on the environment while maintaining their economical benefits.

This innovative work combining bioaccumulation testing with actual field work in promoting sound and cost effective better management practices has allowed WWF to raise the profile of the ICRAN-MAR project in the region. The agriculture work done to date has created the basis for deploying BMPs with the potential to reduce pesticides use by commercial agriculture and therefore to reduce contamination threats to the MAR.

Collaboration between WRI and WCMC has provided the basis for an innovative and comprehensive watershed analysis for the Mesoamerican Reef that was recently released by WRI (data CD and analysis) providing significant insights on the connections between land-based sources of threat and impacts to the MAR. This hydrologic analysis tool works at many scales and allows identification and prioritization of the sub-basins which contribute the most sediment and nutrients to coastal waters along the MAR. This analysis provides region-wide results that *should be considered preliminary and indicative of the overall pattern and magnitude of erosion and nutrient and sediment delivery across the region*.

Results of this analysis show that relevant policy action at a national level to address the contributions from agricultural lands in the region need to be supported. There is great potential and interest in the region to use this tool and its preliminary results. Results can help identify areas in need of better agricultural management, as the analysis identifies vulnerable areas where conversion to an erosive land use should be avoided, or where converted conservation practices should be implemented. The analysis also identifies areas with high erosion and nutrient runoff, where better agricultural management practices should be targeted. In fact, throughout the project, WWF has used the analysis results to target interventions on improved agricultural management.

Sustainable Fisheries

Early in the project, WWF carried out an analysis of the fisheries sector in the four MAR countries to determine needs and a protocol for action to successfully promote community-based fisheries management. Two main types of fishing were identified: 1) Lobster Fisheries, and 2) Finfish Fisheries.

After conducting field studies, several consultation workshops with experts in the region and local fishermen stakeholders, WWF was able to identify all the lobster fishing techniques in the MAR and to produce a comprehensive set of educational materials in support of Best Fishing Practices (BFPs) for lobster. A lobster Manual called “How to profit by practicing sustainable fishing: Lobster Fishing Practices Guidelines for the Mesoamerican Reef” was developed in coordination with local fishermen and has become the core of the project, guiding fishermen to adopt better fishing techniques. All this activities set the basis to achieve more ambitious goals, such as lobster fishery certification, or the establishment of a monitoring system of BFP that allows fishermen to guarantee that their lobsters have been caught using BFP (some seafood buyers have expressed their interest in buying this lobster at a preferential price).

An increasing number of communities have requested to participate in the initiative supporting the adoption of BFP and expressing their interest in engaging in sustainable and profitable alternative economic livelihoods. As the project continues, even more communities become aware of the significance and potential of their contribution to maintaining healthy reef ecosystems.

To address finfish fisheries, an Ecosystem-based fisheries management (EBFM) – with fishermen participation in field data gathering – was selected as the strategy to bridge the link between community-based management and ecological monitoring. The EBFM establishes a series of protocols for the use, monitoring and evaluation of the ecosystems where fishing takes

place. This strategy aims to reverse environmental degradation, and to provide socioeconomic benefits associated with fishing, and to help project partners understand the effects of human activities on ecosystems. The protocols developed have allowed partners to gather relevant scientific high quality information very useful in the designing of fisheries management.

The strategy to introduce the EBFM with fishermen participation is to identify marine protected areas (MPAs) with intense fishing activities; then organize workshops with fishermen and MPA authorities and design a monitoring program with fishermen participation. It is expected this monitoring program will be set up before the end of the project.

Implementation of Reef Check activities under the ICRAN-MAR project has served to produce continuous presence on the ground (and in the water) of RC trainers and trained divers in the monitoring of ecological and socio economical aspects of coral reef health. Allowing non-scientist to collect valuable data and educational support in areas where highly expensive and isolated scientific expeditions were lacking or had limited capacity. This can be easily measured in the vast amount of data collected over the life of the project, which has contributed valuable information for local managers, general public and to the Global Coral Reef Monitoring Network and that is available online free of charge. In addition, local dive centers have started to get the necessary tools to get involved in local reef conservation efforts while they receive financial incentives to offer an added value service to their clients.

Sustainable Tourism

Over the course of the past 2 years, project partners CORAL, UNEP-DTIE and WWF have promoted sustainable tourism in the region by: a) Fostering regional dialogues across a broad sector of industry stakeholders leading to collaborative action on embracing sustainable tourism, b) Facilitating the development of standards and a voluntary code of conduct that can be applied throughout the Mesoamerica region and potentially elsewhere in the Caribbean, and, c) Providing training and support for adoption of the code of conduct complete, leading to the private sector in the MAR being fully engaged in the practice and promotion of sustainable marine tourism. They have facilitated a stakeholder-led process in the marine tourism industry, resulting in the development of an innovative comprehensive set of conservation and safety standards for marine recreation activities such as scuba diving, snorkeling and boating operations.

Workshop trainings in three project pilot sites (Placencia-Belize, Roatan-Honduras, Playa del Carmen-Mexico) have improved the capacity of these communities to address coral reef threats by: a) increasing awareness of reef ecology and sustainable business practices, b) improving local capacity for collaborative coral reef conservation efforts through technical and financial assistance, and c) providing both a process and end product (standards) which will lead to implementation of a code of conduct for marine tourism operations. Over 300 stakeholders in the region have benefited from these activities.

After the standards were unanimously approved by a balloting process with participating of more than 160 local stakeholders (taskforce committee), project partners have initiated a standard testing process that will dictate the potential for replication in the region and elsewhere. 44 companies from across the region signed a letter of agreement to work with CORAL to participate in this process. It is expect that this program will provide a significant amount of data and anecdotal responses that reflect changes in industry practices, measure the effectiveness of the standards, and provide guidance for the future direction of the project.

Early findings allowed partners to identify that there has been very limited education and awareness training on many sustainable tourism and reef conservation issues, and both

individuals and associations in the project pilot sites are regularly requesting additional assistance from CORAL in addressing reef threats and promoting sustainable practices. While tremendous progress in securing buy-in to the process of standards development and implementation, it has become clear that it will require several years of work in the region to ensure widespread adoption of the standards and code of conduct.

Partnership Building/strengthening

Seeking ways to promote long-term sustainability of the project's outcomes, the coordinating and implementing partners have been engaged in leveraging and bringing the project to the attention of other stakeholders in the region. They have participated actively in several activities throughout the Mesoamerican region, such as the Tulum+8 meetings, that bring together a remarkable group of local communities, governments, NGOs, scientists, and the private sector to discuss ways by which conservation actions can be strengthened over the next 5 years. On the technical side, implementing partners have sought ways to enhance activities and leverage project impacts. One of such examples is Coral's establishment of a pro bono agreement with Underwriters Laboratories Inc. for use of their online standards development software.

In addition to coordinating and supervising the implementation of the technical activities, efforts have been made to ensure that duplication of actions is avoided or minimized at best, and that the use of the available financial resources is optimized. This has been made possible through meetings and discussions with representatives of organizations and institutions in the region to identify opportunities for collaboration. The spirit of building alliances and leveraging partnerships in benefit of the coral reefs in the Mesoamerican region is a primary objective for the ICRAN-MAR project and therefore a priority for the project coordination.

Multiple efforts for approaching to different stakeholders of the MAR region have been done, particularly with other regional projects such as the Mesoamerican Barrier Reef System (MBRS), The Nature Conservancy (TNC), The Mesoamerican Reef Fund (MAR Fund), Rainforest Alliance, the Ecorregional Program of the World Wildlife Fund (WWF) and the Conservation of the Mesoamerican Reef Program from Summit Foundation; and with private industries as CropLife Latin America. To date, the level of collaboration/communication with these institutions has varied and in some cases it is still to be determined or identified. Actions continue to be made in this regard.

Management and Administration – Coordination Support

Over the past two years the role of the coordination unit has been fundamental in supporting project performance. Overall project performance has benefited from the coordination's role in facilitating close follow-ups, constant communication, and transparency with project partners and other stakeholders in the region.

Under the direct supervision of UNEP-CAR/RCU and ICRAN, the coordination unit based in Belize City – Project Coordinator and Project Assistant have been engaged, among others, in the following activities:

- Facilitating communication between project partners for the timely and coordinated execution of project activities
- Facilitating direct communications between partners and project coordinator to foster transparency and provide feedback
- Facilitating communications between donors and partners

- Following up on project performance by providing feedback to implementing partners on progress reports and participating at different field activities
- Preparing consolidated reports to donors
- Providing logistical support to partners' activities – workshops, events, etc.
- Providing support to partners by securing endorsements for the project's components through follow up communications with other regional stakeholders with whom partners are building a relationship
- Attending different regional meetings to present project advances and raise the profile of the ICRAN-MAR project.
- Meeting with donors and other regional initiatives to brief on project advances
- Seeking consolidation of collaboration with other partners in the region
- Encouraging partners to participate at different venues to present project results
- Updating project website and producing promotional materials for the project
- Organizing meetings of the TOC and SOSC
- Working with the project assistant in Belize and the financial assistant in Jamaica to ensure proper and timely management of finances and reporting requirements.

OVERALL PROJECT PERFORMANCE

ICRAN-MAR partners have delivered project results as expected and in some instances they have produced more than originally requested in their project documents. Over the course of these years, they have managed to overcome roadblocks encountered during the development of the project to be able to produce the required deliverables.

Some initial roadblocks included:

- Availability of tools to undertake their activities – not always ready or easy to find,
- Need for coordination with other partners in the region – not easy to coordinate or to get information from others,
- Difficulties in timely coordination with other component counterparts – each organization carries out other parallel activities and schedules not always coincided,
- Receptiveness of local institutions and their willingness to provide information – level of response from local partners or their capacity to become involved was different in every country,
- Lack of relevant/available information or data,
- Insufficient project staff at any given time
- Budget constraints – original budget envisioned organization of one regional workshop; responses from regional stakeholders show that the project could have benefited from more resources for on-the-ground consultation and further capacity building.
- Overcoming confidentiality issues – such as in the case of agribusiness providing details about their industrial processes

Some of these difficulties were linked to the very nature of the processes partners were to implement (e.g. signing MoUs with agribusiness, or coordination with other regional initiatives). Others were related to shifts in staff responsibilities since times of project design and conception to actual implementation. In different instances program officers undertaking the planned

activities found that it was difficult to carry out activities or produce results as originally envisioned by their predecessors. Luckily, the adaptive management capacity of the project and the close communication with the coordination unit facilitated overcoming these roadblocks and project results have been achieved.

The program has established and strengthened important alliances with partner organizations and projects (e.g. Conservation International, TNC and FFEM), major international corporations (e.g. Chiquita, Dole, Fyffes, etc.), local industries and local community groups (e.g. fishermen's cooperatives). This mosaic of partnerships and alliances has positioned the project at a strategic point where there is potential to leverage major changes in policies and practices at national and regional levels. These changes are needed to reduce threats from expanding development activities and overall economic growth in the region.

PROJECT STATISTICS – OVERALL INDICATORS

The following indicators are extracted from the project statistics tables below. For more details about particular aspects please refer to Section II of this report.

Table 1: Number of Institutions/Communities Involved Per Sector – See figures 1-7 below

SECTOR	QUANTITY [1]	WM	SF	ST
Govt Agencies	34	16	8	15
Local NGOs	22	7	10	9
Other NGOs/Regional Initiatives	18	10	2	8
Local communities	58	0	56	4
National Institutions [2]	23	10	5	8
Private Sector	115	20	20	77
Total	*270*	*63*	*101*	*121*

(1) Approximate numbers; (2) e.g. Universities, research centers

WM: *Watershed Management*

SF: *Sustainable Fisheries*

ST: *Sustainable Tourism*

Table 2: Leveraged Funds - over $1,600,000 USD in support of activities under the three components

LEVERAGED FUNDS - USD	SOURCE	PARTNER	COMPONENT	SCOPE/COMMENTS
$100,000	Oak Foundation	CORAL	ST	Three-year matching grant
$20,000	Summit Foundation	CORAL	ST	In support of tourism stakeholder attendance and participation at the Tulum +8 conference in Cancun, Mexico.
$57,000	Summit Foundation	CORAL	ST	To facilitate execution of environmental performance assessments, training, and technical assistance with marine recreation providers on the island of Cozumel, Mexico, with a specific focus on cruise industry contractors. The project, to be executed jointly with Conservation International (CI), has the primary goal of minimizing impacts to Cozumel's reef resulting from the rapid growth of cruise tourism on the island in recent years. While CI will engage the demand side of the tourism sector, CORAL will work directly with marine recreation providers, utilizing the ICRAN MAR standards as the primary assessment and training tool for application of better business practices.
$120,000	Bob Toth	CORAL	ST	In-kind services provided by internationally renowned standards consultant Bob Toth for guidance in the standards development process

LEVERAGED FUNDS - USD	SOURCE	PARTNER	COMPONENT	SCOPE/COMMENTS
$100,000	Underwriters Laboratories	CORAL	ST	A pro-bono contract for use of online Collaborative Standards Development Software (CSDS) to facilitate the process of standards development.
$20,000	National Marine Sanctuary Foundation	CORAL	ST	To add San Pedro, Belize and Cozumel, Mexico as new tourism pilot sites in the MAR region. In each site, partners will engage stakeholders with the Sustainable Marine Recreation and Conservation in Action training series, and will further provide technical and financial support for locally led projects
$40,000	National Fish and Wildlife Foundation	CORAL	ST	To add San Pedro, Belize and Cozumel, Mexico as new tourism pilot sites in the MAR region. In each site, partners will engage stakeholders with the Sustainable Marine Recreation and Conservation in Action training series, and will further provide technical and financial support for locally led projects
$200,000	FFEM	WWF	SF	For fisheries management in 3 Marine Protected Areas (Punta de Manabique, Cuero y Salado, Cayos Cochinos); promotion of best fishing practices, development of management plans.
$200,000	Water Fund	WWF	WM	In Guatemala
$30,000	Croplife	WWF	WM	For activities to measure the impact and the bioaccumulation of agricultural effluents on targeted species within the Mesoamerican Reef
$36,000	FFEM	WWF	SF	In support of EBFM, Alternative livelihoods, and Lobster BFP
$45,000	Kukulcan Plaza	WWF	SF	In support of EBFM and Alternative livelihoods
$450,000	Summit Foundation	WWF	WM	Support for bioaccumulation monitoring of marine life within the Mesoamerican Reef to identify agricultural threats. $150,000/year throughout the life of the project. Support in the preparation of the Monitoring Protocol
$50,000	Summit Foundation	WWF	SF	In support of fishermen villages severely impacted by Hurricane Wilma, in November 2005. The purpose of these funds was to pay salaries of unemployed fishermen from Holbox and Chiquila in an ecological monitoring program leaded by WWF experts.
$50,000	Summit Foundation	WWF	SF	In support of EBFM activities
$51,150	Sustainable Fisheries Fund	WWF	SF	In support of MSC lobster certification activities
$75,000	Munson	WWF	SF	In support of EBFM activities
In-Kind	UNEP	UNEP-WCMC	WM	Work on the GEO4 scenarios was co-opted for use in this project, leveraging the considerable investment by UNEP in the regional to global scale scenarios process and models.

WM: Watershed Management, SF: Sustainable Fisheries, ST: Sustainable Tourism

Table 3: Leveraged Impacts – originated from project objectives not contemplated in original project document

ORIGINAL ICRAN-MAR ACTIVITY	PARTNER	COMPONENT	IMPACT
Identify agricultural threats to the MAR	WWF	WM	• Leveraged support from Summit to undertake bioaccumulation studies • Development of monitoring protocol to conduct toxic bioaccumulation testing in the region. WWF has completed 4 rounds of testing in Chetumal Bay Mexico, Belize, and Honduras • This protocol has been used by NOAA in the monitoring of contamination after Katrina's hurricane in New Orleans, US. In addition, it has been adopted by the New Zealand government to monitor contamination of their reef.
Implement BMPs	WWF	WM	SabMiller (The Coca-Cola Company), decided that its key sugarcane producer in Central America (AZUNOSA) signed a collaborative agreement with WWF to work together on BMPs
Implementation of better practices	WWF	All	WWF international wants to replicate the structure and holistic approach of the ICRAN-MAR in other parts of the world.
Community-based ecological and socio-economic monitoring	RC	SF	• Local communities empowered to be part of management actions being designed for the region • Data serves to raise awareness of the coral reef crisis at a local level (reporting bleaching event 2005), making emphasis that these crisis occurs also at the global level. Data collected by participants can be viewed, analyzed and compared globally free of charge online at www.reefcheck.org/datamanagement
Good practices for marine recreation	CORAL	ST	Partnerships with other conservation organizations (e.g. CI) to replicate the strategy in other pilot sites in the region

WM: Watershed Management, SF: Sustainable Fisheries, ST: Sustainable Tourism

Table 4: Project Products used by other institutions – raising the profile of the ICRAN-MAR project

OBJECTIVE	RESULT	PARTNER	COMPONENT	USED BY
Identify agricultural threats to the MAR	Developed a Monitoring Protocol	WWF	WM	Project partners, NOAA, Government of New Zealand
Community-based ecological and socio-economic monitoring	Monitoring data	RC	SF	Provided data to NOAA Coral Reef Watch on the main 2005 Caribbean bleaching event; data from before, during, and immediately after the period June 2005-January 2006.

WM: Watershed Management, SF: Sustainable Fisheries

Table 5: Beneficiaries – over 1,000 direct beneficiaries through various activities in the 3 components

PEOPLE – BENEFICIARIES	COMPONENT	COUNTRY	COMMENTS
25 people trained in the Modelling tools	WM	Regional	Participation at Watershed Management Workshop
More than 50 regional stakeholders informed in preliminary results of watershed analysis	WM	Regional	Participation at Watershed Management Workshop
More than 200 farmers of the Orange Walk District Division.	WM	Belize	Participation at training in the use of biological control to fight the sugar cane Froghopper (*Aeneolamia spp*.) using the fungus *Metarhizium anisopliae*
More than 150 local stakeholders trained in the Reef Check protocol	SF	Regional	Participation at various Reef Check trainings and workshops
Over 300 Fishermen from the 4 countries	SF	Regional	Participation at various Best Fishing Practices studies, publications, workshops and trainings; EBFM; alternative livelihoods
Over 300 individuals from the MAR trained and sensitized on tourism best practices	ST	Regional	Training and participation in development of standards and codes of conduct for marine recreation activities, as well as on the value of coral reefs (including all national and first pilot workshops)

WM: Watershed Management, SF: Sustainable Fisheries, ST: Sustainable Tourism

Figures 1-7. Participation of various organizations by country and component. See Annex 2 for detailed tables

Fig. 1. Type of Organizations Involved in the Project

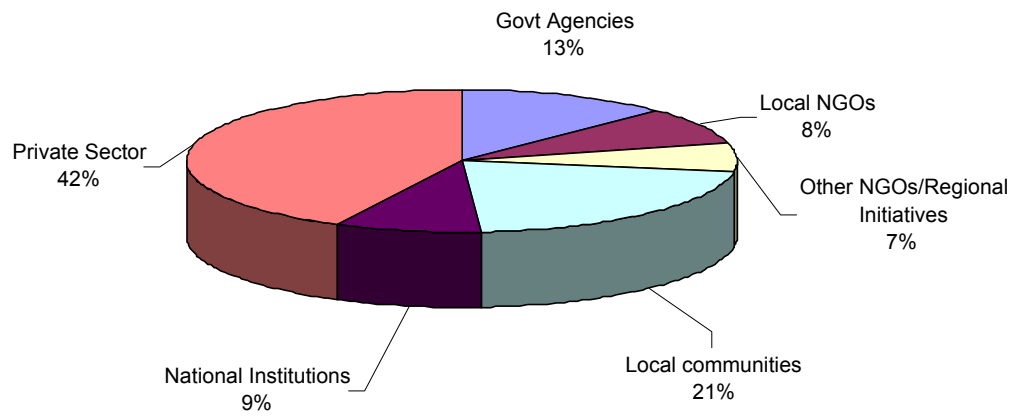


Fig. 2. Government Agencies Participation by Country

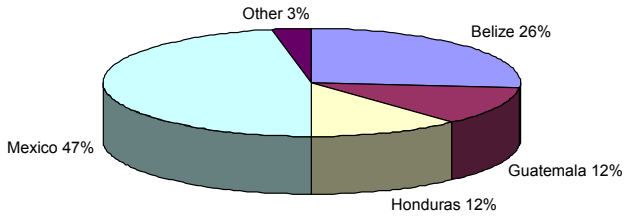


Fig. 3. Local NGOs Participation by Country

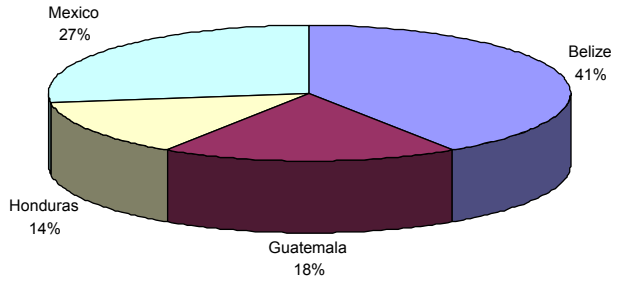


Fig. 4. Other NGOs/Regional Initiatives Participation by Country

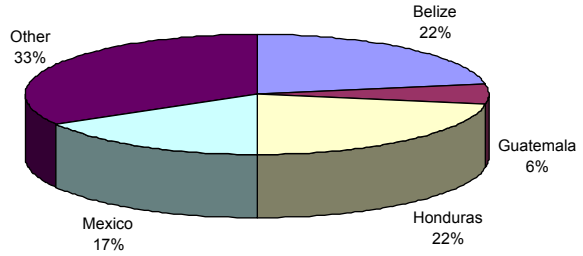


Fig. 5. Local communities Participation by Country

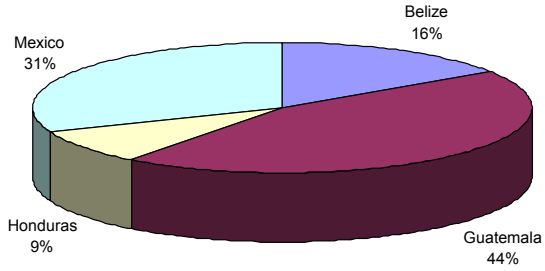


Fig. 6. National Institutions(*) Participation by Country

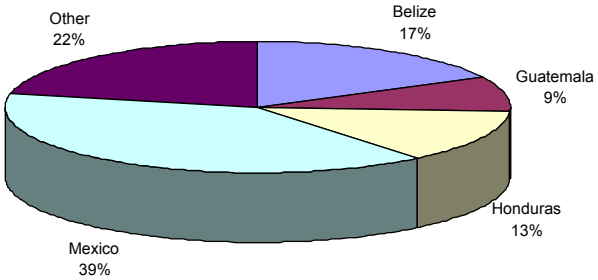
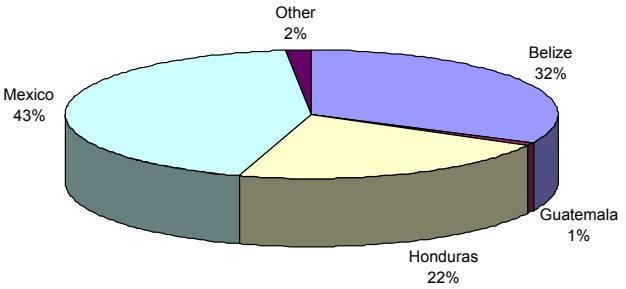


Fig. 7. Private Sector Participation by Country



(*) National Institutions: e.g. Universities, research centers

PROJECT INDICATORS BY COMPONENT – STATUS AS OF DECEMBER, 2006[2]

Watershed Management (Intermediate Result 1). *Partnerships created that produce relevant information and forecasting resulting in improved watershed management in areas impacting the Mesoamerican Reef*

SUB-RESULT 1.1. PARTNERSHIPS ESTABLISHED WITH THE AGRI-BUSINESS COMMUNITY RESULTING IN ADOPTION AND IMPLEMENTATION OF BEST PRACTICES.		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 1.1.1: Identification of best management practices:		
- Develop partnerships with major agribusiness (e.g. Chiquita) and medium and small producers whose operations are carried out in key watersheds draining into the Mesoamerican Reef ▪ Identify key stakeholders ▪ Maintain regular communication and conduct meetings with leading companies ▪ Jointly develop language for MoUs	• MoUs (4) signed with major agricultural companies for the adoption and implementation of BMPs in agri-business	• 100% Completed. Six MoUs already signed: Chiquita, Dole, CropLife, AZUNOSA, ACISON, the Local Union of sugarcane producers ULPCA-CNC from Chetumal Bay, Mexico • 75 % MOU by Fyffes. To be finalized early 2007
- Identification of agricultural threats: focusing on the 8 key threats of each of the 4 agro-industries in the zone compared to those already documented by Rainforest Alliance - Data collection on agricultural production cycles: to understand seasonal variations and feed data into the watershed modeling process - Identify appropriate bio-indicators of agrochemical contamination in fluvial and marine ecosystems identified (this will be done in support of the MAR Project with WWF counterpart funding from the Summit Foundation). ▪ Bioaccumulation study conducted and Ecotoxicology workshop convening experts from leading agro industry enterprises of the region and from agro chemicals-production transnational companies ▪ Conduct agricultural surveys	• Three key threats of each of the four agro-industries identified that are most damaging to the health and integrity of the MAR, compared to information already documented by Rainforest Alliance. • Key agro-chemical impacts on freshwater and marine organisms identified • Protocol for pesticide monitoring in reef organisms developed. • Long-term monitoring of Bioaccumulation foreseen with funding from the Summit Foundation	• 100% completed (Herbicides, fungicides and insecticides were identified – WWF-Ag Brochure published). Monitoring protocol developed. • Activity is ongoing until the end of the project
- Inventory of agricultural practices. Review existing BMPs and develop agricultural "better management practices" handbook for bananas, citrus, oil palm and sugar cane - Develop specific targets for reduced impacts and identify the costs and financial impacts of implementing BMPs.	• Detailed documentation of existing agricultural practices collected • BMPs for each of the agro-industries are identified; including analysis of environmental impacts, acceptable standards and financial	• 50% completed. This activity depended mostly on the signing of MOUs. • An agriculture group, including a representative from the

[2] For indicators as of June 30, 2007 – end of the project, please refer to Section II of this report

SUB-RESULT 1.1. PARTNERSHIPS ESTABLISHED WITH THE AGRI-BUSINESS COMMUNITY RESULTING IN ADOPTION AND IMPLEMENTATION OF BEST PRACTICES.		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
▪ Collect information on existing and proven better practices, agricultural practices, production and threats, the development of specific measurable standards for reduced impacts, and the identification of the costs and financial impacts of implementing BMPs. ▪ Identify innovative producers who already employ better practices ▪ Identify commodity-specific BMPs from different parts of the world that might be relevant for adaptation to the MAR eco-region (utilizing the WWF, RA and ICRAN networks) ▪ Conduct analysis on the relative impacts and costs of each of the identified BMPs	costs associated with BMPs. • Agricultural "best practices" selected and guidelines handbook for bananas, citrus, oil palm and sugar cane developed • Established demonstration site for implementation of BMPs in one key watershed • A constituency developed composed of local government, private and public sector stakeholders to discuss scenarios and implement “better practices” for watershed management	government (SESCCO) was formed. The group is active. • 50% MoU with Honduran Minister of Agriculture and Livestock and with Minister of Natural Resources and the Environment. • 100% MoU with FHIA – strengthen scientific base
Activity 1.1.2: Implementation/Adoption of best practices		
- Conduct an ample consultation and a regional meeting with the agro industry to determine realistic scope of work and to develop concrete and specific standards - Formalize key partnerships: Bring key participants together to review and assess the information collected and to negotiate agreements, - Encourage governments in BMP-based policy making: Begin to sensitize government officials to the value of developing BMP-based regulatory and permitting systems - Develop positive relationships with influential producers: ▪ Attend on-going producer group meetings in addition to face-to-face meetings with innovators, influential individuals and others that need to be brought into the process in order to facilitate the dissemination of BMPs by producers - Implement of best practices together with community initiatives and conduct monitoring within one key watershed demonstration site (determined with feedback from sub-results 1.2 and 1.3)	• MoUs or formal understandings with each of the key producer groups regarding adoption and dissemination of BMPs and information about progress available on the web site. • Promotion of BMPs with at least two agribusiness and medium and small producers • Best management practices for watershed management, to be adopted by at least one key watershed • Survey of palm oil plantations and database and written report with interactive GIS map for: San Alejo Valley, Sula Valley, Northern Honduras, and Aguan River Valley.	• This is an ongoing activity. MOUs have been signed and WWF is working with agribusiness partners in identifying, implementing and evaluating BMPs. • 25% MOU signed by one Palm Oil Producer • 100% MOU signed by one Sugarcane Producer • 90% MOU signed by the Citrus Grower Association, Belize • 80% for San Alejo Valley • 90% for Sula Valley and Aguan River Valley
- Compilation of data on agricultural production cycles of other crops different from the five commodities under the coverage of this ongoing project.	• Formal written report of findings	• 85 % (Report will be presented by June 2007)
- Research, financial analyses and documentation of BMPs on banana, sugarcane, and citrus plantations.	• Report of findings	• On going activity. Final findings will take more than a year to be released

SUBRESULT: 1.2 TRENDS IN LAND USE INTEGRATED WITH SPATIAL, HYDROLOGICAL AND OCEANOGRAPHIC MODELS FOR USE IN MODELLING		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 1.2.1. Predictions of future patterns of land cover changes		
- Make predictions of future land cover change in the MAR by assessing the current pattern of land use within the region, as well as historic changes over the past decade through analysis of existing and scheduled land cover maps.	• Land use and land cover changes from 1990 to 2000 determined	• Complete
Activity 1.2.2. Definition of watersheds discharging along the MAR		
- Conduct a detailed analysis and derive a comprehensive delineation of all the watersheds discharging to the MAR ▪ Use of high-resolution digital elevation data (90 or 100 m resolution) - Refine preliminary watershed delineations with feedback from project partners and through corrective measures such as using improved data on river locations	• Watersheds larger than 25 sq km discharging along the MAR defined. • Production of the first comprehensive database on watersheds for the region • Delivery of results: other report(s) besides ICRAN-MAR internal reports	• Complete • Complete • A project summary report, GIS data and metadata are available on the project summary CD and on the web.
Activity 1.2.3. Hydrologic and spatial analysis of impact of land-cover change on erosion and sediment delivery		
- Evaluate changes in erosion, sediment and nutrient delivery by watershed for all watersheds discharging along the MAR ▪ Analysis to be conducted through coupling of hydrologic networks and watershed boundaries through hydrologic model and Geographic Information Systems (GIS) techniques - Undertake hydrologic and spatial analysis of impact of land-cover change on erosion and sediment delivery ▪ Currently available hydrological models and data sets will be used to explore the dynamics of water and sediment transport within the MAR	• Land cover change estimated for all land areas along the MAR • Data sets on rivers, slope, soil type and precipitation acquired to integrate in hydrologic modeling • Hydrological analysis of sediment and nutrient delivery to river mouths conducted for over 400 watersheds along the MAR. • Delivery of results: other report(s)/publications besides ICRAN-MAR internal reports	• Complete • Complete • Complete • A project summary report, GIS data and metadata are available on the project summary CD and on the web.
Activity 1.2.4. Model calibration		
- Outputs of hydrological modeling and watershed assessments will be evaluated and calibrated against compiled sources and data from satellite imagery.	• Models calibrated to predict impacts of land cover change for all land areas along the MAR • Models refined and validated through a collaborative network, including local stakeholders.	• Complete. WRI and Texas A&M collaborated on model calibration. • WRI collected data from partners to validate the hydrologic model.
Activity 1.2.5. Estimation of dispersion of sediments and nutrients		
- Transport modeling conducted to estimate the extent and location	• Dispersion of sediment and nutrients for all	• Complete. Implemented by

SUBRESULT: 1.2 TRENDS IN LAND USE INTEGRATED WITH SPATIAL, HYDROLOGICAL AND OCEANOGRAPHIC MODELS FOR USE IN MODELLING		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
of sediment and pollution dispersion plumes from river mouths - Data on water chemistry to be obtained from an electronic database of riverine chemistry	land areas draining along the MAR estimated • Circulation model for the MAR region modified (or enhanced) to allow for modeling sediment dispersion • Watershed, hydrological and oceanographic models integrated such that predictions can be made	the University of Miami. • Complete. • Complete. The University of Miami used data from the SeaWifs satellite to validate the circulation model results.

SUBRESULT: 1.3 SCIENTIFIC INFORMATION AND MODELING RESULTS USED TO INFLUENCE DECISION-MAKER REGARDING LAND-USE POLICIES IN ORDER TO DECREASE THREATS TO CORAL REEF OF THE MAR		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 1.3.1 Development of scenarios		
- Scenarios of the possible and probable impacts of land use practices in MAR watersheds on coral reefs will be reviewed through a workshop process (to be held in 2006). - The workshop will convene external experts and local consultants facilitating presentations, brainstorming on future scenarios, and development of scenarios and spatial illustration of scenarios - Identification of regional key stakeholders to participate in the workshop - In addition to sharing the information and scenarios that have been developed with the governments and NGOs partners are hoping to share the scenarios with the NASA project and regional GEF focal point for climate change	• Models applied to the MAR region, and used to produce a series of scenarios to inform and influence policy development and implementation, by illustrating the possible outcome of current trends, and by highlighting the implications of different policy decisions. • Information offered to the governments and NGOs in the region to support them in decision making. • Regional capacity strengthened by the development of a network of project partners including regional organizations. All outputs and data available through locally and regionally staff trained.	• Complete. • Experts convened and workshop executed successfully. • Project results on CD and web; shared broadly. • Network developed and remains active even as project ends.
Activity 1.3.2 Strengthening of capacity within the region to undertake spatial analysis, modeling, and scenario building activities		
- Development of a network of project partners, including a number of organizations within the Meso-American region using project outputs - Data and modelling tools transferred, and training provided, to staff of institutions such as the Coastal Zone Management Unit in Belize, and other relevant partners in the region.	• Capacity within the region strengthened to undertake spatial analysis, modeling and scenario building activities. • Project-produced data institutionalized within the region through local NGOs, government institutions and universities. • Analytical skills transferred used to improve watershed and coastal management long	• 25 people trained at Watershed analysis/GIS training August/06 • All project results, GIS data and metadata are available on the project summary CD and on the web. These have been distributed and adopted in region.

SUBRESULT: 1.3 SCIENTIFIC INFORMATION AND MODELING RESULTS USED TO INFLUENCE DECISION-MAKER REGARDING LAND-USE POLICIES IN ORDER TO DECREASE THREATS TO CORAL REEF OF THE MAR		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
	after completion of this project.	• Many groups have been trained in the modeling methods and some are beginning finer resolution analysis. Results have been provided to CZMAI in Belize, but they no longer have technical staff.

Sustainable Fisheries (Intermediate Result 2) *Local fishers' and cooperatives' capacity strengthened for sustainable fisheries management (through development of industry partnerships, promotion of "better practices", training in financial management, resource management and alternative income generation strategies).*

SUBRESULT: 2.1. COMMUNITY-BASED FISHERY MANAGEMENT IMPROVED THROUGH DEVELOPMENT OF APPROPRIATE PARTNERSHIPS WITH PRIVATE AND PUBLIC SECTOR.		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 2.1.1 Promotion of "best practices" guidelines for lobster and grouper fisheries and implementation of agreements / partnerships and production of brochure with guidelines		
- Develop best practice guidelines for lobster and queen conch and finfish through wide consultation with industry, government, academia, partner NGOs, other projects (PROARCA and MBRS in particular) and communities - Produce brochure featuring fisheries "best practices" guidelines, and other supplemental promotional materials (e.g. posters) to support community education efforts for the adoption of best practices - Conduct a series community meetings/ workshops throughout the region to educate on best fishing practices and to produce the guidelines - A regional sustainable fisheries taskforce of industry leaders will be created through the workshops to review and finalize the document and address any potential inter-country discrepancies	• BMPs guidelines encompassed in "How to profit while fishing in a sustainable way - Best Management Practices for the Mesoamerican Reef". • Best fishing practices brochure distributed to fisheries cooperatives, private industry (e.g. seafood markets) target fishing communities, government departments, local NGO and international projects. • Best practiced guidelines used as the basis for the MoU's to be established between private industry and fishing cooperatives and community associations • Fisheries cooperatives, industries, government departments and NGOs (such as Friends of Nature, WCS, Greenreef Environmental Institute and Nature Conservancy) are collaborating and in agreement with the development of best practices. • Three workshops to adopt lobster BFPs in Belize • Two workshop to train Hondurans fishermen in lobster BFPs	• 100 % completed Spanish version. 75% English Version. • 100% completed. • Ongoing. • 80% and ongoing. • 75% and ongoing • 50% and ongoing • 50% and ongoing. • 75% and ongoing

SUBRESULT: 2.1. COMMUNITY-BASED FISHERY MANAGEMENT IMPROVED THROUGH DEVELOPMENT OF APPROPRIATE PARTNERSHIPS WITH PRIVATE AND PUBLIC SECTOR.		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
	• Fishermen exchange from Honduras and Guatemala to Mexico • Publication: "Best fishing practices in coral reefs: guidelines to gather information that support the ecosystem based fisheries management" (English and Spanish); Ecosystem Based Fisheries Management (EBFM) approach.	
Activity 2.1.2 Expanding partnerships with major seafood buyers		
- Approach private sector seafood purchasing and processing companies in the region to become involved with the use of best practices. - Dissemination of promotional material presenting benefits of adopting best practices - Develop partnerships with major seafood buyers (Darden and others) - Promote best practices and implement partnership agreements	• Promotional material presenting the benefits of adopting BMPs will be printed and disseminated by WWF and partners throughout the fishers' villages in the four MAR countries, as well as in local restaurants and seafood sales centers • Purchasing and processing companies in the region involved in the promotion and implementation of "best practices" • Agreements to trade BFPs lobster, signed by seafood buyers and fishermen cooperatives • Pre-assessment MSC process for lobster caught in Banco Chinchorro and Sian Ka'an	• 100% completed. • 60% and ongoing. Darden and fishermen of Honduras establishing partnership to implement lobster traps previously identified by PROARCA. • 50% • 30%

SUBRESULT: 2.2. COMMUNITY-BASED ECOLOGICAL AND SOCIO-ECONOMIC MONITORING IMPLEMENTED WHERE APPROPRIATE TO SUPPORT COMMUNITY ASSESSMENT AND MONITORING OF THEIR PROGRESS IN RESOURCE MANAGEMENT.		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 2.2.1 Select communities as centers for Reef Check ecological and socio-economic monitoring and provide training		
- Communities selected in collaboration with GEF/MBRS, PROARCA and Partners to complement the MBRS monitoring programme as centers for Reef Check ecological and socioeconomic monitoring - Conduct training in socio-economic and natural resource monitoring and management techniques throughout the MAR. Training conducted once a year in coordination with WWF - Identify and implement appropriate incentives to ensure monitoring sustainability	• 25 individuals from each of the 4 countries trained at each Reed Check session • The communities, which will serve as RC ecological and socioeconomic centers, are selected and established. • 15 people from the Tourism and Fisheries Industries are trained in the RC monitoring methodology.	• All 100 % completed and ongoing

SUBRESULT: 2.2. COMMUNITY-BASED ECOLOGICAL AND SOCIO-ECONOMIC MONITORING IMPLEMENTED WHERE APPROPRIATE TO SUPPORT COMMUNITY ASSESSMENT AND MONITORING OF THEIR PROGRESS IN RESOURCE MANAGEMENT.		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 2.2.2 Trainees responsible for assessing managed areas and adjacent unmanaged areas as controls		
- Trainees collect information and assess their managed areas as well as adjacent unmanaged areas. - Trainees assist nominated target communities through peer-to-peer exchanges	• Team leaders processing and interpreting collected data for demonstration, target and other communities • Data contributed to project databases in the region as well as to the ReefBase global repository • Trainees have conducted 20 standard RC surveys in managed and unmanaged areas.	• 100% completed and ongoing. Data is of public domain and can be accessed through the Reef Check global data base • 100% completed and ongoing. Over 60 surveys already conducted
Activity 2.2.3 Demonstration sites edit and publish existing monitoring manuals in Spanish and English		
- Selected sites serving as monitoring demonstration sites - Existing Reef Check's monitoring manuals published in Spanish and English and used by communities in the MAR and elsewhere in the Caribbean.	• Monitoring manuals in Spanish and English are edited, published and distributed to other communities in the MAR.	• 80% English version widely distributed; Spanish version is being published

SUBRESULT: 2.3. KEY MARINE PROTECTED AREAS STRENGTHENED IN COLLABORATION WITH GEF/MBRS AND PROARCA/APM (TO DEMONSTRATE SUCCESSFUL COMMUNITY-BASED FISHERIES TO THE WIDER COMMUNITY)		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 2.3.1 Conduct at least four exchanges among CBO leaders from Mexico, Belize, Guatemala, Nicaragua, and Honduras		
- Organize and conduct exchanges of fishers among selected demonstration sites, including ICRAN demonstration sites of Hol Chan (Belize) and Sian Ka'an (Mexico), as well as from coastal communities bordering the Cayos Cochinos Reserve and other Bay Islands in Honduras, and communities near Punta de Manabique, Guatemala; Xcalac, Mahaual and Hol Box, Mexico.	• Increased support for marine protected areas, capacity for operating and managing cooperatives and conducting sustainable fisheries • Fishermen trained in information gathering for Ecosystem Based-Fisheries Management (EBFM)	• Ongoing. Fishermen exchanges are ongoing and using the EBFM approach MPAs will be supported with management plans • 50% Two workshops in Honduras and one in Guatemala on EBFM

SUBRESULT: 2.4. LOCAL COMMUNITY MEMBER'S CAPACITY TO ENGAGE IN ALTERNATE LIVELIHOODS SUCH AS COMMUNITY-BASED TOURISM IS INCREASED		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 2.4.1 Specific training in sustainable economic alternatives		
- Organize and conduct trainings for selected communities /	Prepare proposals for EBFM plans in Mexico,	• 30%

SUBRESULT: 2.4. LOCAL COMMUNITY MEMBER'S CAPACITY TO ENGAGE IN ALTERNATE LIVELIHOODS SUCH AS COMMUNITY-BASED TOURISM IS INCREASED		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
fishermen in tour guiding, including dive masters; sports fishing guides; birding and kayaking. The location of training sites will rotate among the countries and participants will be selected from all 4 MAR countries. - Conduct analysis of tourism development viability of each proposed pilot site - Conduct cost-benefit study of the investment in capacity building and the potential benefit to each proposed pilot site - Conduct capability analysis of the incorporation of trained individuals in alternative livelihoods (e.g. tourism) in the economic development of their communities, in the mid term - Conduct trainings in small business management, including finances, Market assessment skills for small businesses, and identification of sustainable economic alternatives	Guatemala and Honduras, with strong scientific bases and fishermen participation • Monitoring campaigns with fishermen in three different MPAs from Mexico, Guatemala and Honduras • Three studies on the state of commercial fish habitats (in Mexico, Guatemala and Honduras) Provide realistic tools to fishermen that want to shift or combine fishing with other activities • Publication of a corrected version of the code of conduct for whale-shark snorkeling • Feasibility study to make adjustments to the whale-shark snorkeling activity	• 30% • 30% • 25%

Sustainable Tourism (Intermediate Result 3) *Through partnerships established with the marine tourism sector, business guidelines and better practices are refined and implemented, thus creating a sustainable industry minimizing threats to the MAR*

SUBRESULT: 3.1. REGIONAL DIALOGUES ACROSS A BROAD SECTOR OF INDUSTRY STAKEHOLDERS LEADING TO COLLABORATIVE ACTION ON EMBRACING SUSTAINABLE TOURISM		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 3.1.1 National Learning Workshops and Creating Networks for Both Suppliers and Purchasers of Marine Recreation Activities		
- Conduct two national learning workshops on year 1 and two on year 3, in collaboration with GEF/MBRS and PROARCA, of marine recreation providers, NGOs, community leaders, bulk purchasers of marine recreation (such as cruise ships, inbound tour operators) and coral park managers creating a network of financially invested stakeholders in sustainable tourism and management of coral reefs. - CORAL – will engage marine recreation providers and MPA managers to support and adopt best practices. - UNEP DTIE – will engage bulk purchasers, inbound operators and hoteliers on minimum standards/best practices for contracting shore-based service providers and creating service agreements. - Compile contact information on all identified groups (private	• 1000+ compiled stakeholder contacts for the region • Examples of media citations, including news articles, radio interviews, and television stories, promoting the initiative • 200+ stakeholders attending national learning workshops and informed and sensitized on the value of coral reefs, best practices, standards and the voluntary code of conduct. • Three workshop evaluations complete and showing indicators of success.	• 100% completed in 2005. 1,200+ compiled stakeholder contacts for the region • 100% complete and ongoing. 10+ media citations, including news articles, magazine awards, radio interviews, and television stories, promoting the initiative. • 100% completed in 2005. Three national learning workshops convened in Mexico, Belize, Honduras. 300+ individuals from the MAR trained and sensitized on best practices, standards and codes of conduct for marine recreation activities, as well as on the value of coral reefs (including all national and pilot workshops.)

SUBRESULT: 3.1. REGIONAL DIALOGUES ACROSS A BROAD SECTOR OF INDUSTRY STAKEHOLDERS LEADING TO COLLABORATIVE ACTION ON EMBRACING SUSTAINABLE TOURISM		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
sector, MPAs, government officials etc). - Invite all groups to workshop 1a - Mexico; 1b – Belize; 1c Honduras. Prepare and coordinate workshop for countries - Distribute Handbook and Tourism Guidelines to participants (Tourism Guidelines are for the providers to handout to their guests. - Make handbook and guidelines materials available on CORAL website to download. - Workshop 1a and 1b and evaluation complete. Follow-ups with all participants - Invite all groups to workshop 2a and 2b. Prepare and coordinate workshop 2a and 2b. Workshop 2a & 2b and evaluation complete. Follow-up with all participants - Report on indicators of success and evaluation	• Training materials distributed • Final National Workshops (2a, 2b) conducted in year three of the project (expected by May-June 2007) • Final report produced	• 100% completed. 125 national workshop evaluations analyzed showing significant support to the initiative; detailed results available in annual report 2005. • 100% completed. Training materials developed for the workshops including 5 tourism guidelines, Guide to Good Practice Handbook, and Supply Chain Management handbook (all in English and Spanish) • Forthcoming at the end of the project • Forthcoming at the end of the project

SUBRESULT: 3.2. CREATION OF STANDARDS AND A VOLUNTARY CODE OF CONDUCT THAT WILL BE APPLIED THROUGHOUT THE MESOAMERICA REGION AND POTENTIALLY ELSEWHERE IN THE CARIBBEAN		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 3.2.1: Develop a regional sustainable tourism code of conduct for marine recreation providers and a mechanism for its regional implementation		
- Identify key organizations, contacts, and get commitments from key organizations for support and create standards task group with representation from all stakeholder groups - Establish and maintain on-line standard forum in coordination with regional on-line bulletin board and install and maintain standards development groupware - Prepare draft standards - Working with standards task group and others, gain support of standards further develop and adopt - Post draft standards for public review, publicize (regional network, in-country workshop 1 series), organize comments - Compile approved standards into a regional code	Regional standards and a voluntary code of conduct for marine recreation providers • Development of draft standards for four areas of marine recreation activities: scuba diving, snorkeling, boat operations, beachfront and poolside activities • Establishment of a library of hard copies and web-based references for existing best practices for marine recreation • Secured contractual agreement for online standards software • 160+ registrants on the standards and code taskforce (SCT), representing a balanced set of interest groups in marine recreation, including suppliers, purchasers and consumers, local community groups, and general interests.	• 75% completed. Standards for scuba, snorkeling and boat operations; balloting complete with unanimous approval. Steering committee decided to postpone pool and beach standards until phase 2 of the project. • 100% completed. Library of examples of best practices provided to stakeholders at national and pilot workshops • 100% completed. Pro-bono contract secured for use of collaborative standards development software with Underwriters laboratories • 100% completed. 191 total representing tourism associations, marine recreation providers, park managers, tour

of conduct in English and Spanish - Report on indicators of success and evaluation	• Project partners trained in on site usage and technical support for online standards software. • Taskforce reaches consensus around marine recreation standards and a voluntary code of conduct (will likely continue into 2006-2007). • Standards published through international standards body (will be based on the timeline of when standards committee finalizes consensus on developed standards).	operators, NGOs, academics, local community groups, among others. • 100% completed. Training finalized in multiple sites in the region. • Standard testing is Ongoing. Will continue until the end of the project. • Not yet complete; awaiting public review and feedback gained from standards testing phase.
Activity 3.2.2: Handbook for Bulk Purchasers of Marine Recreation and Guidelines for Tourists		
- Reprint CORAL tourist guidelines in English and Spanish in coordination with GEF/MBRS and PROARCA - Collaborate with GEF/MBRS on the "best practices" guidelines for MAR - Market the Handbook (to be printed by UNEP-DTIE in English and Spanish and guidelines through workshops and regional network and use for pilot sites etc. - Report on indicators of success and evaluation	Guide to Good Practice for marine recreation providers and guidelines for tourists. • Handbook published in English and Spanish and supplied to all participants of national level and pilot site workshops, with 200+ copies left in each region for follow up distribution. • Tourism guidelines published in English and Spanish with 40,000 copies made available at national workshops and 10,000 left in the region for follow up distribution.	• 100% completed and ongoing. Handbook published in English and Spanish and distributed at national and pilot site workshops, as well as through general outreach • 100% completed and ongoing. 50,000 + guidelines distributed through national and pilot workshops and through general outreach

SUBRESULT: 3.3. TRAINING AND SUPPORT FOR ADOPTION OF THE CODE OF CONDUCT COMPLETE, LEADING TO THE PRIVATE SECTOR IN THE MAR BEING FULLY ENGAGED IN THE PRACTICE AND PROMOTION OF SUSTAINABLE MARINE TOURISM		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
Activity 3.3.2: Pilot Testing Training and Technical/Financial Assistance Program to improve adoption and compliance of Code of Conduct		
- Discuss pilot projects and present at pilot workshop series 1 - Gather MPA and stakeholder support and select 3 pilot sites - Create training materials in Spanish and English - Compile contact information on marine recreation providers and bulk purchasers to participate in pilot projects - Pre-study evaluation on coral reef health and industry practices - Training 1 for pilot site 1, 2, and 3 and evaluation complete with both purchasers and providers - Provide technical support and advice for providers and purchasers – continual - Training 2 for pilot site 1, 2, and 3 with providers and MPA and evaluation complete	• Compilations of baseline data reflecting pre and post-surveys analyzed and findings published and presented. • 50% of marine recreation providers that attend workshops provide feedback, and adhere to standards and the voluntary code of conduct. • Number of companies participating in the development of a local plan for supply chain management • Successful completion of initiative-funded conservation projects that support implementation of standards and the	• 100% completed. Preliminary report on pre-survey of industry practices produced in January, 2006. • 100% completed. Evaluations complete by the majority of participants at all pilot site workshops; in total, 44 companies across 13 destinations signed a formal letter of agreement to participate in the standards testing program. • Incomplete. Ongoing. • 40% Ongoing. Three projects funded by CORAL; one initiated in each pilot site. Each project involves participation from

SUBRESULT: 3.3. TRAINING AND SUPPORT FOR ADOPTION OF THE CODE OF CONDUCT COMPLETE, LEADING TO THE PRIVATE SECTOR IN THE MAR BEING FULLY ENGAGED IN THE PRACTICE AND PROMOTION OF SUSTAINABLE MARINE TOURISM		
ACTIVITIES	**INDICATORS OF SUCCESS**	**STATUS**
- Identify projects with pilot sites and provide additional technical and financial assistance - Training 3 for pilot site 1, 2 and 3 with providers and MPA and evaluation complete - Post - study evaluation on coral reef health and industry practices - Report on indicators of success and evaluation and lessons learned	voluntary code of conduct. Number of companies, institutions, and organizations that have been provided with technical and financial assistance	approximately 8 – 12 marine recreation providers, local Marine Protected Area Managers, and local NGOs; still awaiting microgrant disbursement from WWF for second three projects; have leveraged resources to disburse microgrants in early 2007 to new project pilot sites, including San Pedro, Belize and Cozumel, Mexico

I. PROJECT DESCRIPTION AND OBJECTIVES

The Mesoamerican Reef is the largest barrier reef system in the Western Hemisphere and the second largest in the world. It extends from the Yucatan Peninsula in Mexico through Belize and Guatemala, to the Bay Islands of Honduras. Its waters are home to 66 species of corals and more than 400 species of reef fish. The entire coastal system encompasses habitats and ecosystems such as barrier and patch reefs, riverine and coastal mangroves, seagrass beds and atolls that are critical to the survival of numerous marine and terrestrial species. Its significance as a globally outstanding example of a coral reef complex is reflected in its designation as one of the world's natural wonders, with some portions as World Heritage sites. The reef serves as an important source of economically valuable resources for many coastal populations from the Yucatan in the North to Honduras in the South.

In recognition of the ecological and socio-economic richness and importance of the Mesoamerican Barrier Reef region (MAR), the ICRAN Mesoamerican Reef Alliance (ICRAN-MAR) project was designed in 2003 to contribute to the many local, national and regional-level resource conservation and sustainable development projects that had been initiated in the MAR region since 1990. Discussions among ICRAN representatives and conservation leaders in the MAR region had established that there were opportunities where ICRAN could, and should, become engaged.

As a result, ICRAN partners developed a 3-year initiative to address threats to the MAR under three components known for their potential to strongly impact the coastal and marine ecosystems: watershed management, sustainable fishing, and sustainable tourism. With the generous support of the United States Agency for International Development (USAID) and the United Nations Foundation (UNF), the ICRAN-MAR partners would conduct a set of inter-linked, complementary activities to enable the proliferation of good practices for coral reef management and conservation. The strategy of this Alliance would combine a conservation and sustainable management approach with the creation of partnerships with the private sector to leverage resources and talents to find long-term solutions. Project donors UNF and USAID signed the project agreement on November 2, 2003 and implementing partners initiated project activities in the period of July-September 2004 once technical, logistical, and individual contractual arrangements were finalized.

Project implementing partners are the World Resources Institute (WRI), UNEP-World Conservation Monitoring Centre (WCMC), World Wildlife Fund (WWF), The Coral Reef Alliance (CORAL), UNEP-Division of Technology Industry and Economics (DTIE), and Reef Check. As of November 2, 2006, approximately 29 months after beginning project implementation, partners have achieved significant results, some of which have exceeded original expectations.

While this is the final report to USAID, it is important to mention that it is not the final project report. Project activities are scheduled to finalize by June 30, 2007 and further development and results are expected in the coming months (See Annex 19 for Workplan 2007). The following sections present highlights of project implementation up to date and present expected results as of June 30, 2007. Please refer to previous annual reports for more detailed information about project activities.

A. STRATEGIC OBJECTIVE AND INTERMEDIATE RESULTS

The unifying Strategic Objective (SO) of the ICRAN-MAR Alliance is:

> *Alliances built with the private sector that lead to the sustainable management and viability of the Mesoamerican Reef (MAR).*

Intermediate Result (1): Partnerships created that produce relevant information and forecasting resulting in improved watershed management in areas impacting the Mesoamerican Reef.

1.1 Partnerships established with the agri-business community resulting in adoption and implementation of best practices.
1.2 Trends in land use integrated with spatial, hydrological and oceanographic models for use in modeling.
1.3 Scientific information and modeling results used to influence decision-makers regarding land-use policies in order to decrease threats to coral reefs of the MAR.

Intermediate Result (2): Local fishers' and cooperatives' capacity strengthened for sustainable fisheries management. (Through the development of industry partnerships, promotion of "best practices", training in financial management, resource management, and alternative income generation strategies.)

2.1 Community-based fishery management improved through development of appropriate partnerships with private and public sector.
2.2 Community-based ecological and socio-economic monitoring implemented where appropriate to support community assessment and monitoring of their progress in resource management.
2.3 Key marine protected areas strengthened in collaboration with GEF/MBRS and PROARCA/APM (to demonstrate successful community-based fisheries to the wider community).

Intermediate Result (3): Through partnerships established with the marine tourism sector, business guidelines and best practices are refined and implemented, thus creating a sustainable industry minimizing threats to the MAR.

3.1 Regional policy dialogues and multi-sectoral for strengthened for collaborative action on embracing sustainable tourism by all stakeholders.
3.2 Refinement and adoption of sustainable tourism best practices that have been identified and leveraged within the MAR and elsewhere in the Caribbean region.
3.3 A regional environmental code of conduct implemented for providers of recreation/tourism practices affecting the MAR.
3.4 Use of demonstration sites, in addition to national level workshops, to train marine recreation providers and suppliers in best practices.
3.5 Private and social sector operating in the MAR fully engaged in the promotion and implementation of the best practices identified.

II. IMPLEMENTATION OF THE PROJECT COMPONENTS 2004-2006

The project has evolved since its original inceptions and over the course of the implementation phase. Earlier stages required significant investments to set up the necessary mechanisms to

undertake planned activities and achieve project goals. This included, among others, gathering information and building relationships with local counterparts. Initial results provided a good platform not only to leverage further support from governments and the private sector but also to inform and influence decision makers in the region. Over the course of these years, ICRAN-MAR partners have capitalized on lessons learned and strengthened channels of communication with project partners and other initiatives in the region.

As already indicated in previous progress reports, while the three components of the project are closely interlinked and designed to pursue the overall goal of contributing to the sustainable management and use of the Mesoamerican Reef, each component is independent and as such, each one has had particular characteristics and different levels of complexity. The high dynamism of the project activities and the challenges they have produced, have called for adopting an adaptive approach to allow addressing changes in the implementation mechanisms as appropriate. Under the supervision of the Project's Coordinator this approach has facilitated the reorientation of investments —consequent with the project's objectives— as necessary.

The spirit of creating alliances and consolidating societies with the private sector for the benefit of coral reefs in the Mesoamerican region has been the fundamental objective of the ICRAN-MAR Project. The positive results obtained by the project to date demonstrate that alliances are an effective mechanism for the handling of marine resources and can bring great benefits for the handling of Marine resources. Nevertheless, coordinating efforts is not a simple task and requires commitment and joint work to identify the best strategies that involves relevant stakeholders and especially the local partners.

A. IMPROVED WATERSHED MANAGEMENT (IR1)

Partnerships created that produce relevant information and forecasting resulting in improved watershed management in areas impacting the Mesoamerican Reef

1. Threats – Rationale for Component Design

Alteration of the natural landscape for development, road construction, or agriculture can have adverse impacts on coral reefs through increased delivery of sediment, nutrients, and other pollutants to coastal waters. In the Mesoamerican region, over 300,000 hectares of land are allocated to banana, oil palm, sugar cane, citrus, and pineapple crop production. Eroded sediments and fertilizer and pesticide residues used by farms drain through rivers and streams and enter coastal waters along the Mesoamerican reef.

As the largest industry within the Mesoamerican Reef, commercial and subsistence agriculture employ more than one million people and can generate more than ten percent of the Gross National Product in the MAR Countries. Pasture and cropland provide habitat and food for the majority of the region's terrestrial biodiversity. Soils managed by farmers and ranchers are integral to ecological processes like conserving and filtering freshwater, sequestering carbon, and maintaining biological diversity. With its deep connections to the economy of the region, human societies, livelihoods and biodiversity, agriculture is one of the most important issues and challenges for conservation of life on the Mesoamerican Reef. Consequently, appropriate land-use practices are critical for the management of watersheds to ensure that the transport of sediment, nutrients and other pollutants to coral reefs is minimized.

Partners World Resources Institute (WRI), UNEP-World Conservation Monitoring Centre (WCMC) and World Wildlife Fund (WWF) have collaborated in this component to provide a

comprehensive watershed analysis to help decision making for improved watershed management in the MAR.

2. Description of Component Strategy – Dynamics over the Past 30 Months

This component is integrated by two complementary sub-components:

c) On one end, WWF has focused its efforts identifying sources of pollution and sediment from agricultural activities that have a negative impact on the marine environment, as well as on-the-ground activities with agricultural businesses to adopt a suite of "better management practices". This work was designed to be carried out in three years, has produced concrete results over the past 2 years, and it is still ongoing.

d) On the other end, WRI and UNEP-WCMC have produced information and GIS tools for examining the potential impact of different land use and development options in the region and the associated impacts on water quality on the MAR. These hydrologic models and diagnostic tools help educate and encourage key stakeholders to implement better management practices to reduce impacts on the coastal and marine resources. This work was designed to be carried out during the first two years of the project; although progress was made on many results during 2005, must results were finalized (ultimately achieved) during 2006. It is now almost complete, with only some further follow-up capacity building efforts to fulfill.

In summary:

- UNEP-WCMC – conducted review of historical land use change and supplemented it by compiling statistical data to feed analysis of the land use change drivers; developed land cover change scenarios and provided data sets as input to the hydrologic modeling;
- WRI – implemented the watershed delineation and hydrologic analysis for the MAR region, performed analysis of vulnerability to erosion, and coordinated a circulation modeling along the MAR;
- WWF – is leading the work with agri-business (banana, pineapple, citrus and sugar) to implement better management practices, focused on reducing the presence of pesticides in the MAR marine environment and controlling soil erosion from major commercial agricultural sectors.

Since the early stages of project implementation partners consulted extensively with regional experts, other regional partners, and the private sector to seek feedback, identify opportunities for collaboration, and develop close relationships with the agroindustry for the adoption of better management practices. Data collection and information gathering was possible through collaboration with local institutions, other regional initiatives, and by building on previous work carried out in the region, such as the Reefs at Risk study led by WRI. Likewise, information was shared and feedback was sought from regional counterparts like the USAID PROARCA program and the CCAD/GEF Mesoamerican Barrier Reef System (MBRS) Project.

Taking into account the number of activities within the MAR region whose focus was on watersheds and analysis of land-based sources of threat to coral reefs, the ICRAN-MAR watershed theme partners made considerable efforts to coordinate such activities. Successful collaboration was achieved with the Belize Tropical Forest Studies, Hydrology-Meteorology Department, and the Coastal Zone Management Authority and Institute (CZMAI). Another significant activity focused on watersheds (specifically trans-boundary watersheds) was organized by the MBRS project and implemented by US National Oceanographic and

Atmospheric Administration (NOAA) and efforts were made to ensure linkages and facilitate information sharing. See Annex 2 for a comprehensive list of organizations involved.

3. Major Achievements and Results – Impacts in the Region

The current section provides a narrative description of project results up to the end of the agreement between UNF and USAID (November 2, 2006) and the impacts these have generated in the region. It also describes the expected results to the end of the project and the potential opportunities for continuation beyond the life of the ICRAN-MAR project. For a summarizing table of project indicators and status, please refer to the indicators section of the executive summary in this report.

Partnerships with agribusiness

> Sub-result 1.1. *Partnerships established with the agri-business community resulting in adoption and implementation of best practices*.

The work carried out under the leadership of WWF has undergone a process by which partners were able to first set up the grounds for collaboration with local agribusiness, identifying most pressing threats, and then undertaking specific activities that are yielding significant results for the promotion and adoption of Better Management Practices (BMPs). Along the way, they have been able not only to create partnerships with relevant agribusiness and governments in the region, but also to raise awareness and leverage support from other funding sources.

To date, WWF has achieved expected outputs from workplans 2005 and 2006 as originally planned despite slight variations in implementation due delays in signing agreements with key agroindustries. Signature of MoUs with agribusiness were possible after developing trust and clearly discussing matters such as property rights, confidentiality issues, self-protectiveness, and legal issues.

Major achievements include:

- Agreements (MOUs) signed with agribusiness for the promotion of BMPs. WWF has signed agreements of collaboration with Chiquita, CropLife Latin America, Dole Food Company, *Fundación de Investigación Agrícola* (FHIA), The Association of Citrus Producers from Sonaguera, Honduras (ACISON), and *Azucarera del Norte, S. A*. (AZUNOSA) in Northern Honduras. See Annex 3. In coordination with WWF, these corporations are finding new useful and cost-effective ways to sustain productivity and reduce any possible negative impacts that the use of pesticides has on their products, plants, water, soil, workers, nearby communities and the environment.
- An inventory of plantations and environmental impact assessment for the MAR watersheds. Using satellite images and other GIS tools, including the results from the Watershed Analysis carried out by partners WRI and WCMC (see following section), WWF has determined the type, extension, associated soil loss and other key information to facilitate the selection of the areas, crops and stakeholders to work with, in order to maximize the impact and target key agricultural practices to reduce coastal water pollution and sedimentation in the MAR
- A Contaminant Monitoring Protocol was developed with co-funding from the Summit Foundation. See Annex 4. This protocol has been used by NOAA in the monitoring of contamination after Katrina's hurricane in New Orleans, US. In addition, it has been adopted by the New Zealand government to monitor contamination of its reef. Using this

protocol, WWF has completed four rounds of toxic bioaccumulation testing in Chetumal Bay Mexico, Belize, and Honduras.

- Terms of reference for a collaborative agreement between WWF and The Citrus Growers Association of Belize have been developed and final signing will take place in early February 2007. The Citrus Grower Association Officers showed a very important commitment from their part to work together on the citrus and pineapple issues and expressed a high interest in signing this collaborative agreement.
- As part of the deployment of BMPs, and with the sponsorship of the Summit Foundation, ICRAN-MAR, and CropLife Latin America, WWF is strengthening the Biological control as a way to reduce the impact of pesticides in the Mesoamerican Reef. WWF has implemented the biological control of Froghopper *Aeneolamia postica Walker Homopterous*: Cercopidae, in sugarcane fields in Chetumal Bay, Mexico, Belize, and Northern Honduras. This practice by itself will reduce the use of pesticides by 30% and reduce the cost of controlling the pest by 50 percent.
- Helped established two cover crops in Citrus fields in Belize and Honduras. From these fields WWF will get key information – percent reduction of herbicide use, percent reduction in weed control cost, percent of soil retained by the crop practice, among others – to continue promoting BMPs among agroindustries in the MAR area.
- Engaging governments to promote implementation of BMPs to guarantee continuation of activities after the life of the project. The Minister of Agriculture and Livestock, and the Minister of Natural Resources and the Environment of Honduras have agreed upon language of MoUs for mutual collaboration with WWF (See Annex 5). MoUs will be signed by early 2007.
- Leveraged support from Summit Foundation to complement the work in BMP dissemination by means of a Toxicology Units Program to reduce workers' exposure to pesticide levels of type I and II agrochemicals, which are the most toxic substances for humans and the environment; this program has been established at Dole, Chiquita, and AZUNOSA.
- Developed a collegial relationship with the sugarcane associations in Orange Walk and Corozal Districts in Belize. WWF and the two associations have identified major priority areas to start work despite of not having a signed MOU in place. Areas identified in order of priority are: a) Weather and soil erosion monitoring, b) development of written procedure manuals for pesticide use and nutrition, c) crop estimation, d) SIG-Mapping of sugarcane fields, and e) biological control of major sugarcane pests.
- The Local Union of sugarcane producers ULPCA-CNC and the Civil Association of sugarcane producers from the Rio Hondo watershed (ACCPCA), Chetumal Bay, Mexico, agreed on the common language of MOUs to start collaborative work in identifying and implementing better management practices (BMPs). In addition, both associations in conjunction with San Rafael de Pucte sugar mill sent a signed letter of commitment to make sure that they are willing to participate in adopting BMPs (See Annex 6)
- The Citrus Research and Education Institute (CREI) in Belize, is partnering with WWF implementing a pilot project to reduce herbicide pollution and sedimentation from Belizean citrus production. The project focuses on improving knowledge of environmentally and economically beneficial weed management practices in Belizean citrus, educating farmers about the environmental and economic benefits of alternative weed management, and providing resources for growers to establish cover crops cultures.
- To complement and promote long-term sustainability of project results, and with co-financing from Summit Foundation WWF has established the project "Climatic and Soil Monitoring

System in the MAR Agricultural Areas" by which WWF will monitor[3] soil erosion and weather parameters in sugarcane, oil palm, and citrus plantations in Belize, Guatemala, and Honduras. State of the art GSM-GPRS telemetric real-time weather stations (WS) and Soil Cohesive Meter (SCM)[4] have been purchased from cutting edge precision companies from Austria and England. Weather Stations will be configured to collect and deliver weather data to the PANDA server at La Lima's (Honduras) WWF Linux OS. WWF has already started the process of installing four monitoring stations in the following locations:

- Stann Creek District, Belize - the Citrus Growers Association's citrus fields.
- Orange Walk District, Belize - the Sugarcane Growers Association's sugar cane fields.
- Sonaguera, Colón, Honduras within the Citrus Growers Association's citrus field.
- El Progreso, Yoro, Honduras at an experimental station in HONDUPALMA, to monitor weather parameters in oil palm plantations.

Results will help to identify sites with high erosivity indexes and will complement WRI's Watershed Analysis work; thus, soil BMPs can be deployed to reduce erosion and anticipate to potential erosion.

Data will be graphically displayed using GIS mapping technologies and erosive risk-maps that will help to monitor, on a timely basis, the effect of implemented soil BMPs through the MAR and Collected information will be processed and analyzed using specialized software and distributed widely.

Steps for achieving these results also have included:

- Conducting an inventory of commercial crops produced in the MAR region to identify key agribusinesses and seek their collaboration through the signing of agreements to work together in reducing agrochemical contamination of the MAR.
- Gathering information about areas of production, agricultural production cycles, and identifying the agricultural threats –and main sources of pollution– that are most damaging to the health and integrity of the MAR.
- Conducting an inventory of agricultural practices carried out by the major agroindustry players and identifying better -and worst- management practices as well as producers who already implemented better practices. Collecting information on existing and proven BMPs, such as the biological control of the froghopper in sugarcane crops.
- Convening a series of meetings and workshops with major agricultural producers to establish relationships and build trust. Meetings were held separately for each commodity because of confidentiality issues and property rights. Likewise, WWF attended on-going producer group meetings in addition to face-to-face meetings with innovators, influential individuals that needed to be brought into the process in order to facilitate the dissemination of BMPs by producers.
- Starting monitoring bioaccumulation of agrochemicals in marine life of the MAR. Preliminary results proved agribusinesses were indeed contributing, and agrochemicals were linked to specific agroindustries such as bananas, sugarcane, citrus, pineapples, and palm oil. Data on agrochemicals being used was obtained from larger companies (Dole, Chiquita, and Fyffes) based on good relationships with WWF.

[3] The climatic and soil monitoring system program will be implemented in pineapple with Dole, the citrus growers Association from Belize, the Citrus Growers Association in Honduras, the Sugarcane Growers association in Belize, and oil palm in Honduras.

[4] Measures soil cohesive strength as an indication of erosivity under different agricultural practices

- Developing measurable soil and water standards. An Ecotoxicology workshop was organized in April 2005 to assist with development and implementation of monitoring programs. Ecotoxicology experts from the leading regional agro-industry enterprises and from the transnational agro chemical-production companies discussed protocols for pesticide monitoring in reef organisms. As a result of these consultations, the protocol for pesticide monitoring in reef organisms was designed and produced.
- Focusing on the identification, implementation, and evaluation of specific BMPs to reduce chemical pollution to acceptable levels. Based on bioaccumulation preliminary results, WWF identified BMPs for banana, palm oil, sugarcane, and citrus production which once implemented will reduce key identified agricultural threats to acceptable, measurable standards.
- Participation at the Tulum+8 consultations (September, 2005), promoting an agriculture meeting where representatives from different agribusiness exchanged information about their management practices.
- With co-funding from The Summit Foundation developing a neutral, industry friendly-web site to include most of the information and analysis produced by the project. This site will contain information from the weather and soil parameters monitoring within the Mesoamerican Reef as well as success cases from BMP work.

Focus by country:
- Mexico (Chetumal Bay) – sugarcane. WWF has been able to bring the two sugarcane growers associations and the sugar mill on board.
- Belize – sugarcane and citrus. Partners are working with the two sugarcane growers associations from Northern Belize and the Citrus growers association in the South.
- Honduras – pineapple, citrus, banana, and sugarcane. Dole, Chiquita (bananas and pineapple), and the citrus and sugarcane industries have signed collaborative agreements.
- Guatemala – banana. Dole and Chiquita have been engaged.

SCOPE OF RESULTS – RELEVANCE TO THE REGION

As already mentioned, activities under this sub-component will continue until the end of the project and more results will be delivered (see next section for final outputs). However, results achieved to date provide evidence of the relevance of conducting this work for the benefit of the MAR.
Results:
- **Bioaccumulation monitoring**. Acknowledge that agrochemical bioaccumulation occurs in marine organisms and that this imposes potential harms in the different ecosystems' life chains.
- **Signature of MoUs**. Speaks of the industry's willingness to participate in actions that can lower their impact on the environment while maintaining their economical benefits.
- **Leveraged funding and support**. Speak of the interest by other donors and the private sector to invest in efforts that promote the health the MAR by supporting research, information gathering, and consolidating mechanisms in support of adoption of better agricultural practices.
- **Government involvement**. The fact that government officials from Belize have started following the biological control of the cane fly in sugarcane fields[5] and that the Honduran

[5] Orange Walk and Corozal, Northern Belize

Ministers have expressed their commitments to these efforts, speak of the relevance of the project to the development priorities of the region.

This innovative work combining bioaccumulation testing with actual field work in promoting sound and cost effective better management practices has allowed WWF to raise the profile of the ICRAN-MAR project in the region. The agriculture work done to date has created the basis for deploying BMPs with the potential to reduce pesticides use by commercial agriculture and therefore to reduce contamination threats to the MAR. Agroindustry producers from Chetumal Bay, Mexico, Belize, Guatemala, and Honduras partnering with the project have now a much better understanding about environmental protection, specifically with regards to pesticide use in their production processes.

The fact that this is a voluntary-led process generates sympathy among NGOs, governments, and agroindustries. The approach taken by the ICRAN-MAR Project to gather their collaboration has been well taken by agroindustries. They are convinced that by participating voluntarily the project will achieve measurable results on the ground. The ICRAN-MAR project is building capacity among agriculture producers with regards to environmental awareness, and at the same time, key producers from the different agroindustries are telling the story among themselves, which translates into a good communication and outreach.

Project partners see a significant impact already created by the program in Mexico, Belize, and Honduras, and to a lesser extent in Guatemala[6]. On the long run this impact will be measured in the field utilizing baseline data already compiled by WWF and comparing it with changes in agrochemical use from Dole, Fyffes, and Chiquita's crops. With time, implementation of Better Management Practices to reduce pesticide use will translate into a greater benefit for the Mesoamerican Reef ecoregion and for the nearby communities –and workers – that not only profit from this activity, but who are continuously exposed to agrochemicals.

FINAL OUTPUTS AT THE END OF THE PROJECT

Refer to indicators section in the executive summary for a table with current status of indicators (as of December 2006).

a) Signed MOUs with major agroindustry players regarding adoption and dissemination of BMPs. Dole, Chiquita, Fyffes, CropLife Latin America, Citrus growers associations (Honduras and Belize), sugarcane growers associations (Honduras and Belize), and Hondupalma (Oil palm in Honduras).
b) Inventory of plantations and environmental impact assessment of palm oil plantations within San Alejo Valley, Atlantic Region, and Sula Valley, Northern Honduras. An Oil Palm Geo-referenced Map and data base will be available for distribution at the end of the project.
c) Inventory of plantations and environmental impact assessment of citrus plantations within The Aguan River Basin, Northern Honduras. A citrus Geo-referenced Map and data base will be available for distribution at the end of the project.
d) Report on the identification of present sugarcane management practices and determination of their environmental impact in Chetumal Bay, Quintana Roo, Mexico and Orange Walk and Corozal Districts in Belize. This document will contain present management practices in sugarcane production within the three areas; so that, we can identify and document good and no so good practices; so that, we can deploy and implement better practices to reduce

[6] As determined during project design and established in the Project Document. A greater percentage of activities would take place in the other 3 countries, whose coasts over the Caribbean are larger.

the environmental impact, specifically the accumulation of agrochemicals in marine species in the Chetumal Bay and the MAR habitats.

e) Document of a base study on the change in use and regulations of pesticide use before and after the implementation of CAFTA-DR[7] agreement in Honduras and Guatemala. The report will include a thorough analysis, statistics and changes produced by the incorporation of the treaty. The final document will include specific information regarding the forecast of possible effects of pesticide bioaccumulation in MAR species due to the change in use pattern(s).

f) Preliminary report on the biological control of Froghopper (*Aeneolamia postica Walker*) in sugarcane in Chetumal Bay, Belize, and Honduras. This report will include a financial analysis to establish the feasibility of implementing the program elsewhere.

g) Preliminary report on the use of cover crops to reduce herbicide use and reduce soil erosion in citrus plantations in Belize and in Honduras. The report will include a financial analysis to establish the feasibility of implementing the program in other places.

h) Climatic and Soil Monitoring System in the MAR Agricultural Areas in place and running. GSM-GPRS based weather stations (WS) and Soil Cohesive Meter (SCM) have been purchased from cutting edge precision companies from Austria and England. Weather Stations will be configured to collect and deliver weather data to the PANDA server at La Lima's WWF Linux OS. Collected information will be processed and analyzed using specialized software and distributed through the developing site www.wwfca-agriculture.org which is being built with Summit co-funding.

Watershed Analysis and modeling

> Sub-result 1. 2. *Trends in land use integrated with spatial, hydrological and oceanographic models with strengthened capacity within the region for spatial analysis and scenario building activities*, and
>
> Sub-result 1.3. *Scientific information and modeling results used to influence decision-makers regarding land-use policies in order to decrease threats to coral reefs of the MAR.*

Activities under these two sub-results provided the basis for a comprehensive watershed analysis for the Mesoamerican Reef that was recently released by WRI (data CD and analysis) providing significant insights on the connections between land-based sources of threat and impacts to the MAR. This analysis tool works at many scales and allows identification and prioritization of the sub-basins which contribute the most sediment and nutrients to coastal waters along the MAR[8].

Steps to produce this watershed analysis included the following intermediate results and milestones:

- Definition of all watersheds (400) of at least 5 sq km discharging along the MAR. These were developed by WRI, reviewed and revised several times with collaboration from regional experts. Basins were delineated from 90m resolution NASA SRTM.
- Predictions of future patterns of land cover changes and development of scenarios for the MAR. This activity was led by WCMC and specific outputs were utilized to feed some of the

[7] See section 4 - *Leveraged Support, Impacts and the Larger Scale – The Potential Way Ahead* for more details.

[8] A full detailed report on the methodology and results, can be found in the "*Watershed Analysis for the Mesoamerican Reef*" data CD prepared by WRI. Contains medata that is also available through the SERVIR portal. Report is available online through www.icranmar.org and reefsatrisk.wri.org and presented as Annex 10 of this report

hydrologic model analysis conducted by WRI. Please refer to Annual report 2005-2006 for more details about the methodology, and to Annex 7 for a full technical report on *Land use change modeling for three scenarios for the MAR region*.

- Development and validation of the CLUE-S land-use change model originally developed in Utrecht University (Netherlands) and adapted for this project. Final results for the four countries and the three scenarios were presented at a project watershed management workshop in August 2006.
- Using land cover scenario data produced by WCMC, WRI performed a hydrologic and spatial analysis of impact of land-cover change on erosion and sediment delivery, using the Non-point-Source Pollution and Erosion Comparison Tool (N-SPECT) model developed by NOAA. This public domain tool, was selected in the spirit of cooperation and collaboration with other projects; the MBRS project was using it for its trans-boundary study.
- WRI in collaboration with UNEP-WCMC and WWF, calibrated models to predict impacts of land cover change. WWF reviewed model results and provided leads for data for calibration. WRI did the calibration in collaboration with Texas A&M University.
- WRI in collaboration with UNEP-WCMC and WWF, estimated dispersion of sediment and nutrients along the MAR. WRI managed a subgrant with University of Miami to implement a circulation model. WWF reviewed circulation model results.
- WRI produced the Belize Coastal Atlas, a rich data product that includes GIS data, metadata, reports, and maps of threats to coral reefs in Belize and for all of the Mesoamerican Reef. See Annex 8.
- Under the leadership of UNEP-WCMC and contribution from WRI, a collaborative network and a workshop were organized to evaluate scenarios of land cover change and impacts on coastal ecosystems.
- The watershed management workshop was successfully held in August 2006 at Galen University in Belize. The workshop comprised 1.5 days oriented to policy-makers (40 participants), and 2.5 days of technical training in the use of the CLUE-S and NSPECT models (25 participants). Significant inputs and feedback were obtained from regional experts participating at this event. Information provided by these stakeholders allowed for further validation and calibration of model results.
- Both sessions provided a great opportunity for national specialists to acquire new technological knowledge, coordinate activities, plan their modeling efforts, exchange experiences with colleagues from other countries, and acquire geospatial information developed by the ICRAN-MAR. In feedback provided at the workshop, numerous possible applications of project outputs were identified (e.g. overall land use planning, reporting to UNFCCC). Various potential improvements to datasets and methods were identified, and enthusiasm expressed for potential take-up and adaptation of the models involved. Workshop proceedings can be found in Annex 9[9] of this report.

SCOPE OF RESULTS – RELEVANCE TO THE REGION

This hydrologic analysis serves to integrate a wide range of data, and adapt modeling tools for an innovative, region-wide analysis for the MAR. The region-wide results presented in this analysis *should be considered preliminary and indicative of the overall pattern and magnitude of*

[9] Proceedings available online in English and Spanish, through www.icranmar.org, and www.unep-wcmc.org/assessments/mar

erosion and nutrient and sediment delivery across the region. A detailed report of key findings can be found in Annex 10[10] of this report; mayor findings include:

The origin of sediments and nutrients reaching the MAR:

- Of the 400 watersheds in the MAR region, the Ulua watershed in Honduras was found to be the largest contributor of sediment, nitrogen, and phosphorous.
- It is estimated that over 80% of sediment and over half of all nutrients (both nitrogen and phosphorous) originate in Honduras.
- The modeling suggests that compared to the other countries, relatively minor percentages of the regional sediment load come from Belize and Mexico
- Guatemala was identified as a source of about one-sixth of all sediments and about one-quarter of all nitrogen and phosphorous entering coastal waters along the MAR

Runoff, erosion, and nutrient delivery to coastal waters are increasing:

- As a result of human alteration of the landscape, runoff and associated river discharge at river mouths has nearly doubled; sediment delivery at river mouths has increased by a factor of 20; nitrogen delivery has increased by a factor of 3, and phosphorous delivery by a factor of 7. (Ratios are based on model results for current (2003/04) land cover and on hypothetical natural (unaltered) land cover.

The potential impacts of development and land-use paths are varied:

- Under land-use scenarios which favor free markets and little policy regarding the environment, nutrient delivery is likely to increase by about 10% by 2025, while sediment delivery might increase by 13% or more.
- If environmental policies that favor sustainable development are implemented, nutrient and sediment delivery are likely to be reduced by at least 5% from current levels, fostering recovery of degraded corals.
- Implementation of better agricultural management practices will yield additional reductions in sediment and nutrient delivery beyond those evaluated in this study, which has focused on the effect of changes in land cover

Results of this analysis show that relevant policy action at a national level to address the contributions from agricultural lands in the region need to be supported. These results can help identify areas in need of better agricultural management, as the analysis identifies vulnerable areas where conversion to an erosive land use should be avoided, or where converted conservation practices should be implemented. The analysis also identifies areas with high erosion and nutrient runoff, where better agricultural management practices should be targeted. In fact, throughout the project, WWF has used the analysis results to target interventions on improved agricultural management.

With regard to land use planning, the results also suggest that policies that support sustainable development can reduce sediment and nutrient delivery, thereby decreasing sediment and nutrients reaching the MAR.

Results are applicable not only for agricultural policies, but for other sectors as well. At a September 2005 seminar held in Belize by the Caribbean Community's Climate Change Centre, UNEP-WCMC's Belize-based GIS analyst presented on the ongoing work of the ICRAN-MAR's activities to a group of regional climate change experts. Following the presentation, which

[10] Summary report available online in English and Spanish through www.icranmar.org, and reefsatrisk.wri.org

included demonstration of a possible land use scenario, the local UNEP-WCMC subcontractor was approached by the Chair of Belize's national climate change committee about using the project's scenario outputs for modeling the country's future greenhouse gas emissions. This demonstrates both the relevance of the results achieved by the project and governmental interest in using project outputs and tools.

The final results were disseminated widely to government and non-government organizations in the region and several government agencies are planning to do more detailed local analyses using the tools provided on the data CD. The Hydrology-Meteorology Department of Belize has highlighted the relevance of these tools for several in-country applications, and – understanding the logical limitations of the models – their potential to be used to inform in the preparation of a water management bill to establish a water commission for the country[11].

Press coverage of the analysis results was excellent. The Associated Press covered the December 12, 2006 press conference in Belize City. The AP article was used by more than 150 newspapers, magazines, and radio/TV websites. WRI met with the Prime Minister of Belize to brief him on the project on December 14th. He had seen the study results on local TV on December 12th.

An important aspect of the project is the transferring of these modeling tools to partners in the MAR region so that they might apply them at higher resolution to produce more detailed results for smaller areas within the MAR region. This has been done by means of the watershed workshop and subsequent communications with interested parties, such as the Meteorological Department in Belize, INEGI and CONANP in Mexico. This approach will allow for refinement and better calibration of the model to local circumstances within the region by the institutions interested in the utility of these tools.

CAPACITY BUILDING

Capacity building has been a fundamental element of this component. Project's efforts are extremely relevant to national capacity building, particularly in Belize where significant impacts were realized through the presence of a committed UNEP-WCMC contractor in the earlier stages of the project. UNEP-WCMC initially subcontracted some of its work to a government agency in Belize, the Coastal Zone Management Authority and Institute (CZMAI). While the CZMAI has possessed spatial analytical capacity for the past decade, the work with the ICRAN-MAR continued to maintain human capacity by funding staff, and also strengthened capacity through continuous transfer of analytical methods and data. In addition, the local subcontractor spent significant time informally instructing personnel from a number of institutions in various aspects of spatial analysis and information management, and in sharing data. These institutions include Galen University, the University of Belize, the Fisheries Department, the Forest Department, the Belize Audubon Society, and the Land Information Centre, among others[12].

In 2005, the local UNEP-WCMC subcontractor engaged an electronic forum of Belizean spatial analysts seeking to both (a) repatriate crucial spatial data from foreign (mainly U.K.-based) sources such as the Ordnance Survey and Natural Resources Institute, and (b) continue to build capacity in the form of the national spatial data infrastructure. To this end, he played a key role

[11] Ramon Frutos, Hydrology-Meteorology Department of Belize; intervention at the CD launch event, December 12, 2006, Radisson Hotel, Belize City

[12] See Annex 2 for more institutions

in the organization of the first-ever Geographic Information Systems Day in Belize, an event celebrated annually around the world since 1987 that took place for the first time on November 16, 2005 at the campus of Galen University.

Unfortunately, the analyst attached to CZMAI resigned in December 2005, meaning that the implementation of these local capacity building functions for the remainder of the project had to be redeployed elsewhere. However, the analyst is now working for the SERVIR Mesostor initiative at CATHALAC (Water Center for the Humid Tropics of Latin America and the Caribbean), and he has been of great help in ensuring that ICRAN MAR project outputs will be represented on this data portal. An ongoing cordial relationship has fostered links between the project and the broader Mesoamerican region; he attended the project workshop in August 2006, both assisting in facilitation and providing an implementation of NASA's WorldWind software.

In addition to the above, the project also transferred data and analytical methodologies to the countries of the MAR through continued engagement of professionals in the region, and the coordination of the regional watershed management workshop held in August 2006. At the workshop 25 regional experts were trained and there was much interest for further training and in-country and long-distance support. As a result, UNEP-WCMC has requested that their implementation period is extended to June 30 2007 to allow this ongoing interaction with users of the project outputs and models. Currently, a workplan is being refined to facilitate this further capacity building efforts.

INFORMATION DISSEMINATION

All project results have been made available to the wider public through final technical project reports, internet sites, and data CD. These resources can be found at:

- ICRAN-MAR project website. www.icranmar.org
- Project summary reports and maps. Reefs at Risk. reefsatrisk.wri.org
- Workshop proceedings; pdfs of presentations given at the workshop; technical document on Land use change modeling for three scenarios for the MAR region. See: http://www.unep-wcmc.org/assessments/mar.
- An electronic e-mail group was established to facilitate communication amongst regional partners using the land use and hydrology models for which training was provided at the August 2006 workshop. See: http://groups.google.com/group/mar-watersheds
- Maps prepared by the WCMC focal point in Belize in preparation for consultation with local (i.e. Belize) land use experts concerning the land use scenarios. See: www.biodiversity.bz
    - Comparison of national mangrove cover data for 1992 and 2004, showing areas cleared for coastal development in that period (surprisingly only 3,600 acres cleared in the 12-year period): http://www.biodiversity.bz/downloads/bz_mangrove_clearing_1992-04.pdf
    - Comparison of the 90m SRTM-derived slope data with that of our national soil / terrain mapping project, conducted by U.K. Overseas Development Administration between 1986 and 1992: http://www.biodiversity.bz/downloads/bz_slope_maps_comparison.pdf
    - Land cleared as of the period 1989-90-92 (from Belize's first national land use mapping project), showing 0.5 million acres (of 5.6 million acres) of converted lands: http://www.biodiversity.bz/downloads/bz_devt_1989-90-92.pdf
    - Land cleared as of 2004 (the most recent national land use data available), showing over 1 million acres of converted lands: http://www.biodiversity.bz/downloads/bz_devt_2004.pdf

- GIS data are available online via the SERVIR web site at http://servir.nasa.cathalac.org or http://servir.nsstc.nasa.gov

4. Leveraged Support, Impacts and the Larger Scale – The Potential Way Ahead

Partnerships with agribusiness

The agricultural work the ICRAN-MAR Alliance is supporting in the region under the leadership of WWF has proven to be innovative and is setting the basis for a solid long-term program that will benefit the Mesoamerican region. Evidence suggests there is interest and potential to replicate project strategies in other areas of the region and beyond.

- **Leveraged support[13].** Financial support from other institutions has been leveraged to complement project activities and allowing consolidation of project results. Summit foundation committed resources in support of bioaccumulation studies, monitoring and consolidation of BMPs. CropLife – Latin America made a pledge to contribute with funds to enhance the scientific base to demonstrate the persistence and the impacts of agrochemicals in the MAR. The fact that this additional support has been leveraged speaks of the relevance of this work for the benefit of the region. Their support to these efforts is strengthening and paving the way for the continuation and sustainability of this work beyond the life of the ICRAN-MAR project. However, CropLife's contribution will come to an end in 2007 and there is need to seek additional funding.

- **Beyond project original activities.** The original project goal of identifying agricultural threats led to the development of an agrochemical monitoring protocol that is now being used in other regions of the world. The development and execution of the Toxicology Units Program supported by Summit constitutes a significant element in the consolidation of the Better Management Practices project that WWF carries out in the MAR.

- **Filling gaps.** The project is filling gaps that Agriculture Departments in the countries have not fully addressed in the past. Through the ICRAN-MAR project Belizean and Mexican sugarcane growers are having the opportunity to improve their production techniques while producing sugar in a more environmental and economical sustainable way. Other examples include the cover crop projects in Belize and Honduras.

- **Developing marketing linkages.** WWF started ifluencing key investors in the region to improve their enterprises with the concept of BMP-based production. A clear example of this influence is the relationship that WWF-US developed with SabMiller (The CocaCola Company), which decided that its key sugarcane producer in Central America (AZUNOSA) signed a collaborative agreement with WWF to work together on BMPs.

- **Application of project results.** The monitoring protocol has been used by NOAA in the monitoring of contamination after Katrina's hurricane in New Orleans, US. In addition, it has been adopted by the New Zealand government to monitor contamination of their reefs.

- **Potential for replication.** Activities and results under the ICRAN-MAR project have been very well received and commended within the international WWF organization, so much that top management wants to implement it in other parts of the world. The Global Agriculture

[13] See Table 1 in the executive summary for more information

Network, in its January 20007 meeting in Berlin, Germany, will discuss potential places and approaches to implement the program.

- **Catalytic effects in the region.** With the signature of MoUs with Dole and Chiquita for the implementation of better management practices in their banana and pineapple operations, it is hoped that other banana, pineapple, citrus, palm oil, and sugarcane producers located in the Mesoamerican Reef territory will join the initiative and implement BMPs in their production processes.

- **Changes in national laws and regulations.** Due to the formal adoption of the Central America Free Trade Agreement (CAFTA), and the anticipated influence in the crop distribution and pesticides use, WWF is developing the project "Analysis of the CAFTA impact in the importation and use of pesticides in the MAR Watersheds". This activity began in Guatemala in June 2006 and aims to: a) identify the possible change in crops and pesticides use, b) determine the new pesticide use regulatory requirements under CAFTA, and c) forecast the possible environmental impacts due to anticipated changes in pesticides use and WWF's current information on bioaccumulation in marine organisms. This study is being carried out under the leadership of the Guatemalan Clean Production Center and the main conclusions and strategic recommendations will become available early in 2007.

- **Strengthening scientific base.** The partnership (MoU) with FHIA is of great relevance for the strengthening of joint scientific and research capabilities to promote agriculture BMPs in the region. FHIA recently started the project "Citrus Producers in the Aguán River Basin, and Palm Oil Producers in the Coastal Plains of Department of Atlántida, Honduras" which will develop the baseline information for the long term monitoring of the environmental impacts caused by this industry in the Aguán River Basin area and nearby marine ecosystems. This project will complement some of WWF's strategy in agriculture by: a) developing a citrus producers data base, b) establishing a citrus grower working group based on the MoU already signed with WWF – whereby the industry is committed to implementing sustainable citrus production practices – and, c) developing a citrus threats analysis, a geo-referenced map and a preliminary report of recommended local better management practices.

- **Improving communication and information exchange.** Communication between industries within countries and industries among countries has improved. As a result, different BMPs among countries can be shared and there is interest in doing so. Sugarcane growers from Mexico, who are the leaders in biological control of insects have expressed willingness of sharing this information with Belizean and Honduran sugarcane growers. The Sugar Mill officers from San Rafael de Pucte, Quintana Roo, Mexico, provided AZUNOSA in Honduras with blueprints and production costs for the construction of a laboratory for the production of *Metarhizium spp*. There is potential for more information exchange.

Watershed Analysis and modeling

Through the development of these activities, a number of benefits to the region have been obtained, many of which have the potential to link with other ongoing activities to secure the long-term sustainability of these results, and promote the conservation of the coastal and marine ecosystems of the MAR.

- **Benefits to the region.** The close coordination of activities between WRI and UNEP-WCMC has yielded remarkable results in the region. Their activities have filled up a critical

information niche by developing tools and producing data that no other initiatives had produced in the region. In addition, the wealth of expertise of the partners has been transmitted to other institutions and personnel in the region, thus providing significant transfer of information and capacity building.

- **Potential to link with other ongoing initiatives.** Analyses such as these can help to evaluate progress in reducing land-based sources of threat. A number of national initiatives, as well as donor-funded regional initiatives, seek to reduce or mitigate threats to the MAR. This analysis can help these initiatives to estimate their progress by giving them the information they need to ensure they are moving in the right direction.

- **Potential to target policies.** More detailed modeling is needed to create more accurate information at higher resolutions. Regional-scale analyses are useful for providing an overview and for prioritizing areas in which action is needed. However, *local analyses provide more detailed and accurate information that policymakers need in order to target their interventions*. The tools provided on the data CD, Watershed Analysis for the Mesoamerican Reef, allow users to perform more detailed analyses of sediment and nutrient delivery within smaller areas in the MAR region, such as at the watershed level. More specifically, the model can be applied to individual watersheds or groups of watersheds using data provided or with the user's own data. More detailed local modeling will improve the accuracy of the results, by using higher resolution data on slopes and land cover, and by calibrating the model to local soils and precipitation regimes.

- **Catalytic effects on other agencies.** Government agencies in each of the four countries are interested in applying the modeling tools at higher resolution for local areas to address specific policy questions such as: a) Targeting of implementation of better agricultural management practices; b) Integrated watershed management; c) Reforestation; d) Evaluation of progress against policy indicators / objectives. Land use scenario data outputs can assist in guiding land use planning both at the regional/eco-regional scale and at the national level. The project has catalyzed key stakeholders' thinking about land use planning by merely collating simple but relevant data on the changing physical landscape surrounding the Mesoamerican Reef. In presenting data and model outputs to these critical decision-makers, opportunities for collaboration not originally envisioned are created.

- **Beyond agricultural sector.** The land use scenarios outputs are also desired within the climate change sector for modeling of potential changes to carbon stocks over time. These models can provide an indication of economic benefits that might possibly be lost by unregulated expansion of agricultural frontiers. This is particularly relevant to nations involved in Clean Development Mechanism (CDM) projects through the Framework Convention on Climate Change (UNFCCC), and potentially in any future avoided deforestation mechanism (currently under discussion within this Convention).

- **Regional cooperation.** Transnational natural resource management can be strongly supported by analyses such as these. To mitigate and reduce the land-based threats to the MAR, constructive regional cooperation among a variety of stakeholders is necessary. Examples include the multilateral cooperation agreements among the four countries involved in this analysis, and agreements between the agriculture and tourism sectors and civil society groups. This tool works across borders and sectors, creating information that allows productive discussion on threat origins and potential mitigation measures

- **Beyond regional borders.** WRI partnered with TNC to bring the University of Miami onboard to implement a circulation model for the MAR region to examine the transport of sediment (buoyant matter) to the Mesoamerican Reef. Not only the region benefited from the knowledge gained, but the University also benefited from this research experience, and can incorporate the lessons learned in other studies.

- **Data flow.** Throughout the project, data has flowed not only from UNEP-WCMC and partners to the region, but also from the region to UNEP-WCMC and partners. As the biodiversity assessment arm of the United Nations Environmental Programme, UNEP-WCMC is more easily able to access data on the Mesoamerican region through its involvement in the project. Several improvements to the quality of the World Database of Protected Areas, which UNEP-WCMC manages, have been undertaken as a result.

- **Cross-fertilization.** While both the improved watershed management component and the project overall seek to provide decision-makers with results of analyses of impacts of current activities on the health of the Mesoamerican Reef, the project has had a welcome impact in the region with regard to the support of environmental information systems (particularly spatial analysis). This is accomplished both through the development of information products which enrich the overall regional and national spatial data infrastructures, but also through the enrichment and cross-fertilization with existing mechanisms for information sharing and data analysis. A prime case in point is the hosting of the project's spatial data products on SERVIR, the Mesoamerican System for Visualization & Environmental Monitoring. Both the ICRAN-MAR project and SERVIR are USAID-supported initiatives whose outputs are inter-related in terms of spatial data products. Not only does the data produced by the ICRAN-MAR project enrich SERVIR, but the wide dissemination of data through SERVIR has enhanced regional awareness of the project and its objectives.

Further needs and potential)

- It would be valuable to extend the current analysis to include the effect of improved agricultural management practices on erosion and pollutant runoff. Such an extension would require detailed information on how each practice influences erosion rates and pollutant runoff. Once such information is available, it should be possible to use the model to evaluate reductions by treating each management intervention on each land cover type as a unique category with specific erosion and pollutant runoff characteristics. For example, citrus groves with cover crops planted to reduce erosion might be treated as a separate category. It is expected that WWF, as a result of their on-the-ground work with agribusiness and through their continuous Ecoregional work, can provide this type of information to feed the model.
- The scope of the current project did not include a module to calculate/consider the impacts of this sediment and nutrient delivery on the coral reef: how do different reef communities and topographies respond? What are the drivers of vulnerability to sediment deposits? It would be valuable to collaborate with experts on this issue.
- The scenario modeling undertaken during this project stretches to 2025. Minimal attention is paid to climate change within the modeling, though increased vulnerability is described within the narrative scenarios. Any further development of this work could consider:
    - The future impacts of climate change on terrestrial issues such as agricultural suitability and fire frequency
    - The interaction between climate impacts on coral reefs (warming seas, coral bleaching, acidification) and sedimentation impacts

- An obvious next step would be to look at marine reserve planning and vulnerability of existing marine reserves in the context of climate change and sediment threats. For example, network design could optimize larval dispersal opportunities and to include more resilient reef types (Schuttenberg 2001)[14].

- There is scope for using this type of modeling approach in local to regional scale GEO exercises, and perhaps national scenario exercises, ideally with training sessions conducted in Spanish. Regional capacity building by involvement within the GEO process would be a useful way to go about this. At least in Latin America, GEO already has some direct access to a broad range of policy makers

5. Lessons Learned and Recommendations

Most of the following lessons and recommendations come directly from the implementing partners.

Partnerships with agribusiness

- Original assumptions in implementation time and in seeking collaboration within the agroindustries were imprecise. Gaining trust from an agribusiness sector that was being attacked by environmentalists for contaminating the environment and depleting natural resources took longer than originally anticipated. It took time to make them understand the project's strategy of voluntary engagement and sustainable use of resources.
- When planning, consideration needs to be given to the agroindustries' willingness to participate and the different constraints and drawbacks they have in their agroindustries. Confidentiality and property rights have to be taken in consideration.
- Now that key agribusiness are on board and working voluntarily makes them feel as a part of the solution, project partners do not want to lose this momentum and are looking for potential funding opportunities.

Watershed Analysis and modeling

<u>Technical – activities</u>

- One of the major lessons to be drawn from the project is that of technology transfer. While institutions like the World Resources Institute and the World Conservation Monitoring Centre possess great analytical capacities, with proper engagement of local institutions and individuals, it is possible to build local capacity in meaningful ways. In the case of the work led by UNEP-WCMC, the decision was taken to hire both a skilled land use modeler as well as a spatial analyst from the project region, which served the dual purpose of getting activities done AND to simultaneously contribute to building capacity in the region.
- The watershed theme included analytical components implemented by WRI and UNEP-WCMC and on-the-ground activities lead by WWF. This combination of analytical and on-the-ground activities was very effective.
- Application of modeling tools that can be transferred to the region, such as the N-SPECT hydrological model, probably add more value than the very analytically-complex, computationally intensive models such as the circulation model run at the University of Miami, which requires a UNIX system and cannot be transferred

[14] Schuttenberg, H.Z. ed. 2001. Coral Bleaching: Causes, Consequences and Response. Selected Papers presented at the 9th International Coral Reef Symposium on "Coral Bleaching: Assessing and Linking Ecological and Socioeconomic Impacts, Future Trends and Mitigation Planning". Coastal Resources Center, Univ. of Rhode Island.

- Model validation is an important part of model application. The hydrologic and circulation models were validated, but rather late in the project. Emphasis on data collection for model validation and execution of validation earlier in the project would be useful.
- Validation of models is a vital component of a modeling effort. It can take considerable time to acquire appropriate data for validation. Collecting such data early in the project and doing preliminary validation as early as possible will help to identify potential errors in the model.
- A more conventional scenarios approach, with a narrative generation workshop prior to the modeling, would have helped maximize the relevance of the narratives to the region. This would have required a more substantial budget, to allow a scenario generation workshop as well as the evaluation and training workshop
- The only workshop featured in the project plan is a scenario communication and training workshop; a second modeling phase was not taken into account in the original design. Regional-scale scenarios produced from the GEO process had to be adapted for the MAR. While these do have broad legitimacy, the ideal situation is to develop the scenarios working together with the people who are interested in the results, and to be able to include their feedback after the first modeling round.

Coordination and Management

- During project design it should be necessary to make sure that all core partners have the staff and skills required for project execution. It took UNEP-WCMC approximately nine months to identify and hire consultants to begin their component of the project. This delayed the start of some key activities whose outputs were necessary for WRI and thus, compressed the time available for project execution.
- The ICRAN-MAR project strives to complement existing activities in the region. Significant effort was invested in trying to collaborate with the MBRS project, but unfortunately this was not possible to the extent originally envisioned.
- While it is important to share project plans and results, it is advisable not to make project activities dependent on groups or other activities that do not have the time/interest/resources to collaborate.
- Frequent reporting requirements have been found to be more time consuming than for most projects partners are involved in. It is consider that this has incurred costs in terms of staff and consultants' time that could perhaps have been better spent on the work itself.

B. SUSTAINABLE FISHERIES (IR2)

Local fishers' and cooperatives' capacity strengthened for sustainable fisheries management. (Through the development of industry partnerships, promotion of "best practices", training in financial management, resource management, and alternative income generation strategies.)

1. Threats – Rationale for Component Design

Fishing is probably the most socially and economically important activity for many coastal communities in the MAR region. In the last decade, however, catches have decreased as the key commercial species such as lobster, conch, snappers and groupers are over exploited. This trend represents a global crisis related to coral reefs, and unsustainable fishing practices are among the leading causes.

Adoption of better fishing practices (BFP) and monitoring of their potential effects contribute to localized management efforts. For the past two years, project partners World Wildlife Fund (WWF) and Reef Check have engaged community stakeholders in education and awareness activities on the need to adopt better fishing practices, and have trained them in ecological and socioeconomic monitoring of reef health using the Reef Check protocol.

The main objective of this component has been to support the generation of tools and capacities for management to increase institutional capacity, dissemination of key information and creation of incentives for users and stakeholder groups that identify sustainable use patterns of the MAR's natural resources.

2. Description of Component Strategy – Dynamics over the Past 30 Months

This component was designed around four original sub-results. Just like with the previous component, project partners have engaged in extensive consultations with regional experts, local partners, and the private sector to identify opportunities for collaboration and potential common grounds where to develop more specific activities. Over the course of project implementation partners have faced different obstacles that nonetheless have not prevented them from achieving significant results. Adjustments in project activities have been necessary to adjust the original proposal to the realities of the region. These adjustments have been reflected in each annual workplan and seeking approval from the donors and the coordinating unit.

Sub-result 2.1 Community-based fishery management improved through development of appropriate partnerships with private and public sector and best practice guidelines for sustainable harvesting of principal MAR coral reef fisheries *(To be led by WWF during the 3 years of project implementation)*

Considering that unsustainable fishing, particularly overfishing, is pervasive throughout the MAR and remains one of the major impediments to a healthy reef system, the challenge at the beginning of the project was to develop a protocol for the community-based fishery management. This protocol should contain the guidelines to successfully promote the community-based fisheries management in the different types of organizations (associations, cooperatives, etc) of the four MAR countries. An important element under this management scheme was to develop partnerships with private and public sector, mostly with the seafood buyers. Because of their economic value, seasonality, domestic importance, and gears used, the analysis of fisheries sectors in the four countries in the MAR, led to differentiate two types: 1) **Lobster Fisheries**, and 2) **Finfish Fisheries**. Therefore, the way to fulfill the first sub-result was to develop the guidelines for better management practices for lobster and for finfish fisheries.

Lobster Fisheries

A diagnostic of the Lobster fisheries in the MAR concluded that the main problems are: 1) the illegal catch of under-sized lobster (baby-lobster); 2) capture of egg-laying females; 3) the use of unsustainable practices such as SCUBA diving, or diving with compressor; 4) fishing without proper permits, and minimal government resources for monitoring and enforcement; 5) Honduras fisheries are legally over-exploited; and 6) Mexico and Belize fisheries are exploited at their maximum levels.

All these elements were considered in the design of activities for lobster Better Fishing Practices (BFP) development, which were guided by the publication and promotion of the booklet: "How to profit by practicing sustainable fishing: Lobster Fishing Practices Guidelines for the Mesoamerican Reef" (See Annex 11).

Finfish Fisheries

Finfish Fishery in the MAR is more complicated to address. Fishing in the MAR is carried out by more than 9,000 artisanal fishermen from hundreds of poorly organized communities and cooperatives, and with little control over access to fishery resources. Addressing this required a complex set of strategies, combining sub-results: 2.1. Community-based fishery management, and 2.2. Community-based ecological monitoring.

Ecosystem-based fisheries management (EBFM) – with fishermen participation in field data gathering – was selected as the strategy to bridge the link between community-based management and ecological monitoring. The EBFM establishes a series of protocols for the use, monitoring and evaluation of the ecosystems where fishing takes place. This strategy aims to reverse environmental degradation, and to provide socioeconomic benefits associated with fishing, and to help project partners understand the effects of human activities on ecosystems. The protocols developed have allowed partners to gather relevant scientific high quality information very useful in the designing of fisheries management.

The strategy to introduce the EBFM with fishermen participation is to identify marine protected areas (MPAs) with intense fishing activities; then organize workshops with fishermen and MPA authorities and design a monitoring program with fishermen participation. It is expected this monitoring program will be set up before the end of the project.

Sub-result 2.2 Community-based ecological and socio-economic monitoring implemented where appropriate to support community assessment and monitoring of their progress in resource management. *(To be led by Reef Check in collaboration with WWF during the 3 years of project implementation)*

In addition to the monitoring efforts described above in the framework of the EBFM, Reef Check has engaged community stakeholders providing training in the socio economical and ecological aspects of coral reef health, thus empowering them to be part of local solutions efforts to a global reef crisis.

Local communities and institutions were engaged since funding was provided for the implementation of the project. Local leaders and coral reef stakeholders in the four countries were approached and later identified as potential implementers of RC-ICRAN-MAR activities. Engagement of Guatemalan stakeholders was lagged for some time but is now up to date; communities in general have responded very positively as they now have the much needed tools to provide local solutions to a global problem.

Training of fishermen and tour operators in monitoring techniques usually takes place at the park facilities which allows park staff and college students to attend the training sessions as well. Having a mixed and balanced group of novice and experience divers facilitates knowledge exchange and in turn increases the learning rate. Fishermen participants in the training activities are selected based on their level of involvement and use of park resources, as well as their interaction with park managers. By involving the fishermen there is a greater likelihood for their involvement in management efforts.

Through these activities local fishermen, in general, feel that as important stakeholders they are being taken into account for any management actions being designed for the region. They feel they have the capacity to assess the health of reef resources, enabling them in looking at ecological trends in their own terms. Project partners are strongly supportive of government-related strategies to conserve coral reefs, but also seek the empowerment of direct resource users that have a day-to-day impact on ecologically relevant species and

critical habitats. By getting involved in local conservation efforts, trained fishermen can then be selected by managers for future work related to conservation in the area.

Sub-result 2.3 Key marine protected areas strengthened in collaboration with GEF/MBRS and PROARCA/APM (to demonstrate successful community-based fisheries to the wider community). *(To be led by WWF during the year one of project implementation)*

Fishermen exchanges facilitate learning by sharing information to solve problems that fishermen face on a daily basis. At the same time, these activities increase fishermen trust in conservation initiatives, and raise the profile of their knowledge and perspectives to be taken into account for future conservation actions.

With the goal of strengthening fishermen organizations and capacity-building among fishermen groups, WWF sponsored fishermen participation at the "1st Workshop on Sustainable Fisheries in the Mesoamerican Reef" fostered by the MBRS in Chetumal, Mexico on November 2004. Fishermen from Quetzalito, Puerto Barrios, Punta de Manabique, and the Network of Caribbean Fishermen gathered to share technical information and financial knowledge, and ranged from well organized fishermen to those less organized from different countries and/or regions.

In addition to the above, during year one of implementation, WWF organized other fishermen exchanges, especially from Guatemala to Mexico (where fishermen associations are usually more organized and have more expertise in community management, and in particular fishermen from Punta Allen, Sian Ka'an). Fishermen from Punta Allen have overcome a history plagued with misfortunes, such as hurricanes, bankruptcy, and bad administration of their resources; currently they are among the most organized and successful fishermen communities in the region and they are willing to share their experiences and lessons learned. With these experiences Guatemalan fishermen learned about fisheries management, community based management, and resource and nature conservation.

Sub-result 2.4 Increased local community member's capacity to engage in alternative livelihoods such as community-based tourism. *(To be led by WWF during the 3 years of project implementation)*

To strengthen the capacity of local fishermen communities, project partners have been engaged in facilitating different training exercises in support of alternative livelihoods. Early training activities included tour guide training courses for fishermen in Sarteneja (Belize), Sian Ka'an, and Xcalak (Mexico); as well as two workshops on the mariculture of seaweed for regional fishers in collaboration with Alan Smith, a leading regional expert and trainer from CANARI in St. Lucia. However, alternative livelihoods seem to depend more on the market forces than on the capacity to provide good or services from the fishermen communities. Experts on mariculture suggested that international markets demand exotic species that could become invasive in the MAR. For that reason, seaweed culture may not be a competitive activity as alternative livelihood in the MAR.

Current trends in the economy of the region give signals that tourism will become the most important activity in the near future. Governments are investing on it, and fishermen may be an important component of this new activity. More recent efforts under the ICRAN-MAR project report that whale-shark swimming service provided by fishermen from Holbox has become an important alternative livelihood for fishermen, and they have stopped fishing 50% of their time, since high aggregations of whale-shark occur every year from May to September. Hundreds of visitors from U.S. and Europe demand the service paying a high price to experience this activity.

In spite of of the early tour guide trainings and the interest of fishermen for more training in alternative livelihoods, the ICRAN-MAR Fisheries Component has experienced some limitations in this front, producing little impact on the sector. Therefore until the end of the project efforts will continue supporting fishermen involvement in the monitoring exercises.

The revised strategy pertaining to sub-results 2.1, 2.3, and 2.4 has contemplated completing most activities in Mexico[15] by the second year of the project, where WWF's project staff is based and where there is a better understanding of the local circumstances. Field work in the other countries started analyzing particular situations and the general context to determine key stakeholders and the specific strategy per country. In Belize for example, much attention has been paid to the establishment of no-take zones, and the government has advanced greatly on that front. Therefore, the Fisheries Department from Belize expressed little interest in working with the EBFM methodology being developed under the auspices of the ICRAN-MAR project. For the past year, work has been carried out on a full time basis in Belize, Honduras and Guatemala, and the entire budget is being invested in the activities for those countries. The level of advance in Belize, Honduras and Guatemala is good, and no problems are foreseen to fulfill the activities by the end of the project.

Table 6: Fisheries Component – Percentage of efforts invested by country – as of December 2006

Strategy	Activities	México	Guatemala	Belize	Honduras
Lobster (BFP)	Workshops	100%	--	50%	33%
	Publication	100%	--	80%(1)	--
	Distr. Of Publications	100%	100%	10%	33%
	Other meetings	100%	--	100%	--
Finfish (EBFM)	Workshops	100%	33%	--	33%
	Publications	100%	--	--	
	Distr. Of Publications	100%	100%	50%	50%
	Other meetings(2)	100%	100%	100%	100%
	Monitorings	100%	0%	--	0%
	Studies	100%	0%	--	0%
	Other	100%	--	--	--
Alternative livelihoods	Fishermen Exchanges	100%	50%	--	50%
	Workshops	100%	100%	--	--
	Publications	100%	--	--	--
	Feasibility Studies	10%	--	10%	10%
Reef Check monitoring	Reef Check Centers	100%	100%	100%	100%
	Trainings	100%	60%	100%	100%
	Surveys	100%	30%	100%	100%

(1)-English version of Lobster BFP manual is under revision of (BFCA). The final version will be presented in a plenary workshop in Belize City, in the National Fishermen Federation facilities.

(2)-Meetings with domestic and regional authorities, private sector for partnership, MBRS and other NGO for coordination, key fishermen leaders, regional forums, universities, etc.

[15] Fisheries sector has a higher level of organization (as compared to the other countries of the MAR) in Mexico, and it is where WWF's Senior Fisheries Officer is based (reducing implementation costs)

3. Major Achievements and Results – Impacts in the Region

The current section provides a narrative description of project results up to the end of the agreement between UNF and USAID (November 2, 2006) and the impacts these have generated in the region. It also describes the expected results to the end of the project and the potential opportunities for continuation beyond the life of the ICRAN-MAR project. For a summarizing table of project indicators and status, please refer to the indicators section of the executive summary in this report.

Major achievements include:

- A detailed study about all the lobster fishing techniques in the MAR. In cooperation with fishermen and local authorities identified the techniques that are more environmentally friendly, the ones that allow abiding to regulations, that reduce risks of illegal catching, and the ones that reduce the risk of health/security problems
- Development of lobster Manual "How to profit by practicing sustainable fishing: Lobster Fishing Practices Guidelines for the Mesoamerican Reef" (see Annex 11). The content of this book was discussed with fishermen before it was printed (Spanish version)[16], and in spite of its technical and scientific contents, the language it uses is rather simple, making it an easy reading for fishermen. This booklet has become the core of the project, guiding fishermen to adopt better fishing techniques. It gives relevance to organization agreements, emphasizes the importance of abiding regulations, and educates fishermen in the knowledge of the resource.
- More than 1,200 copies have been distributed among fishermen in workshops, fishermen exchanges, training sessions, meetings, etc. Through these activities project partners have identified fishermen cooperatives and groups that are performing better management practices and some fishermen are working to obtain the MSC certification, which will be an important consequence of the ICRAN-MAR project.
- Production of other educational materials (see Annex 12 for plasticized cards)
- MoU signed with the Regional Federation of Cooperatives from Quintana Roo, Mexico – over 1,000 fishermen members – to adopt and promote the use of lobster BFP
- Alliances built between the private company Darden and fishermen organizations from Honduras to initiate pilots to introduce environmental-friendly traps – developed by PROARCA – in artisanal and industrial fisheries[17]. Darden is the most important importer of lobster in the U.S., and it manages the restaurants "Red Lobster".
- Development of an EBFM methodology for the region and production of the book "Best Fishing Practices in Coral Reefs; Methods for collecting ecological data that support the Ecosystem-Based Fisheries Management" (See Annex 13). This methodology was successfully tested in Yum Balam, Mexico, after Hurricane Wilma hit Holbox fishermen village. The book was produced with direct contribution from local fishermen through their participation at various workshops, field monitoring exercises, and incorporating their inputs.
- This manual has been delivered to fishermen and MPA authorities, and the strategy is to initiate the EBFM in five Marine Protected Areas (MPAs) before the project concludes.

[16] English version waiting to be revised by Belizean stakeholders

[17] Darden will give a grant to APESCA (chamber of industrial vessel owners) to produce the traps and will pay on-board observers who will certify that fishermen are no longer taking undersize and pregnant female lobsters

- Reef Check centers have been set up in the four ICRAN-MAR countries, providing trained staff and educational materials in Spanish and English (See Annex 14 for English version of RC protocol)
- Production of updated educational materials and data collecting and analysis tools in English and Spanish usable by non-scientist immediately after field surveys are completed
- Over 190 people trained in Reef Check's socioeconomic and ecological monitoring of coral reef health. Trainees include local trainers, fishermen, Diving staff, students, park staff, and general public (See Annex 2 for more information)
- Design and set up of a coral reef monitoring program inside and outside MPAs. Training, data collection and analysis are conducted locally by community stakeholders, making them part of the solution of the global coral reef crisis.

Steps for achieving these results also have included:

- For the development and promotion of lobster BFP: 10 workshops organized, two studies carried out, three different publications released (English and Spanish), one fishermen exchange organized, over 3,000 printed materials distributed among fishermen and stakeholders, and two MOUs signed.
- For the development and promotion of EBFM: 10 workshops organized, five studies carried out, five monitoring exercises undertaken, two publications released (English and Spanish), three fishermen exchanges organized, and over 1,000 printed materials distributed among fishermen and stakeholders.

SCOPE OF RESULTS – RELEVANCE TO THE REGION

As already mentioned, activities under this sub-component will continue until the end of the project and more results will be delivered (see next section for final outputs). However, results achieved to date provide evidence of the relevance of conducting this work for the benefit of the MAR.

Over the course of these years, the project concept has allowed developing a systematic organization of relevant activities leading efforts toward the sustainable use of fisheries resources considering as much as possible the principles of building alliances with the private sectors, community-based management, ecological monitoring, and to a less degree alternative livelihoods. It is important to note that impacts/changes have not been as immediate as originally anticipated, because due to the complexity of the problem it has taken partners considerable time to reach the current status.

Best Fishing Practices – Community management

For many years, conservation efforts in the MAR have not been easy to address within the fisheries sector because of the lack of solutions that satisfy fishermen needs. Different projects have not been able to satisfactorily reach out to the thousands of users spread throughout the 1,000 km of coast, who are catching over 100 species using 50 different gears. The ICRAN-MAR project has been able to propose a potential way to successfully approach the sector: BMP for lobster coupled with community-based management using EBFM, and fishermen participation in ecological monitoring. Still, due to the nature and complexity of the problem, it will take some time before these avenues can demonstrate greater impacts. Current results

under the ICRAN-MAR project nonetheless are paving the way for long-term conservation and community management efforts in support of healthy reefs and healthy communities.

The community participatory strategy followed by the project has been vital to gain fishermen trust and collaboration to achieve project results. Fishermen have welcomed the educational project materials on better practices that have been produced especially for them[18]. Their active participation through discussions, workshops, studies, and drafts revisions for the elaboration of these materials, give them a sense of ownership, a feeling that they are some of the main "actors" in those books and they are more willing to practice some of those recommendations. They enjoy discussing fish species names, abundances, sharing empirical ecological and biological information, and learning from scientists and from other fishermen.

Workshops organized in different villages to discuss BFP have allowed fishermen to express their point of view regarding the possibility to shift their current techniques to BFP. While some fishermen[19] understand and recognize the usefulness or practicability of the BFP techniques, others express doubts about the efficiency of BFPs as compared to their traditional techniques. Fishermen exchanges have served to change this perception and slowly more fishermen are considering adopting BFP. A significant achievement is the commitment from the Regional Federation of Cooperatives from Quintana Roo, Mexico, to adopt and promote the use of BFP.

All this activities set the basis to achieve more ambitious goals, such as lobster fishery certification, or the establishment of a monitoring system of BFP that allows fishermen to guarantee that their lobsters have been caught using BFP (some seafood buyers have expressed their interest in buying this lobster at a preferential price). In fact, in October 2006, WWF and the Fishermen Federation from Quintana Roo requested a two-year grant from the Sustainable Fisheries Fund to conduct a pre-assessment of six lobster fishing cooperatives[20] along the Caribbean coast of Mexico. ICRAN-MAR Best Fishing Practices resulted in a great interest from fishermen to pursue the Marine Stewardship Council certification. This MSC certification for lobster activity is ongoing and will have results at the end of 2007.

The ecosystem-based management approach has been a novelty in the region. The project is elaborating one of the first cases in the world where EBFM is applied to elaborate management plans involving fishermen in scientific data gathering. This initiative has had a positive impact in Marine Protected Areas where fishing is an important activity. MPA's authorities have welcomed the methodology to work with fishermen to produce the basic information that can lead to the establishment of a management plan. Five MPAs have requested to participate in this program: Yum Balam, Banco Chinchorro Biosphere Reserve, Cayos Cochinos National Park, Cuero y Salado Wildlife Refuge, and Punta de Manabique Wildlife Refuge. These sites are preparing to initiate ecological monitoring using the EBFM protocol with participation of MPAs staff and fishermen. At the end of the project, the bases to continue the fisheries management plans in the five sites will be set. Project partners expect to train 250 fishermen and 20 biologists from MPAs, in ecological monitoring and elaborate 5 studies on the ecosystem status and fish assemblages, with emphasis in finfish species (commercial species).

[18] Such as the booklet "How to profit by practicing sustainable fishing", plasticized cards, posters, or "Best Fishing Practices in Coral Reefs"

[19] In Punta Herrero, Mexico, fishermen have stopped using the hook, and they are using shades and "hammo". In different villages from Belize, fishermen are trying using shades and traps instead of hooks.

[20] Six cooperatives with 255 fishermen who have concessions to catch lobster in the Biosphere Reserves Banco Chinchorro and Sian Ka'an

An increasing number of communities have requested to participate in the initiative supporting the adoption of BFP and expressing their interest in engaging in sustainable and profitable alternative economic livelihoods. As the project continues, even more communities become aware of the significance and potential of their contribution to maintaining healthy reef ecosystems.

Ecological and socio-economic monitoring

Monitoring results to date reflect the reality and current status of fisheries resources in the MAR region, documenting coral bleaching, and the scarcity of economically important species and reduced population levels of second-order reef fish species like parrot fish and snappers. Besides creating a scientific baseline on the current trends of reef health on the region, this data collection process not only serves to document the status of reefs, but also empowers the communities in the MAR region and raises local awareness and supports localized management efforts.

Implementation of RC activities under the ICRAN-MAR project has served to produce continuous presence on the ground (and in the water) of RC trainers and trained divers in the monitoring of ecological and socio economical aspects of coral reef health. Allowing non-scientist to collect valuable data and educational support in areas where highly expensive and isolated scientific expeditions were lacking or had limited capacity. This can be easily measured in the vast amount of data collected over the life of the project, which has contributed valuable information for local managers, general public and to the Global Coral Reef Monitoring Network and that is available online free of charge. In addition, local dive centers have started to get the necessary tools to get involved in local reef conservation efforts while they receive financial incentives to offer an added value service to their clients.

Training workshops are not only used to training local stakeholders in coral reef monitoring but also to raise awareness of the coral reef crisis at a local level, making emphasis that these crisis occurs also at the global level. Data collected by participants can be viewed, analyzed and compared globally free of charge online at www.reefcheck.org/datamanagement

Collaboration with National Parks ensures that trainees are active users of coral reef resources in the MAR area. That is the case with *"Parque Nacional Arrecifes de Cozumel"*, which has been partnering with Reef Check to conduct training workshops and facilitate surveys in Mexico.

The involvement of the private sector has also been fundamental for the implementation of these activities; there is great interest from local tourism operators to get the necessary tools and develop the skills to participate in conservation and offer this added value to their costumers. Fishermen cooperatives have also being engaged, Punta Allen fishermen have strongly indicated their efforts in coral reef conservation as a mean to make fishing sustainable in the long term.

FINAL OUTPUTS AT THE END OF THE PROJECT

Refer to indicators section of the executive summary for a table with current status of indicators (as of December 2006).

a) *5 baseline studies of fish and benthic assemblages and coral reef condition, produced for communities in Mexico, Honduras, and Guatemala by June 2007*. In Yum Balam, Banco Chinchorro (Mexico), Cuero y Salado, Cayos Cochinos (Honduras), and Punta de

Manabique (Guatemala), WWF will collaborate with fishermen to design and implement a baseline study of fish populations and status for each site that will serve as a basis for creating an EBFM plan. The first step is to train participating fishermen in the EBFM protocol. Once completed, these fishermen will have learned how to: (a) survey adult fish along a 50 meter transect, (b) measure topographic complexity along the transect, (c) use video to record the bottom along the transect, (d) count the number of coral colonies along the transect, (e) sample benthic groups using the intercept point technique, (f) record key invertebrates along a band transect. Equipped with these skills, over the course of the next year, fishermen will be able to participate in the data collection and monitoring of fish populations and will have gained the knowledge needed to play a strong role in designing future management options that meet their needs and protect the MAR.

b) *242 fishermen involved and 90 trained in the monitoring protocol*. Experience dictates that when fishermen actively participate in field work and provide basic data for scientific analysis, they will be more receptive to the recommendations that can emerge from the scientific studies. The next step after creating the baseline analysis of fish populations and status is to begin to formulate management recommendations like no-take zones and other designations. As the research progresses, WWF will present the findings of the research to the fishermen and to get their input and reactions.

c) *12 technical staff from four Marine Protected Areas trained in the monitoring protocol*. With the intention of transferring the monitoring protocol to MPA authorities, it will be necessary to train their staff in the same technique as fishermen, but in analytical skills too. The book "Best Fishing Practices in Coral Reefs; Methods for collecting ecological data that support the Ecosystem-Based Fisheries Management" has three sections of specialized contents in statistical and ecological analysis, as well as electronic spreadsheets programmed to perform ecological calculus after capturing data on fish assemblages and coral video recording. With these tools, MPA staff will be able to update the information that will be useful in developing fisheries management plans.

d) *Two printed books and electronic version in English and Spanish about lobster BFP and EBFM monitoring protocol (5,000 copies distributed in the ecoregion).* At the end of the project, all the materials produced during the last two years, will be distributed among fishermen, fisheries and MPA authorities, and other key stakeholders in the region. These materials include the core books as well as supplementary publications such as pamphlets, brochures, and posters[21].

e) *Two MOUs signed by Fishermen Organizations (Mexico and Belize) to promote the use of lobster BFP.* These MOUs are very important to gain support from legitimized fishermen organizations. The purpose of these MOUs is collaboration to perform joint and individual activities to achieve sustainable use of fisheries in the MAR. These MOUs establish the basis for cooperation between WWF and the fishermen organization to continue lobster BFP, and have a commitment from fishermen to support future lobster MSC certification process. Fishermen organizations form Belize and Mexico represent about 2,000 fishermen, but clearly not all of them will achieve the BFP standards or the MSC certification.

f) *Two agreements between private sector (seafood buyers) and producers to trade lobster BFP.* Darden, a US company will provide a grant to start the use of BFP among Honduras fleet to catch lobster. It is obvious that under this scheme, Darden will not gain a certification on the products they are introducing to the US, but there will be a strong partnership and commitment between the vessels owners who participate in the project,

[21] See Annex 12 for plasticized cards – lobster BFP

and Darden. Another agreement will take place in the next "lobster season" (from July to February 2007) between a local restaurant based in Cancun and the fishermen from Punta Herrero, who are using lobster BFP. They will agree to sell their product and WWF is designing a monitoring protocol to ensure that fishermen are catching lobster under BFP.

g) Ready-to-use data sets available online and free of charge on socioeconomic and ecological parameters on coral reef health using the Reef Check protocol.

h) Reef Check educational and training material both in English and Spanish for local stakeholders to use for local conservation efforts and to continue implementation after ICRAN-MAR project ends.

4. Leveraged Support, Impacts and the Larger Scale – The Potential Way Ahead

Fisheries activities undertaken with the auspices of the ICRAN-MAR project have been innovative and have created great expectation among fishermen and other stakeholders.

- **Leveraged support[22].** Financial support from other institutions has been leveraged to consolidate project results and to continue some activities beyond the life of the ICRAN-MAR project. Sustainable Fisheries Fund provided a grant to support artisanal fishermen from Banco Chinchorro and Sian Ka'an Biosphere Reserve in pursuing MSC certification for lobster. Munson Foundation, Summit Foundation, Kukulcan Plaza, and FFEM have provided support for EFBM activities and to complete the management plans in five Marine Protected Areas.

- **International forum.** FAO (Food and Agriculture Organization) and GCFI (Gulf of Mexico and Caribbean Fisheries Institute) have a great interest in addressing the challenges for sustainable fisheries in the Caribbean. There has been close communication with these organizations for the production and application of the lobster manual. They have been helpful venues to approach private sector on environmental and marine resource problems.

- **Filling gaps.** The project is filling gaps that Agriculture Departments in the countries have not fully addressed in the past. Through the ICRAN-MAR project Belizean and Mexican sugarcane growers are having the opportunity to improve their production techniques while producing sugar in a more environmental and economical sustainable way. Other examples include the cover crop projects in Belize and Honduras.

- **Developing marketing linkages.** Major seafood buyers like Darden are interested in supporting these BFPs by partnering with fishermen organizations to introduce environmental-friendly traps, support lobster certification processes and promote markets for lobster obtained with BFPs. In time, it is expected that this first step will be followed by other companies.

- **Coordinating with other initiatives in the region.** Communication and coordination with other partners is very important to avoid duplication of efforts and facilitate information sharing. Over the last two years partners have been successful in bringing leaders from different key organizations to meetings where projects were discussed and information was gathered. Feedback provided at these meetings allowed some organizations to delineate future actions and projects, improved cooperation, and duplication is decreasing with the time.

[22] See Table 1 in the executive summary for more information

- **Reducing open access.** An important avenue to explore in the future is that of responsible fisheries: It is fundamental to reduce open access in MAR fisheries, which can be done by strengthening current fishermen, providing them legal tools to avoid poaching (such as concessions, community surveillance and enforcement programs, or management plans), providing them scientific support for fisheries and ecological monitoring, and training in organization or helping them to have their own financial support to keep those programs.

- **Capacity building**. The creation of RC centers at the four ICRAN-MAR countries enables local stakeholders to continue RC activities (surveys and trainings) on the long term, beyond the life of the ICRAN-MAR. At the same time, they now have the tools needed to support other project initiatives and leverage funds on their own with or without RC supervision.

- **Communities empowered.** This project has served to strengthen and empower local stakeholders in current coral reef conservation educational and monitoring tools. One of the most important aspects of the Reef Check protocol is that it can be learned by the majority of community members in developing countries, where local capacity in using highly scientific monitoring protocols difficult if not impractical to achieve

- **Practical methodology.** Reef Check Foundation and local partners are collecting baseline information on the status of coral reefs inside and outside of protected areas with unprecedented frequency. The monitoring protocol that was designed by Reef Check has proven to be simple and yet scientific enough to be able to be used by anybody interested in coral reef conservation and basic snorkeling skills and no scientific background.

- **Contribution to global efforts.** An important aspect of the implementation of the Reef Check surveys has been the documentation of the bleaching events that have been affecting coral reefs globally. During 2005 Caribbean reefs suffered one of the strongest bleaching events ever recorded, and devastating effects are evident. Local volunteers are expecting to continue monitoring Caribbean reefs on a continued basis and they are prepared to document any other bleaching events. This documentation will support conservation efforts to address problems related to global warming. Project partners have already provided data to NOAA Coral Reef Watch for the compilation of information on the main 2005 Caribbean bleaching event.

- **Continuous need.** A lot more monitoring and training is needed to address the scale of the coral reef crisis, and this will take the efforts of many organizations in the MAR region and elsewhere. The ICRAN-MAR project has showed that it is possible to contribute implementing a volunteer-based program to monitor coral reef health in a frequency that would be significant to detect changes in case of natural disasters (ie. Hurricanes) or human interventions in the long term.

5. Lessons Learned and Recommendations

- Given that fishermen ply their trade in areas they know well, their participation is fundamental to the process of identifying fishing sites to be monitored. Experienced fishermen have substantial empirical knowledge based on observations over many generations. Incorporating fishermen inputs is very important during all the process of field monitoring. It also helps build trust with the fishermen with respect to EBFM, and provides legitimacy with the fishing communities as their knowledge is taken into account when building databases.

- Challenges may surface when adapting globally used educational materials to local names and concepts to a non-scientific community. It is important to get timely contributions from local stakeholders to accurately overcome these challenges.
- More monitoring and training is needed to address the scale of the coral reef crisis. But it is possible to use a volunteer based program to contribute
- To pursue long-term sustainability of conservation efforts in the MAR region it is important to support the creation of solid local foundations providing tools and capacity building.
- Tuning private sector and fishermen to work together in a win-win relationship takes a significant amount of time. It requires raising fishermen standards to speak in the appropriate language, and convincing private sector on the importance of marine resources conservation.
- The human dimension in the protection of the MAR ecosystems is very important to achieve successful results. Fishermen want to be part of the new processes that are emerging in the region (domestic policy is promoting the development of other more profitable activities such as tourism).
- It is necessary to develop more regulatory management schemes, but at the same time develop processes by which fishermen are aware of the importance of voluntarily protecting the ecosystems. Future projects in the region must keep in mind the importance of providing fishermen with skills that help them perform economically feasible activities.
- In some countries in the future, fisheries management plans will become part of the MPA management plans. It will be a difficult but necessary step to determine the maximum number of fishermen that an MPA is capable to sustain with a minimum quality of life, without putting in risk the ecosystems and the biomass. If open access is not avoided, the current trends of degradations produced by fisheries will continue until reaching dramatic condition of coral reefs in the MAR.

C. SUSTAINABLE TOURISM (IR3)

Through partnerships established with the marine tourism sector, business guidelines and better practices are refined and implemented, thus creating a sustainable industry minimizing threats to the MAR

1. Threats – Rationale for Component Design

Tourism is the fastest growing industry in the MAR, with diving and coastal tourism as the principal socio-economic drivers in the majority of sites in the region. In response to the demands of increasing numbers of tourists in the region, many destinations experienced rapid growth and development of coastal infrastructure and marine recreation activities. Additionally, the region has seen exponential growth of cruise ship tourism in recent years, bringing an estimated 6 million tourists to Mesoamerica in 2004 alone.

While this growth in tourism development and associated activities has brought economic benefits to communities throughout the MAR, the area has simultaneously seen an increase in negative impacts to reef resources, including pollution, over-fishing, improper sewage disposal, and irresponsible marine recreation activities. Stakeholders in the tourism industry have the potential to identify and implement best practices and models of sustainability that channel the resources of this sector in support of coral reef conservation and protection.

Over the last two years, partners CORAL, UNEP-DTIE, and WWF have facilitated a stakeholder-led process in the marine tourism industry, resulting in the development of

comprehensive conservation and safety standards for marine recreation activities such as scuba diving, snorkeling and boating operations.

2. Description of Component Strategy – Dynamics over the Past 30 Months

This component was designed to promote sustainable tourism in the region by:

- Fostering regional dialogues across a broad sector of industry stakeholders leading to collaborative action on embracing sustainable tourism
- Facilitating the development of standards and a voluntary code of conduct that can be applied throughout the Mesoamerica region and potentially elsewhere in the Caribbean
- Providing training and support for adoption of the code of conduct complete, leading to the private sector in the MAR being fully engaged in the practice and promotion of sustainable marine tourism

Initially, project partners focused efforts heavily on outreach to both introduce the project to multiple communities throughout the region, and recruit participants to develop the marine recreation standards. This early outreach culminated in three national learning workshops which realized excellent attendance and participation by a broad set of interest groups in the region, including tourism industry associations, marine recreation providers, boat captains and tour guides, the cruiseline industry, non-governmental organizations and academics, bulk purchasers of tourism activities, local community groups, and many others (See Annex 2). The national workshops helped project partners realize the broad level of interest in the initiative from across the region. Yet they also helped project partners realize the limited nature of funding for this first phase of the project. It became clear early that a concerted effort would need to be made, even with budget limitations, to engage the marine tourism sector beyond the three pilot sites that were eventually selected for the project.

Due to limited resources for execution of this first phase of the project, partners focused their efforts in three pilot sites: Playa del Carmen, Mexico, Placencia, Belize, and Roatan, Honduras. While considerable effort has been expended to maintain a regional presence in the region, 80% or more of our resources have been utilized on work in these select pilot sites. While direct work is carried out mostly in the pilot sites, partners maintain a regional approach to certain key programmatic elements, such as stakeholder involvement in the standards development process, broad measurement of current industry practices, and testing and implementation of the standards and code of conduct.

Project partners capitalized on interest and momentum generated at the national workshops to maximize recruitment for the standards development process, survey current industry practices throughout the region, and engage the taskforce steering committee (STC) to identify topics for standards development, set operating procedures in place, and launch the standards development process with the whole committee. Simultaneously, under CORAL's leadership and with collaboration from WWF, the first training workshops in the pilot sites were conducted, raising awareness on issues ranging from coral reef ecology, identification of local threats, establishment of locally driven solutions, and marketing conservation and sustainability.

As partners moved into year two of the project, momentum was gained and widespread participation was realized in the development of three marine recreation standards, including scuba diving, snorkeling and boat operations. Surprisingly, when balloting was conducted, unanimous approval of the three standards was achieved by members of the taskforce committee, which is rare in standards development. This unanimity gives the project strong

leverage as it moves into the testing phase for standards implementation (ongoing in early 2007).

The second workshop series, 'Conservation in Action', was jointly planned and executed by CORAL and UNEP during this same time. The workshop was designed to review local reef threat assessments identified by industry stakeholders and MPA managers in the previous workshop and identify, plan, and implement community-based conservation projects that reduce these threats. Partners made a concerted effort to time these workshops with the culmination of the standards development process, so as to generate momentum and build capacity in the region for implementation of the standards and the code of conduct. In the summer and fall of 2006, a major outreach effort was made to recruit companies for testing and implementation of the standards. A total of 44 companies from across the region signed a letter of agreement to work with CORAL in an official capacity with this program. It is expect that the program will provide a significant amount of data and anecdotal responses that reflect changes in industry practices, measure the effectiveness of the standards, and provide guidance for the future direction of the project.

While the project has been successful to date, there have been many challenges faced along the way that required adaptive management and creative solutions. For example, use of the online technology provided by Underwriters Laboratories appeared to dampen the expected level of participation by committee members throughout the region. In response to this challenge, partners conducted several trainings throughout multiple sites in the region so stakeholders gained familiarity and comfort with use of the system.

3. Major Achievements and Results – Impacts in the Region

The current section provides a narrative description of project results up to the end of the agreement between UNF and USAID (November 2, 2006) and the impacts these have generated in the region. It also describes the expected results to the end of the project and the potential opportunities for continuation beyond the life of the ICRAN-MAR project. For a summarizing table of project indicators and status, please refer to the indicators section of the executive summary in this report.

Major achievements include:

- Workshop trainings in three project pilot sites (Placencia-Belize, Roatan-Honduras, Playa del Carmen-Mexico). In each pilot site, workshop trainings have improved the capacity of the destination to address coral reef threats by increasing awareness of reef ecology and sustainable business practices, improving local capacity for collaborative coral reef conservation efforts through technical and financial assistance, and providing both a process and end product (standards) which will lead to implementation of a code of conduct for marine tourism operations.
- Production of tourism guidelines (English and Spanish) for diving, whale watching, underwater cleanup, snorkeling, turtle watching; over 50,000 disseminated throughout the region. See Annex 15.
- Development and unanimous approval of three marine recreation standards (scuba, snorkeling, and boat operations) See Annex 16.
- Pilot sites' capacity improved to address sustainability and reef conservation issues through educational and highly interactive workshops, as well as technical and financial support for locally led conservation initiatives. In each pilot site, pioneering partnerships are improving

infrastructure and collaborative relationships that lead to adoption of better business practices and improved marine protected area management.

- Disbursement of micro-grants and technical support for locally led conservation initiatives,
- Launching of the testing phase for standards implementation with operators throughout the region.
- The ICRAN-Mesoamerican reef alliance was awarded the "Best Environmental Initiative of 2005" by November 2005 issue of the Scuba Diving Magazine.
- 44 companies from across the region have signed a letter of agreement to work with CORAL in an official capacity with testing and implementation of the standards.
- Leveraging of resources and expansion of program to new pilots sites (Cozumel-Mexico, San Pedro-Belize)
- Secured commitments from major tourism promotion institutions in each region to highlight businesses participating in the program through press releases, written stories on the web and in tourism publications. These include the Promotional Trust of the Riviera Maya, The Belize Tourism Industry Association, and the Belize Tourism Board.
- Partnerships with several companies throughout the region collaborating with CORAL to utilize the good practice guidelines to educate both staff and visiting tourists at their facilities and on their boats. Three of the largest marine recreation providers and one NGO of Quintana Roo, Mexico (including Scuba Caribe, Xel-Ha, and Xcaret – marine recreation providers; Centro Ecologico Akumal - NGO) have created a poster size copy of the good practices guidelines (including their logo) and have them on display at their respective facilities. Given the size of these companies, CORAL estimates 2 million tourists a year are being educated by these guideline displays.

Steps for achieving these results also have included:

- Dissemination of the English and Spanish version of the "Practical Guide to Good Practice: Managing Environmental Impacts in the Marine Recreation Sector" at the National Workshops. See Annex 17 and 18.
- Development of online computer software for standards development with support from Underwriters Laboratories. Software translated into Spanish.
- CORAL, WWF and UNEP/DTIE facilitated the creation of Taskforce Groups for the elaboration of Codes of Conduct in three countries.
- Completion of final report on surveys of current industry practices in Mesoamerica
- Securing endorsements for project support from the office of the Secretary of Tourism in Quintana Roo, Mexico

SCOPE OF RESULTS – RELEVANCE TO THE REGION

As already mentioned, activities under this sub-component will continue until the end of the project and more results will be delivered (see next section for final outputs). However, results achieved to date provide evidence of the relevance of conducting this work for the benefit of the MAR.

Since the inception of the ICRAN Mesoamerican Reef Alliance project, promotion and adoption of good practices supporting economic and environmental sustainability in the marine tourism arena across the region has improved rapidly. In 2004, virtually no work had been attempted on

the regional level to engage stakeholders in a participatory process that would lead to the development, and eventual implementation, of good practices, standards and an overall code of conduct for marine tourism. The project has made notable gains in this area. While there is still a tremendous amount of work to be done to ensure region wide buy-in and implementation of good practices, it is essential that this work be coupled with the development of conservation alliances that reduce threats, support effective marine protected area management, and share benefits with local communities.

Evaluations of the workshop trainings show that the project has raised awareness on the issue of sustainable tourism and increased knowledge by stakeholders in the areas of ecology, reef threats, and development of action plans for locally led solutions. Most impact and change of behavior is evident in the pilot sites, notably Placencia and Roatan, and to a lesser but still significant extent in Playa del Carmen. As partners recently executed the first trainings in San Pedro, they are beginning to see behavior changes in this destination as well.

Additionally, the Conservation in Action workshop series has improved the capacity of local stakeholders to work collaboratively on reef conservation initiatives and implementation of standards and an overall code of conduct. Partners are currently seeing the effectiveness of these trainings manifest in the region as stakeholders in each pilot site are working collaboratively in pioneering partnerships to execute conservation initiatives funded by the project partners.

The standards testing and implementation program was launched in December 2006. As part of the testing process, participants will be required to submit two progress reports measuring their own performance—based on the requirements of the standards—and providing narrative feedback on the challenges they face in determining the attainability, affordability, and effectiveness of the standards. Additionally, partners will utilize a similar assessment tool engage in a third party, “anonymous shoppers” program to gain additional data on operator performance. It is expect that the data gathered from this testing phase will both identify challenges for widespread adoption of the standards, and guide the future direction on work on sustainable marine recreation in the region.

The primary focus of the work with communities has been through execution of training workshops, participatory development of standards, and disbursement of microgrant funds and technical support for locally led conservation initiatives. While each project pilot site has unique problems and needs, the common thread which unites them is recognition by stakeholders of the existing threats to their reefs, and a common desire to work collaboratively to address these threats. In all sites, evidence shows that, prior to the training workshops, there was a very limited understanding of issues such as reef ecology, sustainable business practices and marketing conservation. Additionally, stakeholders in each site showed limited experience and ability to work collaboratively on local conservation initiatives. Following the project’s Sustainable Marine Recreation and Conservation in Action training series, stakeholders showed a strong understanding of the threats their reefs are facing, and have a basic understanding of how, as an industry, they can organize themselves and work collaboratively to address these threats.

During the final six months of the project, marine recreation providers throughout the region will take their first concrete steps at testing and implementing the standards and code of conduct into their day to day business practices. 44 marine recreation providers across 13 destinations in the region have signed a letter of agreement to participate in an official capacity in this program. Data and anecdotal feedback gained during this time will be presented at the final

national learning workshops[23], and will guide the future direction of the next phase of this initiative.

FINAL OUTPUTS AT THE END OF THE PROJECT

Refer to indicators section of the executive summary for a table with current status of indicators (as of December 2006).

a) Six national learning workshops convened in Mexico, Belize, and Honduras (three to launch the project and three to culminate the first phase of the project)
    i. Over 400 people trained and sensitize on the economic and ecological value of coral reefs, threats to reefs, sustainable business practices, standards and the code of conduct for marine recreation
    ii. Widespread distribution of workshop training materials in Spanish and English
    iii. Workshop evaluations reflected effectiveness of the trainings and stakeholder buy-in, development, and adoption of sustainable business practices
b) Regional Marine Recreation Standards and a Code of Conduct unanimously approved by stakeholders, and a mechanism developed for implementation
    i. Three marine recreation standards complete and unanimously approved by taskforce committee, including scuba diving, snorkeling and boat operations
    ii. Pilot testing and implementation phase complete with regional participation from marine recreation providers demonstrating the affordability, attainability and effectiveness of the standards and code of conduct
c) Widespread distribution of Handbook and Guidelines for Good Practices for Marine Recreation Providers
    i. Handbook developed and distributed in English and Spanish
    ii. Guidelines developed and distributed in English and Spanish
d) Pilot site training and three to five private sector/business and park management conservation initiatives successfully complete and increasing collaboration within industry and between industry and park management authorities
    i. Completion of pre-survey of industry practices and preparatory steps taken for post-survey analysis with over 100 marine recreation providers in multiple sites in Mexico, Belize and Honduras
    ii. Completion of stakeholder trainings and pre-survey of reef health (in conjunction with Reef Check) in project pilot sites. Post surveys not complete.
    iii. Completion of three sustainable marine recreation training workshops in pilot sites in Mexico, Belize, and Honduras. Workshop evaluations reflected an increase in participant knowledge of reef ecology, threats, solutions for sustainable business practices and marketing conservation
    iv. Completion of three Conservation in Action training workshops, leading to identification of locally led conservation initiatives, and development of action plans for standards implementation and execution of conservation initiatives
    v. Park infrastructure and marine education conservation initiative complete and expanding in Roatan, Honduras (mooring buoys, channel markers, taxi lanes, signage)
    vi. Mooring buoy program complete and expanding in Placencia, Belize (30+ mooring)

[23] To be conducted in Belize, Honduras, and Mexico

vii. Mooring buoy program complete and expanding in Playa del Carmen, Mexico (29 mooring)
viii. Conservation initiatives identified, funded and launched in San Pedro, Belize and Cozumel, Mexico

4. Leveraged Support, Impacts and the Larger Scale – The Potential Way Ahead

Fisheries activities undertaken with the auspices of the ICRAN-MAR project have been innovative and have created great expectation among fishermen and other stakeholders.

- **Leveraged support[24].** In addition to major support received from the United Nations Foundation and United States Agency for International Development, CORAL has leveraged additional financial support for the project from Oak Foundation, R.B. Toth Associates, Underwriters Laboratories Inc., National Marine Sanctuary Foundation, Summit Foundation, National Fish and Wildlife Foundation. CORAL has successfully acquired resources to expand the number of pilot sites in the region where standards can be tested, partnerships and alliances developed, and conservation projects launched by locally based stakeholders.

- **Additional pilot sites.** Partners' efforts in the region have led to acquisition of resources to add two new pilot sites to the project: Cozumel, Mexico and San Pedro, Belize. CORAL will engage in similar capacity building efforts in these sites, including workshop trainings, technical and financial support for locally-led conservation initiatives, and creation of incentives for standards implementation.

- **Capacity building.** Tremendous progress has been made in building capacity for sustainable marine recreation in select sites in the MAR through workshop trainings, participatory development of standards, and initiation of collaborative, locally led conservation projects. Over 300 stakeholders in the region have benefited from these activities.

- **Potential for expansion.** It is both imperative and timely not only to continue, but actually to expand these efforts throughout the region. A growing number of businesses are showing interest to adopt the standards and change their day to day business practices. Additionally, park managers in each country of the region have shown a strong interest in creating dialogue with the marine recreation industry, and using the standards and code of conduct as a tool to maximize industry support for effective marine protected area management.

- **Catalytic effects.** Not only can the standards be used to improve private sector operations in marine protected areas, but supporting conservation initiatives can build the capacity of both of these groups to work collaboratively to reduce reef threats, improve effective management, and share benefits of sustainable tourism with local communities. Moreover, it is vital to build upon the initial support given to the standards from the cruise lines, as the explosive growth of this sector is causing widespread impacts on coral reefs in the region.

- **Replication and collaboration.** There is great potential for collaboration with other conservation organizations. In fact, Conservation International (CI) is partnering with CORAL to facilitate execution of environmental performance assessments, training, and

[24] See Table 1 in the executive summary for more information

technical assistance with marine recreation providers on the island of Cozumel, Mexico, with a specific focus on cruise industry contractors. The project has the primary goal of minimizing impacts to Cozumel's reef resulting from the rapid growth of cruise tourism on the island in recent years. While CI will engage the demand side of the tourism sector, CORAL will work directly with marine recreation providers, utilizing the ICRAN-MAR standards as the primary assessment and training tool for application of better business practices. In addition to this, there is interest from the Mesoamerican Program of The Nature Conservancy (TNC – MAR Program) to collaborate in the replication of these experiences and in using the tourism standards.

- **Beyond the MAR.** The high level of success achieved in the tourism component and the receptiveness and stakeholders' willingness to be part of these efforts have opened the door for replication opportunities in other parts of the world. CORAL is currently taking lessons learned and identifying ways to improve the efficiency of the standards development and how to adapt it in Maui, Hawaii.

5. Lessons Learned and Recommendations

- *Cultivate industry ownership of the standards*. Partners realized early on the importance of building a sense of industry ownership in both the development and eventual implementation of the standards. To date, this has proved a very effective strategy, as many operators in the region feel that they are the ones who wrote these standards. Not only has this engendered trust and pride in the process, but it serves to break down the acrimony that often exists between industry and outside forces (government, park managers, etc.) that commonly impose rules and regulations that industry feels are burdensome. Both the grassroots process and the end product of standards development will support implementation of good practices in the region for years to come.

- *Promote transparency throughout the process*. An effective aspect of the project's strategy has been to have a very open and transparent process in determining who would be involved in standards development, as well as how the participatory nature of the project was the guiding principle that would lead to a conservation tool which would benefit a broad set of tourism stakeholders. This transparency and openness has helped increase collaboration among groups that have had a previous history of distrust and acrimonious relationships. For example, both private industry and marine protected area managers now recognize the mutual benefit of the standards, and further, have begun to collaborate on local conservation initiatives that are building capacity for reef conservation and adoption of the standards and code of conduct.

- *Facilitate locally-based partnerships and coordination to implement standards and supporting conservation initiative**s***. It became apparent early on in the project, that in each pilot site there was very little collaborative action taking place (whether within industry, or between industry and resource managers) on issues of sustainable tourism and reef conservation. Combined with the participatory nature of the standards development process, the action plans for standards implementation and conservation initiatives that were developed in each pilot site have both increased and improved the organizational ability and desire for stakeholders to work together on mutual goals. Pioneering partnerships are now making great strides in each pilot site by engaging in collaborative efforts to increase economic and environmental sustainability of the marine tourism industry.

- *Be prepared for challenges and delays in using online technology*. Problems in the use of the UL online standards technology, combined with multiple language issues and discomfort in the use of technology, hindered the partner's ability to get early traction on the standards development process. Partners learned from this by working closely with UL to fix the problems with its technology and improve usability of the system. Additionally, several on-site trainings were conducted in the use of the online software with stakeholders in multiple sites, and this improved the level of participation in the project.

- *Utilize incentives and momentum to promote implementation*. As business people, marine recreation providers need to see a return on their investment in adopting the standards into day to day business practices. CORAL has begun to create incentives by offering businesses who participate in the standards testing program a complimentary one year CORAL business membership, which allows promoting businesses as participants in a program aimed at improving the economic and environmental sustainability of marine recreation in Mesoamerica. As companies make progress in implementing the standards, additional opportunities will arise to create incentives for marketing sustainable tourism and institutionalizing the standards and code of conduct.

- There is a strong need for creation of dialogue between different sectors, most notably the private sector and marine protected area managers. The standards for marine recreation have shown, however, that these two groups have mutual interests in protecting and conserving reefs, and in addition to improving business practices, the standards will likely serve as a bridge to improve relations between these two groups.

- There have been many challenges in project execution, and as a result it has been necessary on several occasions to rethink the strategy. This has required adaptation of the management approach to both meet the needs of stakeholders on the ground, and adjust to working within the framework of a complex, multi-region and multi-partner project.

The complex structure of a multi-organizational project has represented one of the most challenging aspects of this project component. The original project document did not provide enough detail about the responsibilities and contractual obligations of each partner. Additionally, it proved to be problematic that CORAL was given the majority of resources for execution of the tourism component, with limited resources provided to WWF and UNEP for their respective roles. This left CORAL to complete the vast majority of work, often created delays in project execution, and left certain programmatic elements incomplete. And while candid conversations with partners were commonly helpful in resolving some issues of project execution, to date some programmatic elements remain incomplete, such as pre and post surveys on reef health, and distribution of microgrants to support locally led conservation projects.

III. FINANCIAL STATUS

Financial reports presented to USAID as of the end of contractual obligation, November 2, 2006:

- Project Financial Expenditure report as of December, 2006 – See next page
- Financial Status Report SF269 Form – See Annex 1 attached.

Project Financial Expenditure report as of December, 2006 - FOURTH QUARTER 2006

GRANT No: 596-G-00-03-00215-00
Implementing Unit: UNEP-CAR/RCU in coordination with UNEP/DTIE, UNEP/WCMC, WWF, WRI, ReefCheck, CORAL
Project Title: USAID/UNEP-CAR/RCU Mesoamerican Coral Reef Alliance
Project commencing: November 2, 2003
Project ending: November 2, 2006
Period: 1 October to 30 December, 2006

	A	B	C					D	E
APPROVED BUDGET LINE ITEM	**Total Budget USAID**	**Budget for The Calendar Year 2006 (USAID+UNF)**	**Cumulative Project Expenditures through Jan 1, 2004 Sept 30,2006**	**Estimated Project Expenditures for the period of Oct 1,2006 - December 30, 2006**			**Total Estimaded for this quarter**	**Estimated Cummulative Project Expenditures January 1, 2004 to Dec 30, 2006**	**Budget Balance (USAID funding)**
				Oct	Nov	Dec			
1100 Project personnel and benefits	480,122	463,962	881,528	15,367	21,955	15,521	52,844	934,372	-454,250
1200 Consultants	68,045	97,910	181,548	6,052	146	100	6,298	187,846	-119,801
1300 Administrative support	91,145	35,376	60,295	1,729	1,627	680	4,036	64,331	26,814
1400 Volunteers		0	0	0	0	0	0	0	0
1600 Travel	100,924	104,104	173,805	13,020	484	1,500	15,004	188,809	-87,885
2200 Sub-contracts (WWF,CORAL,WRI,DTIE)	256,935	205,145	283,562	27,075	2,983	2,000	32,058	315,620	-58,685
2201 Sub-contract- MBRS*	204,617	134,307	285,786	16,688	11,401	15,840	43,929	329,715	-125,098
2202 Sub-contracts WCMC	84,544	0	0	0	0	0	0	0	84,544
3100 Fellowships		0	0	0	0	0	0	0	0
3200 Group training	1,200	7,382	2,404	0	0	0	0	2,404	-1,204
3300 Meetings	3,000	18,587	20,734	0	0	0	0	20,734	-17,734
4100 Expendable equipment	25,420	18,434	33,411	900	-382	800	1,318	34,729	-9,309
4200 Non-expendable equipment	13,100	9,328	10,290	0	0	0	0	10,290	2,810
4300 Premises	21,617	15,892	18,898	1,822	1,885	900	4,607	23,505	-1,888
5100 Operation	2,573	1,600	23,654	422	422	425	1,269	24,923	-22,350
5200 Reporting costs	46,246	36,267	47,081	-4,104	5,722	3,699	5,317	52,398	-6,152
5300 Sundry	21,890	34,012	30,515	1,178	829	233	2,240	32,755	-10,865
5400 Hospitality		0	0	0	0	0	0	0	0
5500 evaluation	7,193	10,856	0	0	0	0	0	0	7,193
Total Direct Project Cost	1,428,571	1,193,160	2,053,512	80,149	47,072	41,698	168,920	2,222,432	-793,861
Programme Support costs (5%)	71,429	59,658	102,676	4,007	2,354	2,085	8,446	111,122	-39,693
GRAND TOTAL	**$ 1,500,000.00**	**$ 1,252,818.24**	**$ 2,156,187.78**	**$ 84,156.44**	**$ 49,426.22**	**$ 43,783.16**	**$ 177,365.82**	**$ 2,333,553.60**	**$ (833,553.60)**

NB: The expenditures should be reported in line with the specific object of expenditure as per project budget.

1. Current table reflects expenses covered with USAID funds. Total Budget (column A) and Budget Balance (column E) do not include UNF funds.

2. UNEP interprets "unliquidated obligations" to mean the same as "accruals"

IV. TABLE OF ANNEXES

Annex 1	Financial Status Report SF269 Form
Annex 2	Tables - Participation of various organizations by country
Annex 3	MoUs with Agribusiness
Annex 4	Contaminant Monitoring Protocol
Annex 5	Agreement with Honduran Ministers in support of BMPs
Annex 6	Letter of commitment Local Union of sugarcane producers, Chetumal
Annex 7	Technical report on Land use change modeling for three scenarios for the MAR region
Annex 8	Belize Coastal Atlas
Annex 9	Watershed Management Workshop proceedings
Annex 10	Watershed Analysis for the Mesoamerican Reef; Report
Annex 11	Lobster Manual – Spanish
Annex 12	Losbter BFPs – Plasticized cards
Annex 13	Best Fishing Practices in Coral Reefs – EBFM Manual
Annex 14	Reef Check's Monitoring Protocol – English
Annex 15a	Tourism Guidelines – English
Annex 15b	Tourism Guidelines – Spanish
Annex 16a	Marine recreation Standards – English
Annex 16b	Marine recreation Standards – Spanish
Annex 17a	Practical Guide to Good Practice: Managing Environmental Impacts in the Marine Recreation Sector - English
Annex 17b	Practical Guide to Good Practice: Managing Environmental Impacts in the Marine Recreation Sector - Spanish
Annex 17c	Practical Guide to Good Practice: Managing Environmental Impacts in the Marine Recreation Sector - French
Annex 18a	Marine Checklist – English
Annex 18b	Marine Checklist – Spanish
Annex 18c	Marine Checklist – French
Annex 19	ICRAN-MAR workplan 07

Other documents available:

- Project promotional flyers
- Press releases and other promotional materials
- Letters of endorsement
- Best Environmental Initiative - Scuba Diving Magazine November 2005
- Distribution lists – publications
- Workshops' individual reports
- Tourism industry survey report
- CSDS Tutorial Development of Standards
- Circulation modeling report – Dynamics of buoyant matter in the MAR

ANNEX 2. Tables - Participation of various organizations by country

1. PARTICIPATION OF GOVERNMENT AGENCIES BY COUNTRY. – SEE FIGURE 2 EXECUTIVE SUMMARY

GOVT. AGENCIES	COMPONENT	COUNTRY	COMMENTS
Coastal Zone Management Authority and Institute (CZMAI)	WM/ST	Belize	Local Staff supported through project; participated in project activities for WM; Participation at National Learning workshop Belize
Department of Environment	WM	Belize	Participation at Watershed Management Workshop; Participation at National Learning workshop Belize
Fisheries Department	WM	Belize	Participation at Watershed Management Workshop
Government of Belize's Geology & Petroleum Department	WM	Belize	Through capacity building efforts and information sharing with WCMC and WRI
Hydrology-Meteorology Department	WM	Belize	Participation at Watershed Management Workshop
Land Information Center	WM	Belize	Participation at Watershed Management Workshop
Ministry of Natural Resources	WM	Belize	Participation at Watershed Management Workshop
Sapodilla Cays Marine Reserve (SCMR)	ST	Belize	Participation at National Learning workshop Belize
US Embassy	WM	Belize	Participation at Watershed Management Workshop
Consejo Nacional de Areas Protegidas (CONAP)	WM	Guatemala	Participation at Watershed Management Workshop
Ministerio de Ambiente y Recursos Naturales	WM	Guatemala	Participation at Watershed Management Workshop; frequently briefed on ICRAN-MAR Activities
Unidad de Pesca	WM	Guatemala	Participation at Watershed Management Workshop
UNIPESCA	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
Minister of Agriculture and Livestock	WM	Honduras	In process to sign MoU for support to the implementation of BMPs
Minister of Natural Resources and the Environment	WM	Honduras	In process to sign MoU for support to the implementation of BMPs
Ministry of Tourism	ST	Honduras	Participation at National Learning workshop Honduras
SERNA	WM	Honduras	Participation at Watershed Management Workshop
Área de protección de flora y fauna Yum Balam	ST	Mexico	Participation at National Learning workshop Mexico
Ayuntamiento Cozumel Ecologia	ST	Mexico	Participation at National Learning workshop Mexico
CONANP	WM	Mexico	Participation at Watershed Management Workshop
CONANP Isla Contoy	ST	Mexico	Participation at National Learning workshop Mexico
CONANP Parque Nacional Isla Mujeres	ST	Mexico	Participation at National Learning workshop Mexico
Direccion de turismo Benito Juarez	ST	Mexico	Participation at National Learning workshop Mexico
Direccion Medio Ambiente	ST	Mexico	Participation at National Learning workshop Mexico
INEGI	WM	Mexico	Participation at Watershed Management Workshop
Parque Marino Puerto Morelos	ST	Mexico	Participation at National Learning workshop Mexico
Parque Nacional Arrecifes de Cozumel	SF	Mexico	Serves as RF country focal point to conduct monitoring trainings
Parque Nacional Sistema Arrecifal Veracruz	ST	Mexico	Participation at National Learning workshop Mexico
Reserva de la Biosfera de Banco Chinchorro	ST	Mexico	Participation at National Learning workshop Mexico
Reserva de La Biosfera de Sian Ka'an CONANP	ST	Mexico	Participation at National Learning workshop Mexico
Secretaria de Turismo de Quintana Roo	ST	Mexico	Participation at National Learning workshop Mexico
Sian Ka'an biosphere Reserve Authority	SF	Mexico	Participation at fishermen Exchange from Guatemala to Mexico

GOVT. AGENCIES	COMPONENT	COUNTRY	COMMENTS
OSPESCA	SF	Nicaragua	Organized a regional lobster fisheries management workshop - collaboration with WWF

2. *PARTICIPATION OF LOCAL NGOS BY COUNTRY. – SEE FIGURE 3 EXECUTIVE SUMMARY*

LOCAL NGOS	COMPONENT	COUNTRY	COMMENTS
Belize Audubon Society	WM/ST	Belize	Through capacity building efforts, with WCMC and WRI; Participation at National Learning Workshop Belize
Belize Foundation for Research & Environmental Education	WM	Belize	Through capacity building efforts and information sharing with WCMC and WRI
Belize Tropical Forest Studies	WM	Belize	Through capacity building efforts, with WCMC and WRI
BELPO	WM	Belize	Participation at Watershed Management Workshop
Friends of Nature	WM/SF/ST	Belize	Through capacity building efforts, with WCMC and WRI; facilitated RC training; Participation at National Learning workshop Belize
Green Reef	SF	Belize	Local Reef Check Center; collaboration with WWF for ecotourism training of fishermen
Programme for Belize	WM	Belize	Through capacity building efforts and information sharing with WCMC and WRI
TIDE	WM	Belize	Participation at Watershed Management Workshop
TASTE	ST	Belize	Participation at National Learning workshop Belize
Asociación de Biología Marina de Guatemala (ABIMA)	SF	Guatemala	Local Reef Check Center
Fundacion Mario Dary (FUNDARY)	SF	Guatemala	Collaborates with RC training
FUNDAECO	SF	Guatemala	Collaboration with workshops on sustainable fisheries in the MAR; fishermen exchanges from Guatemala to Mexico
FUNDARY	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
Bay Island Conservation Association (BICA), Utila	ST	Honduras	Participation at National Learning workshop Honduras
Cayos Cochinos Reef Fund	SF	Honduras	Local Reef Check Center
Fundacion PROLANSATE	ST	Honduras	Participation at National Learning workshop Honduras
Amigos de Sian Ka'an	SF/ST	Mexico	Participation at National Learning workshop Mexico
Biosistemas Integrales	SF	Mexico	Participation at Expert Group Meeting on Ecosystem Modeling of Coral Reef Fish Communities
Centro Ecológico Akumal	SF/ST	Mexico	Trained in the Reef Check monitoring protocol; participation at National Learning workshop Mexico; promoting the good practice guidelines to educate both staff and visiting tourists at their facilities and on their boats.
Centro Mexicano de Derecho Ambiental	ST	Mexico	Participation at National Learning workshop Mexico
Fundacion Aviomar	ST	Mexico	Participation at National Learning workshop Mexico
Instituto Tecnológico de Chetumal	SF	Mexico	Participation at Expert Group Meeting on Ecosystem Modeling of Coral Reef Fish Communities

3. *PARTICIPATION OF OTHER NGOS/REGIONAL INITIATIVES BY COUNTRY. – SEE FIGURE 4 EXECUTIVE SUMMARY*

OTHER NGOS/REGIONAL INITIATIVES	COMPONENT	COUNTRY	COMMENTS
Healthy Reefs Initiative	WM	Belize	Collaboration
Mesoamerican Barrier Reef System (MBRS/SAM) Project	WM	Belize	Collaboration
TNC Belize	WM	Belize	Collaboration
Wildlife Conservation Society	WM/ST	Belize	Collaboration; Participation at National Learning workshop Belize
Gulf of Honduras Project	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico

Proyecto de Manejo Ambiental de Islas de la Bahía (PMAIB)	ST	Honduras	Participation at National Learning workshop Honduras
SIDA	WM	Honduras	Collaboration
USAID/MIRA	WM/ST	Honduras	Participation at Watershed Management Workshop; Participation at National Learning workshop, Honduras
USAID/MIRA – FUCSA	WM	Honduras	Participation at Watershed Management Workshop
PNUD	SF	Mexico	Participation at fishermen Exchange from Guatemala to Mexico
The travel foundation	ST	Mexico	Participation at National Learning workshop Mexico
Whale Shark and Oceanic Research Center	ST	Mexico	Participation at National Learning workshop Mexico
CATHALAC	WM	Panama	Collaboration
Rainforest Alliance	ST	Regional	Participation at National Learning workshop Mexico
TNC MAR program	WM	Regional	Collaboration
WWF-Central America	WM	Regional	Collaboration
Global Vision International	ST	UK/USA	Participation at National Learning workshop Mexico
Conservation International - CELB	ST	USA	Participation at National Learning workshop Belize; collaboration in the development of tourism standards

4. *PARTICIPATION OFLOCAL COMMUNITIES BY COUNTRY. – SEE FIGURE 5 EXECUTIVE SUMMARY*

LOCAL COMMUNITIES	COMPONENT	COUNTRY	COMMENTS
Belize Fishermen Cooperative Association	SF	Belize	Training in mariculture; participation at various workshops and trainings on BFP; revising English version of Lobster Manual
National Fishermen Producers Cooperative Society Ltd.	SF	Belize	Ongoing collaboration for BFPs
Northern Fishermen Cooperative Society Ltd.	SF	Belize	Ongoing collaboration for BFPs
Placencia	SF/ST	Belize	Participation at sustainable fisheries/ecotourism-related activities
San Pedro	SF/ST	Belize	Participation at sustainable fisheries/ecotourism-related activities
Sarteneja Fishermen	SF	Belize	Received practical Ecotourism Training for fishermen - training in marine conservation, including copies of the CORAL guide “A Practical Guide to Good Practice: Managing Environmental Impacts in the Marine Recreation Sector”, and in Reef Check monitoring.
Tour Guide Assoc. - Northern Belize	ST	Belize	Participation at National Learning workshop Belize
Tour Guide/South Belize	ST	Belize	Participation at National Learning workshop Belize
Monkey River	SF	Belize	Participation at sustainable fisheries/ecotourism-related activities
Aldea Buena Vista Miramar	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
Aldea Cayo Quemado	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
Cabo Tres Puntas	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
Cooperative Río Dulce, Livingston	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
Estero Lagarto	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
Fishermen from Livingston	SF	Guatemala	Trained in the Reef Check monitoring protocol
Fishermen from Puerto Barrios	SF	Guatemala	Trained in the Reef Check monitoring protocol and in capacity building for implementation of BFPs
Fishermen from Punta Manabique	SF	Guatemala	Trained in the Reef Check monitoring protocol and in capacity building for implementation of BFPs; Participation at the 1st Workshop on Sustainable Fisheries in the Mesoamerican Reef (2004)
Fishermen from Quetzalito	SF	Guatemala	Participation at the 1st Workshop on Sustainable Fisheries in the Mesoamerican Reef (2004)
Fishermen Network from Guatemala and Lago de Izabal, y Cayo Quemado	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
Fishermen from Bocas de Polochic	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico

LOCAL COMMUNITIES	COMPONENT	COUNTRY	COMMENTS
Fishermen from Cabo Tres Puntas	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
Fishermen from Estero Lagarto	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
Fishermen from Miramar	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
Fishermen from Puerto Barrios	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
Fishermen from San Francisco del Mar	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
Garifuna Fishermen from Livingston	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
La Graciosa	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
Quetzalito	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
San Francisco del Mar	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
Santa Isabel	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
Trasmalleros Fishermen from Livingston	SF	Guatemala	Participation at fishermen Exchange from Guatemala to Mexico
Motagua	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
La Ceiba	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
Sambo Creek	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
Rio Esteban	SF	Guatemala	Participation at sustainable fisheries/ecotourism-related activities
Coordinación de la Red de Turismo y Pescadores de Cayos Cochinos APESCA	SF	Honduras	Active participation in activities to identify, adopt and implement Best Fishing Practices
Fishermen from Cayos Cochinos	SF	Honduras	Trained in the Reef Check monitoring protocol
Fishermen from East End.	SF	Honduras	Trained in the Reef Check monitoring protocol
Fishermen from Nueva Armenia	SF	Honduras	Trained in the Reef Check monitoring protocol
Nueva Armenia	SF	Honduras	Participation at sustainable fisheries/ecotourism-related activities
Banco Chinchorro	SF	Mexico	Participation at sustainable fisheries/ecotourism-related activities
Cancún	SF	Mexico	Participation at sustainable fisheries/ecotourism-related activities
Chiquilá	SF	Mexico	Participation at sustainable fisheries/ecotourism-related activities
Contoy	SF	Mexico	Participation at sustainable fisheries/ecotourism-related activities
Cooperativa de Producción Pesquera de Cozumel	SF	Mexico	Received RC training
Cooperative Vigía Chico	SF	Mexico	Participation at sustainable fisheries/ecotourism-related activities; Participation at fishermen Exchange from Guatemala to Mexico
Federación de Cooperativas de Quintana Roo	SF	Mexico	Active participation in activities to identify, adopt and implement Best Fishing Practices
Federation of Fishermen from Quintana Roo	SF	Mexico	Participation at fishermen Exchange from Guatemala to Mexico
Fishermen from Cozumel	SF	Mexico	Trained in the Reef Check monitoring protocol
Fishermen from Xcalak	SF	Mexico	Participation at 'Ecotourism and environmental interpretation training course
Holbox fishermen village	SF	Mexico	Testing of the EBFM methodology in Yum Balam, Mexico, after Hurricane Wilma hit Holbox fishermen village. Participation at sustainable fisheries/ecotourism-related activities
Isla Mujeres	SF	Mexico	Participation at sustainable fisheries/ecotourism-related activities
Mahahual	SF	Mexico	Participation at sustainable fisheries/ecotourism-related activities
Puerto Morelos	SF	Mexico	Participation at sustainable fisheries/ecotourism-related activities
Punta Allen fishermen	SF	Mexico	Collaboration in community-based management and monitoring; promote sustainable fisheries among fishermen
Regional Federation of Cooperatives from Quintana Roo	SF	Mexico	Signed an MOU to adopt and promote the use of BFP
Tulúm	SF	Mexico	Participation at sustainable fisheries/ecotourism-related activities

LOCAL COMMUNITIES	COMPONENT	COUNTRY	COMMENTS
Xcalak	SF	Mexico	Participation at sustainable fisheries/ecotourism-related activities

5. PARTICIPATION OF NATIONAL INSTITUTIONS BY COUNTRY. – SEE FIGURE 6 EXECUTIVE SUMMARY

NATIONAL INSTITUTIONS	COMPONENT	COUNTRY	COMMENTS
Belize Agriculture Health Authority (BAHA)	WM	Belize	Attended field day to learn about how the Mexican cane farmers have used biological control against the cane fly.
Galen University	WM	Belize	Participation at Watershed Management Workshop
Peace Corps volunteers	SF	Belize	Trained in the Reef Check monitoring protocol
University of Belize	WM	Belize	Participation at Watershed Management Workshop
Guatemalan Clean Production Center	WM	Guatemala	Participation in the "Analysis of the CAFTA impact in the importation and use of pesticides in the MAR Watersheds"
Universidad del Valle	WM	Guatemala	Participation at Watershed Management Workshop
Fundación de Investigación Agrícola (FHIA)	WM	Honduras	Signed MoU to consolidate the partnership with WWF to strengthen joint scientific and research capabilities to promote agriculture BMPs in the region
Instituto Hondureño de Turismo (IHT)	ST	Honduras	Participation at National Learning workshop Honduras
Roatan Institute for Marine Sciences (RIMS)	ST	Honduras	Participation at National Learning workshop Honduras
CANACO SERVITUR Playa del Carmen	ST	Mexico	Participation at National Learning workshop Mexico
CINVESTAV-Merida	SF	Mexico	Participation at Expert Group Meeting on Ecosystem Modeling of Coral Reef Fish Communities
ECOSUR	WM	Mexico	Participation at Watershed Management Workshop
La Salle Centro de investigaciones turísticas	ST	Mexico	Participation at National Learning workshop Mexico
La Salle University, Cancun	SF	Mexico	Coordination with WWF to publish a Technical report describing the lobster marketing chain in the Mexican Mesoamerican Reef, including detailed data on producers, wholesalers, retailers, and importers from other countries
National Fisheries Institute	SF	Mexico	Participation at Expert Group Meeting on Lobster Fisheries
Universidad del Caribe	ST	Mexico	Participation at National Learning workshop Mexico
Universidad La salle Instituto de Investigaciones	ST	Mexico	Participation at National Learning workshop Mexico
Centro Geo	WM	México	Participation at Watershed Management Workshop
NOAA	WM	USA	Provided feedback to modeling efforts; utilized monitoring protocol
Sustainable Fisheries Fund	SF	USA	Leveraged support to conduct a pre-assessment of six lobster fishing cooperatives along the Caribbean coast of Mexico
University of Rhode Island	ST	USA	Participation at National Learning workshop Belize
University of Miami	WM	USA	Subcontracted to do circulation modeling
Washington and Lee University	ST	USA	Participation at National Learning workshop Mexico

6. PARTICIPATION OF PRIVATE SECTOR BY COUNTRY. – SEE FIGURE 7 EXECUTIVE SUMMARY Y

PRIVATE SECTOR	COMPONENT	COUNTRY	COMMENTS
Ambergris Divers	SF	Belize	Trained in the Reef Check monitoring protocol
Amigos Del Mar	SF	Belize	Trained in the Reef Check monitoring protocol
Aqua Divers	SF	Belize	Trained in the Reef Check monitoring protocol
Belize Dive Connection	ST	Belize	Participation at National Learning workshop Belize
Belize Diving Adventures	SF	Belize	Trained in the Reef Check monitoring protocol
Belize Ocean Divers	ST	Belize	Participation at National Learning workshop Belize

PRIVATE SECTOR	COMPONENT	COUNTRY	COMMENTS
Belize Sugar Cane Farmers Association	WM	Belize	Collaboration in the adoption of BMPs
Belize Sugar Industries Ltd (BSI)	WM	Belize	Attended field day to learn about how the Mexican cane farmers have used biological control against the cane fly.
Belize Tourism Board	ST	Belize	Participation at National Learning workshop Belize
Boat Captain - Hustler Tours	ST	Belize	Participation at National Learning workshop Belize
Bottom Time	SF	Belize	Trained in the Reef Check monitoring protocol
Chuck & Robbie's	SF	Belize	Trained in the Reef Check monitoring protocol
Citrus Growers Association of Belize	WM	Belize	In process to sign MoU for the implementation of BMPs
Citrus Research and Education Institute (CREI)	WM	Belize	Implementing a pilot project to reduce herbicide pollution and sedimentation from Belizean citrus production.
Cruise Solutions	ST	Belize	Participation at National Learning workshop Belize
Discover Divers	SF/ST	Belize	Trained in the Reef Check monitoring protocol; Participation at National Learning workshop Belize
Ecologic Divers	SF	Belize	Trained in the Reef Check monitoring protocol
El Divino beach	ST	Belize	Participation at National Learning workshop Belize
Fyffes	WM	Belize	In process to sign MoU for the implementation of BMPs
Hamanasi	ST	Belize	Participation at National Learning workshop Belize
Hustler Tours	ST	Belize	Participation at National Learning workshop Belize
Muzamanzie	ST	Belize	Participation at National Learning workshop Belize
Parula Village	ST	Belize	Participation at National Learning workshop Belize
Ramon's Village	SF/ST	Belize	Trained in the Reef Check monitoring protocol; Participation at National Learning workshop Belize
Reef Adventure	SF	Belize	Trained in the Reef Check monitoring protocol
Reef Adventures	ST	Belize	Participation at National Learning workshop Belize
Rum Point Inn	ST	Belize	Participation at National Learning workshop Belize
Searious Adventures	ST	Belize	Participation at National Learning workshop Belize
Seasports Belize	WM/ST	Belize	Participation at Watershed Management Workshop; Participation at National Learning workshop Belize
Second Nature Divers	ST	Belize	Participation at National Learning workshop Belize
Splash Dive Shop	ST	Belize	Participation at National Learning workshop Belize
Sugar Industry Control Board	WM	Belize	Participation at training in the use of biological control to fight the sugar cane Froghopper (*Aeneolamia spp.*) using the fungus *Metarhizium anisopliae*
Sugarcane associations in Orange Walk and Corozal Districts	WM	Belize	Collaboration in the adoption of BMPs
TMM Bareboat Charters	ST	Belize	Participation at National Learning workshop Belize
Toadal Adventure	ST	Belize	Participation at National Learning workshop Belize
Turtle Inn	ST	Belize	Participation at National Learning workshop Belize
Whipray Caye Lodge	ST	Belize	Participation at National Learning workshop Belize
Pana Divers	SF	Guatemala	Collaborates with RC training
AGROTOR - Palm oil plantations from independent producers	WM	Honduras	Were visited to evaluate the risk of contamination. WWF concluded that herbicides are the major threat to the environment.
APESCA - chamber of industrial vessel owners	SF	Honduras	Manifested their interest in participating in a pilot project to introduce “environmentally friend traps” for lobster
Association of Citrus Producers from Sonaguera, (ACISON)	WM	Honduras	Signed MoU for the implementation of BMPs
Azucarera del Norte, S. A. (AZUNOSA)	WM	Honduras	Signed MoU for the implementation of BMPs
Bay Islands Beach Resort	ST	Honduras	Participation at National Learning workshop Honduras
Chiquita Brands Inc.	WM	Honduras	Signed MoU for the implementation of BMPs
Coral Cay Marine and Nature Park	ST	Honduras	Participation at National Learning workshop Honduras

PRIVATE SECTOR	COMPONENT	COUNTRY	COMMENTS
Dockside Dive Center at Coco View Resort	ST	Honduras	Participation at National Learning workshop Honduras
Dole Food Company	WM	Honduras	Signed MoU for the implementation of BMPs
Grayline tours	ST	Honduras	Participation at National Learning workshop Honduras
Hondupalma - Palm oil plantations from independent Cooperatives	WM	Honduras	Were visited to evaluate the risk of contamination. WWF concluded that herbicides are the major threat to the environment.
Hotel Bella Vista	ST	Honduras	Participation at National Learning workshop Honduras
Island Pearl Hotel	ST	Honduras	Participation at National Learning workshop Honduras
Laguna Beach Resort	ST	Honduras	Participation at National Learning workshop Honduras
Luna Consultores	ST	Honduras	Participation at National Learning workshop Honduras
Palmetto Bay Plantation	ST	Honduras	Participation at National Learning workshop Honduras
Reef Guiders	ST	Honduras	Participation at National Learning workshop Honduras
RoatanBruce Show	ST	Honduras	Participation at National Learning workshop Honduras
SabMiller (The CocaCola Company)	WM	Honduras	Decided that its key sugarcane producer in Central America (AZUNOSA) signed a collaborative agreement with WWF to work together on BMPs
San Pedro Tour Guide	ST	Honduras	Participation at National Learning workshop Honduras
Sandy Bay-West End Marine Park	ST	Honduras	Participation at National Learning workshop Honduras
Sueno del Mar	ST	Honduras	Participation at National Learning workshop Honduras
Tyll's dive	ST	Honduras	Participation at National Learning workshop Honduras
Utila Dive Centre	ST	Honduras	Participation at National Learning workshop Honduras
Utila East End Newspaper	ST	Honduras	Participation at National Learning workshop Honduras
Akumal Dive Shop	ST	Mexico	Participation in National Learning Workshop
Aque Safari	ST	Mexico	Participation at National Learning workshop Mexico
Asociación de Prestadores de Servicios Acuáticos (APSA). Cozumel	ST	Mexico	Participation in National Learning Workshop
Asociación Hoteles de la Riviera Maya (AHRM)	ST	Mexico	Participation at National Learning workshop Mexico
Asociación Nacional de Operadores de Actividades Acuáticas y Turísticas (ANNOAT). Cozumel	ST	Mexico	Participation in National Learning Workshop
Aventura Maya Expeditions	ST	Mexico	Participation at National Learning workshop Mexico
Aviomar	ST	Mexico	Participation at National Learning workshop Mexico
CAST	ST	Mexico	Participation at National Learning workshop Mexico
Ceibon Tours	ST	Mexico	Participation at National Learning workshop Mexico
Coop Turistica Isla Morena	ST	Mexico	Participation at National Learning workshop Mexico
Coop. Punta Allen	ST	Mexico	Participation at National Learning workshop Mexico
Coop. Turística ensueños del caribe	ST	Mexico	Participation at National Learning workshop Mexico
Cooperativa Chiquila	ST	Mexico	Participation at National Learning workshop Mexico
Cooperativa turistica Los Gaytanes	ST	Mexico	Participation at National Learning workshop Mexico
Cruceros Maritimos del Caribe	ST	Mexico	Participation at National Learning workshop Mexico
Deportes Acuáticos	SF	Mexico	Trained in the Reef Check monitoring protocol
EMEA	SF	Mexico	Trained in the Reef Check monitoring protocol
Empresas Turisticas Nacionales	ST	Mexico	Participation at National Learning workshop Mexico
Federation of tour operators	ST	Mexico	Participation at National Learning workshop Mexico
First Choice	ST	Mexico	Participation at National Learning workshop Mexico
Garrafon Natural Reef Park	ST	Mexico	Participation at National Learning workshop Mexico

PRIVATE SECTOR	COMPONENT	COUNTRY	COMMENTS
Grupo Cacum SA de CV	ST	Mexico	Participation at National Learning workshop Mexico
Iberostar	SF	Mexico	Trained in the Reef Check monitoring protocol
ICM y L Puerto Morelos	SF	Mexico	Trained in the Reef Check monitoring protocol
Kukulcan Plaza Mall	SF	Mexico	Through a foundation raised money to support conservation activities in the MAR, particularly in Mexico. This foundation chose WWF-ICRAN-MAR project to give a grant in support of EBFM activities in two MPAs, as well as for printing whale-shark materials.
Local Union of sugarcane producers ULPCA-CNC, Chetumal Bay	WM	Mexico	Letter of commitment to participate in adoption of BMPs
LTU- Touristik	ST	Mexico	Participation at National Learning workshop Mexico
Mex-Atlantica Tours SA de CV	ST	Mexico	Participation at National Learning workshop Mexico
Mistic Diving Puerto Morelos	ST	Mexico	Participation at National Learning workshop Mexico
Mystic Diving Puerto Morelos	ST	Mexico	Participation at National Learning workshop Mexico
Parque Xcaret	ST	Mexico	Participation at National Learning workshop Mexico
Playa Maroma	ST	Mexico	Participation at National Learning workshop Mexico
Playa Mia Empresas Turisticas Nacionales	ST	Mexico	Participation at National Learning workshop Mexico
Royal Caribbean Cruises Intercontinental Cruises	ST	Mexico	Participation at National Learning workshop Mexico
San Pedro Tour Guide	ST	Mexico	Participation at National Learning workshop Mexico
San Rafael de Pucte sugar Mill	WM	Mexico	Agreed on the common language of MOUs to start collaborative work in identifying and implementing better management practices (BMPs). Sent a signed letter of commitment to make sure that they are willing to participate in adopting BMPs
Scuba Cancun	ST	Mexico	Participation at National Learning workshop Mexico
Scuba Caribe	SF	Mexico	Trained in the Reef Check monitoring protocol
Scuba Caribe	ST	Mexico	Promoting the good practice guidelines to educate both staff and visiting tourists at their facilities and on their boats.
Staff Divers	SF	Mexico	Trained in the Reef Check monitoring protocol
Staff Divers	SF	Mexico	Trained in the Reef Check monitoring protocol
Sugar Cane Production Committee of San Rafael de Pucte	WM	Mexico	Trained Belizean farmers in Biological control of the cane fly froghopper (*Aeneolamia spp*.) using the fungus *Metarhizium anisopliae.*
Tankh-ha Dive Center	ST	Mexico	Participation at National Learning workshop Mexico
The Civil Association of sugarcane producers from the Rio Hondo watershed (ACCPCA)	WM	Mexico	Agreed on the common language of MOUs to start collaborative work in identifying and implementing better management practices (BMPs). Sent a signed letter of commitment to make sure that they are willing to participate in adopting BMPs
World TUI	ST	Mexico	Participation at National Learning workshop Mexico
Xcaret – marine recreation provider	ST	Mexico	Promoting the good practice guidelines to educate both staff and visiting tourists at their facilities and on their boats.
Xel-Ha Actividades recreativas	ST	Mexico	Participation at National Learning workshop Mexico
Xiimbal Turismo Sustentable	ST	Mexico	Participation at National Learning workshop Mexico
CropLife LatinAmerica	WM	Regional	Signed MoU for the implementation of BMPs
Darden (Main lobster importer to the US)	SF	USA	Will give a grant to produce environmentally friendly traps for APESCA to use and will pay on-board observers who will certify that fishermen are no longer taking undersize and pregnant female lobsters

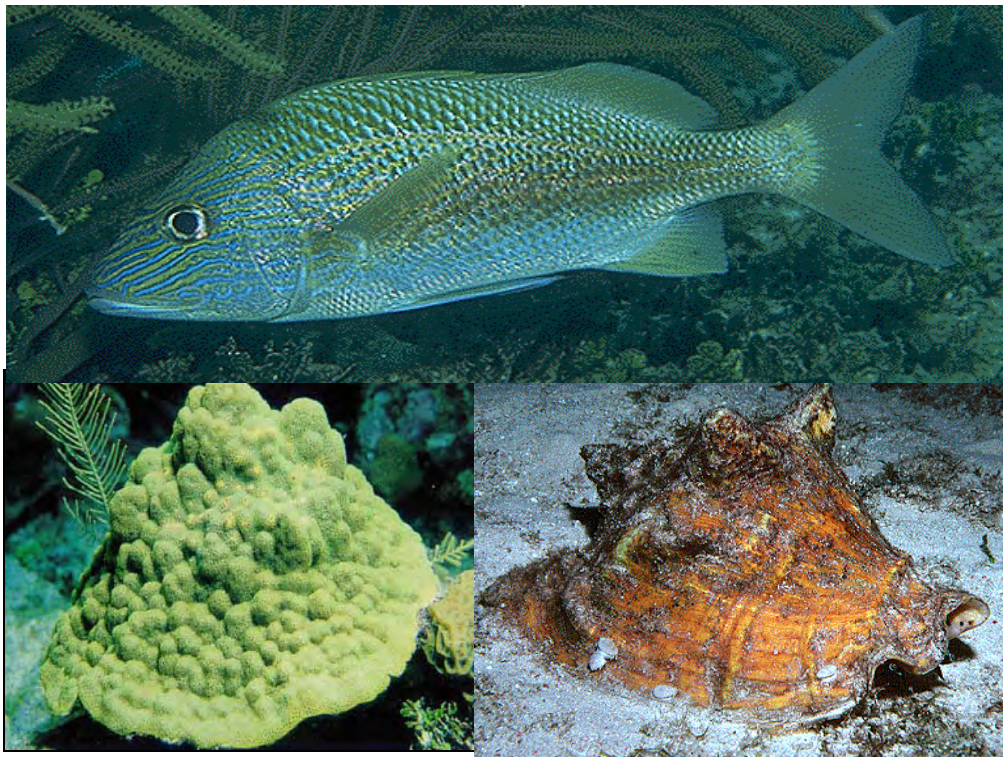
7. ORGANIZATIONS INVOLVED IN DIRECT CAPACITY BUILDING – WATERSHED MANAGEMENT

Capacity Building	Component	Country	Comments
CZMAI	WM	Belize	Local Staff involved
Belize Audubon Society	WM	Belize	Through capacity building efforts, with WCMC and WRI; Participation at Watershed Management Workshop

Department of Environment	WM	Belize	Participation at Watershed Management Workshop
Fisheries Department	WM	Belize	Through capacity building efforts, with WCMC and WRI; Participation at Watershed Management Workshop
Forest Department	WM	Belize	Through capacity building efforts, with WCMC and WRI; Participation at Watershed Management Workshop
Galen University	WM	Belize	Participation at Watershed Management Workshop
Land Information Centre	WM	Belize	Through capacity building efforts, with WCMC and WRI; Participation at Watershed Management Workshop
Ministry of Natural Resources	WM	Belize	Participation at Watershed Management Workshop
University of Belize	WM	Belize	Through capacity building efforts, with WCMC
CONAP Guatemala	WM	Guatemala	Participation at Watershed Management Workshop
MARN	WM	Guatemala	Participation at Watershed Management Workshop
Unidad de Pesca	WM	Guatemala	Participation at Watershed Management Workshop
CONANP	WM	Mexico	Participation at Watershed Management Workshop
INEGI	WM	Mexico	Participation at Watershed Management Workshop

Sampling, Biomarker and Contaminant Chemical Target Analysis Protocol

Assessing the Effectiveness of Agricultural Better Management Practices in the Mesoamerican Reef



December 2005

Haereticus Environmental Laboratory

WWF

ICRAN International Coral Reef Action Network

UNEP

USAID FROM THE AMERICAN PEOPLE

UNITED NATIONS FOUNDATION

PREFACE

While excess nutrients and over-fishing are widely recognized as a major contributors to global coral reef decline, the role of chemical pollutants, including those derived from agricultural activities, as potential agents of reef ecosystem decline has rarely been studied or recognized as a significant threat.

However, recent studies within the largely offshore reef habitats of the Mesoamerican Reef of bioaccumulation of agrochemicals in a variety coral reef species have found that such contamination is present on offshore reefs. Our strategy, therefore, involves linking monitoring of bioaccumulation in marine organisms with the agrochemicals used by key industries in the agribusiness sector and our collaborative efforts to reduce those with the highest risks to marine life. The development of this monitoring protocol is in an effort to establish baseline conditions for subsequent monitoring of the success of these management interventions (better management practices or BMP's) aimed at reducing the contamination. It is the first in a series of protocols, and will be followed by protocols for the incorporation of targeted biomarkers and eco-toxicology assays. Together these will help to establish ecological risk framework appropriate to this marine ecosystem.

We encourage collaborations with researchers from conservation organizations, government and industry from the region and from the global community, who have similar aims and monitoring needs.

For More Information Contact:

Craig Downs
Executive Director
Haereticus Environmental Laboratory
488 Little Lake Lane
Amherst, Virginia 24521 U.S.A.
Phone/Fax: 434-263-5740
Email: haereticus1@direcway.com

Melanie McField
Senior Marine Scientist, WWF
PO Box 512
7 Fullers Court
Belize City, Belize, Central America
Phone: (501) 223-7680
Email: mmcfield@wwfca.org

Jose Vasquez
Senior Agricultural Officer, WWF
FHIA La Lima, Cortes
P.O. Box 2067
San Pedro Sula, Cortes, Honduras
Phone:(504)668-2470 668-2078
Email:jvasquez@wwfca.org

Liza Agudelo
ICRAN-MAR Project Coordinator
Coastal Resources Building
Princess Margaret Drive,
Belize City, Belize, Central America
Phone: (501) 223-4673/84
Email:lagudelo@icran.org

Or Visit: www.wwfca.org; www.worldwildlife.org ;www.icranmar.org

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Sampling, Biomarker, and Contaminant Chemical Target Analysis Protocols for Assessing the Effectiveness of Agricultural Better Management Practices in the Mesoamerican Reef

This document contains contaminant chemistry analysis protocols for organochlorine pesticides and polychlorinated biphenyls, including the collection and analysis of biological and sediment samples. It was prepared for WWF and the ICRAN MAR Alliance by Craig Downs, Executive Director of Haereticus Environmental Laboratory in collaboration with Melanie McField, WWF Centrral America.

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Monitoring Protocol for Assessing the Effectiveness of Agricultural Better Management Practices in the Mesoamerican Reef

This document contains sample collection, preparation and analysis protocols that can be used on the target organisms of grunts, conch, and coral. It was prepared for WWF and the ICRAN MAR Alliance by Craig Downs, Executive Director of Haereticus Environmental Laboratory in collaboration with Melanie McField, WWF Central America.

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Chapter 1
Sampling Protocol for Contaminant Chemical & Biomarker Analysis

1.1.1 Materials

Materials that are needed to collect *Porites asteroides*(coral), *Strombus gigas* (queen conch, mollusc), and *Haemulon plumieri* (white grunt, fish) for organic contaminant chemistry analysis. Units are suggested for a single sampling time-point for 4 sites

	Item	Source	Catalog #	Units
1.	Oak Ridge Centrifuge tube, 50 mL	Nalgene Labware	3114-0050	8
2.	Oak Ridge Centrifuge tube, 30 mL	Nalgene Labware	3114-0030	60
3.	Oak Ridge Centrifuge tube, 10 mL	Nalgene Labware	3114-0010	60
4.	Al Stohlman Brand Drive Punch 13/64”	www.sbeartradingpost.com	35005-06	10
5.	Stainless steel dissection probe	Fisher Scientific	NC9727105	10
6.	Stainless steel scissors	www.discountofficesupplies.com		1
7.	Surgical scissors	www.drinstruments.com	6SS	12
8.	Stainless steel cutlery knife			1
9.	Heavy duty aluminum Foil, clean	VWR	29952-200	1
10.	Hammer	?	?	2
11.	Chisel, 5”(125) long x 5/16”(8.0)	www.steritool.com	10280	8
12.	Scalpel, stainless steel	VWR	BD-371030	15
13.	Scalpel blades, stainless steel	VWR	BD-371111	1 case
14.	Forceps	VWR	25716-002	12
15.	Forceps #2	VWR	25728-001	5
16.	Nine-piece Dissecting kit	VWR	25640-002	2
17.	Acetone, GC-grade, 99.5%	VWR	VW0370-7	1
18.	Nitric acid (50%)	VWR	VW3335-1	2
19.	Mortar, 65 mL, case of 18	VWR	50420-223	2
20.	Mortar, 145 mL, case of 12	VWR	50420-245	1
21.	Pestle, case of 18	VWR	50420-427	2
22.	Pestle, case of 12	VWR	50420-449	1
23.	Nitrile gloves, small, box	VWR	40101-344	2
24.	Nitrile gloves, medium, box	VWR	40101-346	2
25.	Nitrile gloves, large	VWR	40101-348	2
26.	Hydrosorb 1 12x12, 150 count	VWR	33344-044	1
27.	MVE Doble 28 Cryo shipper	MVE	MVE11527730	2
28.	MVE Doble 28 shipping container	MVE	?	2
29.	No.2 graphite pencil	local store	?	10
30.	Liqui-Nox Phosphate-Free Detergent	VWR	21837-005	2
31.	Double distilled water, 30L	?	?	
32.	Empty, black 35mm film canisters with lid			80
33.	Cable ties, 6-8 cm in length			80
34.	Cable ties, 30 cm in length			4
35.	Aluminum carabiner 6-10 cm in length			4
36.	Igloo Marine 54 cooler	www.igloo-store.com		2
37.	Collapsible fish trap 32 in. x 24 in.	www.nylonnet.com	FT-B	3

A listing of materials necessary for conducting assays will be found in each assay section.

Need access to Liquid nitrogen and dry ice.

1.1.2 Sample Nomenclature

Samples will be identified by three category designations: Site, Species, and order of collection.

All sites are designated by a capital letter. For example, the site in Barbareta, Honduras will be referred to in all collections as "A"; the site in Turneffe, Belize will be designated as "C". Species in the collection will be designated as "X", "Y", or "Z".

"X" = *Porites asteroids*
"Y" = *Strombus gigas*
"Z" = *Haemulon plumieri*

Individual samples collected from each site from any species will be designated as a number; the designation reflected by the numerical order it was collected. For example, the first coral sample collected in Barbareta will be designated as "1". The second coral sample collected in Barbareta will be designated as "2", etc… The first grunt sample collected in Barbareta will be designated as "1", etc…

Hence, all samples in shipping/archival containers, notebooks, and manifests will be identified by the designation:

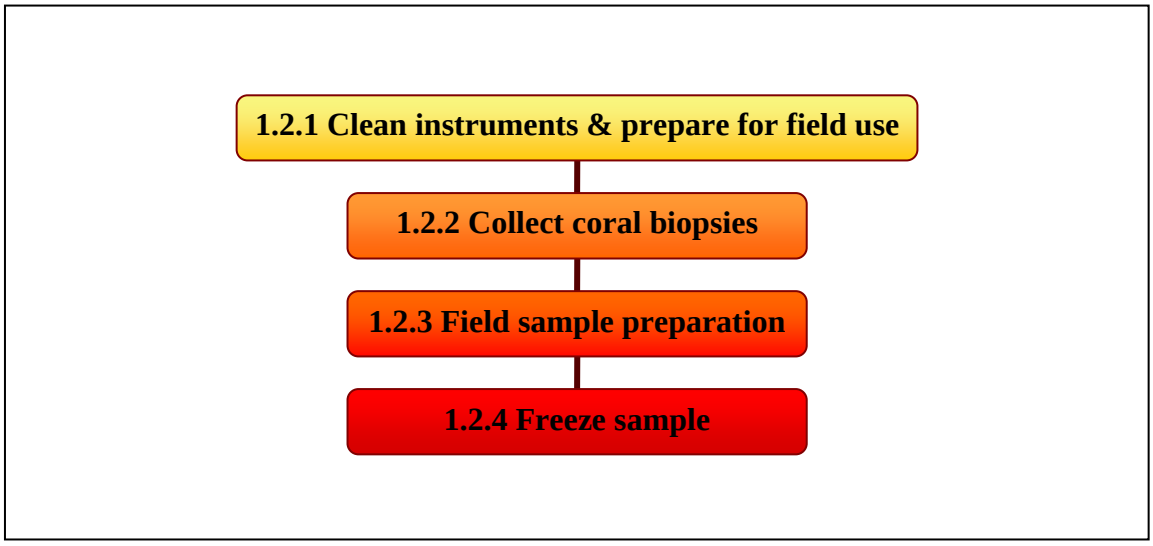
[Letter (site), Letter (species), Number (sample)]

For example, the first coral sample collected in Barbareta will be designated and labeled as [AX1]. The second coral sample collected in Barbareta will be designated and labeled as [AX2], etc… The first and second Queen Conch samples collected at Tuneffe will be designated and labeled [CY1] and [CY2], respectively.

1.1.3 Sampling Protocol Strategy

The sampling protocol for biological samples assumes that an individual that is collected will be assayed for both biomarkers and contaminant chemical target analytes. If biological samples are collected only for biomarker analysis, or if financial constraints make it difficult to obtain Teflon tubes, then an alternative step is provided. This alternative step wraps the samples in acetone-rinsed aluminum foil and places the sample in a polypropylene tube (in place of the Teflon tube). Using aluminum foil is not an ideal alternative, because it does not exclude the possibility of cross contamination between samples, and in some cases, between sites if the samples are all stored in the same freezer or liquid nitrogen cryo-shipper. Additional acetone-rinsed pieces of aluminum foil should be collected at the time of sampling and placed in a separate polypropylene tube. This foil will act as a control to determine if any of the residual target analytes may have been derived from the aluminum foil or the polypropylene tube.

1.2 Sample Collection & Preparation for Coral



Operations Chart for Coral Collection & Preparation for Contaminant Chemistry Analysis

Materials Needed:

- Al Stohlman Brand Drive Punch 13/64”
- Stainless steel dissection probe
- Heavy-duty Aluminum Foil
- 5 mm Teflon Layflat bags
- 35 mm film canisters with lids
- Both sizes of cable ties
- Polypropelene Falcon Tube, 50 mL
- Aluminum carabiner
- Clip-n-seal, large
- Liqui-nox detergent
- Pencil
- Acetone
- Double Distilled water
- Squirt bottle

1.2.1. Preparation for Cleaning

Arrange equipment and materials so they can be easily accessed once you start the cleaning process. Once you start cleaning, do not touch any other equipment or surfaces with the gloves you are wearing. If you must, remove the gloves and put on a new pair of clean gloves. Any stray contamination introduced during the cleaning process will affect the subsequent analysis.

1. Fill a new Teflon-coated squirt bottle with acetone. Identify the bottle with “acetone”.

2. Fill a new Telfon-coated squirt bottle with the distilled water. Identify the bottle with "water".
3. Fill a new squirt bottle with a 70% solution of acetone (ratio of 70 ml acetone to 30 ml distilled water). Identify the bottle with "70%".
4. Mix up a solution of 10% Liqui-nox detergent and place in a wash pan.
5. Place the roll of aluminum foil on a counter or table for cutting.
6. Cut a 30 cm x 30 cm section. In the top left-hand corner use a #2 pencil to inscribe an "A". The letter will let you know which side you have cleaned later.
7. Cut a piece of foil into 10 - 10 cm x 20 cm pieces. Use the pencil to inscribe an "A" in one corner of each piece.
8. Cut a piece of foil into 24 – 6 cm x 6 cm pieces. Use the pencil to mark the middle of each foil square with a sample designation number (e.g., [AX1], [AX2], [BX1], etc.) There should be 24 separate designation numbers.
9. Put on a clean pair of nitrile gloves.
10. Wash the side of the 30 cm x 30 cm piece of aluminum foil, with the "A", with acetone using the squirt bottle. Use acetone-cleaned forceps to manipulate the foil piece; handling of the aluminum piece with a gloved hand should be kept at a minimum.
11. Wash one side of each piece of 10 cm x 10 cm aluminum foil with acetone using the squirt bottle. Set the unwashed side face-down on a clean counter. Allow the foil to dry (15 minutes).
12. Rinse the forceps with acetone. Use the forceps to pick up each 6 cm x 6 cm piece of foil for cleaning. Wash both sides of the foil square with acetone using the acetone-squirt bottle. Allow to air dry on a 10 cm x 20 cm piece of acetone-rinsed aluminum foil.
13. Allow all pieces of foil to air dry, about 15 minutes.
14. Acetone-rinse four Oak Ridge 50 mL Teflon tubes/caps. Allow to air dry, then seal the tube.

1.2.2 Clean Instruments & Prepare for Field Use

1. Wearing the nitrile gloves, wash the Drive Punches and Dissection probes in the 10% Liqui-nox detergent.
2. Remove all residual detergent on the instruments by rinsing the instruments with distilled water using the squirt bottle.
3. Rinse instruments with acetone using the squirt bottle.
4. Place instruments on acetone-cleaned aluminum foil and allow to completely dry.
5. Place one Drive Punch and one Dissection Probe onto a single 10 cm x 20 cm aluminum foil piece (on the side of the foil that was washed with acetone).
6. Wrap the instruments with the acetone-cleaned aluminum foil.
7. Place one aluminum-covered instrument set into Teflon Layflat bag.
8. Seal the Layflat bag.
9. Punch a single hole in the lid of the 35 mm canister using the point of a sharp knife, about 1 mm in diameter and about 4 mm from the edge of the lid.

10. Punch a single hole in the side of the 35 mm canister, about 1 mm in diameter, and about 5 mm below the lip of the canister.
11. Punch a single hole at the bottom of the 35 mm canister, about 2 mm in diameter, and in the center.
12. Loop the lid and canister together with the 6-8 cm long cable tie. Make sure not to constrict the cable tie loop too tightly. The lid must be able to come off, and be put back on, the canister easily.
13. Quickly rinse the inside of the canister and the inside of the lid with the 70% acetone solution, followed very quickly with washing with double distilled water. Acetone can melt plastic.
14. Allow to air dry, then cap the containers.
15. Number each canister with a number, from 1 to 6, by etching the number to the outside of the canister with a sharp knife.
16. Assemble six canisters together by looping the 30 cm cable tie through the 6-8 cm cable tie loop (see Figure 1).
17. Gather the six sample-foil squares that pertain to a single sampling site into a Teflon Layflat bag that has been rinsed with acetone/air dried. Seal the bag.
18. Identify the four Oak Ridge 50 mL Teflon tubes/caps. Using a Dremmel with a fine point or a knife, etch the site and species designation onto the side of the tube. Each tube should have a different designation code.
19. Finally, place a carabineer onto the 30 cm cable-tie loop (see **Figure 1**).

Figure 1. Basic configuration design of 35 mm film canister loop for coral sampling

1.2.2. Collection of Coral Biopsies

Collection of samples is assumed to be conducted by SCUBA diving off a boat. There should be three people for the collection, the two collection divers and the 'boat person'.

1. Once collection divers have donned their dive gear, divers should put on nitrile gloves. The 'boat person' will latch the 35 mm film canister to the wing diver's buoyancy control device using the carabineer.

2. Remove a single set of drive punch/dissecting probe from its protective covering; the drive punch and the hammer are taken by the lead diver.

3. The wing diver will bring with them the dissecting probe.

4. Once at the target site, the lead diver will place the drive punch on the apex of the coral colony. The apex of the coral is the area of the coral that is perpendicular to the surface of the water, and should receive the greatest amount of incident light (**Figure 2**). Do not collect the biopsy from the coral edge, as you may collect non-coral tissue, thereby introducing significant artifact into the study (**Figure 3**).

5. With several taps with the hammer, the drive punch should be driven into the colony about 1 cm. The diver must go deep enough into the coral colony so that the biopsy contains all visible tissue (**Figure 4**). For most boulder corals, the tissue can extend into the skeleton from 1mm to as much as 10 mm. If boring sponge is present, try not to collect the sponge with your biopsy – resample from the same coral colony, or sample from a different coral colony. The coral biopsy will remain in the drive punch.

6. The lead diver hands the drive punch that contains the biopsy to the wing diver. The wing diver, using the dissecting probe, pushes out the coral biopsy. Using a 5 cm x 5 cm square of acetone-cleaned aluminum foil, wrap the coral biopsy in the foil. Place foil-wrapped coral biopsy into the open 35 mm film canister. Once the biopsy is in the canister, seal the canister with the lid.

7. Wing diver will then return the drive punch to the lead diver.

8. Ideally, every sample should have a new drive punch/probe, though in most cases, this many not be financially possible. If this constraint is present, repeat sampling procedure with the next coral colony using the same coring device for all colonies at a given site.

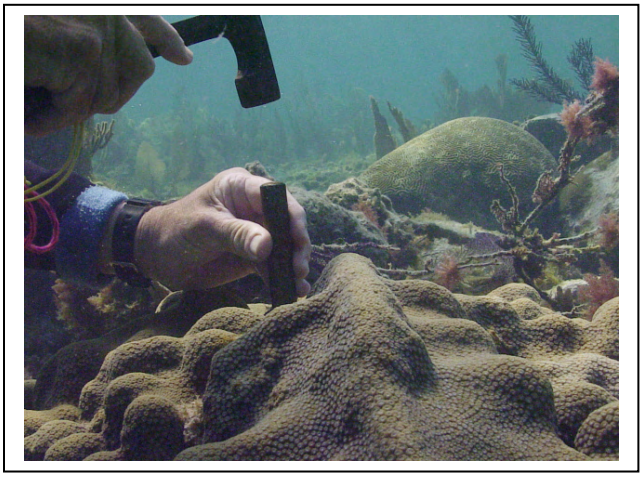


Figure 2. Place drive punch at the apex or very near the absolute apex of the coral colony. The biopsy lesion should be completely surrounded by healthy coral tissue. Unlike this picture, diver should wear nitrile gloves.

Figure 3. The biopsy SHOULD NOT be taken from tissue that is near the edge of the coral colony

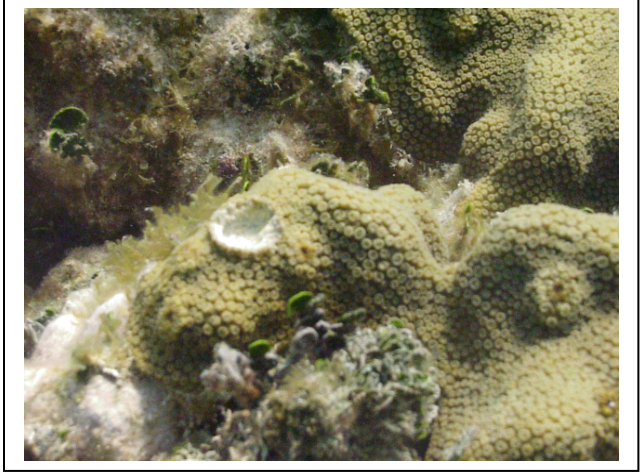


Figure 4. The divot created by the biopsy should tell you whether or not your biopsy went deep enough into the coral skeleton. You should see that the bowl of the divet extends below the tissue layer by about 2-3 mm.

1.2.3. Field Sample Preparation

1. During the diver interval, the boat person should make ready the 6 cm x 6 cm foil squares, a clean surface area to work on (a sheet of acetone-washed aluminum foil laid across the top of the igloo marine cooler). Boat person should be wearing clean nitrile gloves.

2. At the surface, the wing diver hands the film canister loop to the boat person.

3. Opening a single film canister, the boat person removes the coral biopsy from the canister using acetone-rinsed forceps. Remove the foil encasing the coral biopsy. Place biopsy on one of the 6 cm x 6 cm foil squares, place sample on top of the penciled number. Fold the foil square over the biopsy and crease with sharp edges and a rolled/pinched seal.

4. If coral is being used for contaminant chemistry analysis, place foiled biopsy into the 50 mL Oak Ridge Teflon centrifuge tube; the tube that is designated for this sampling site. If coral is being used only for biomarker analysis, place foiled biopsy into a 50 mL polypropylene Falcon Tube that has a 1 mm whole drilled into its side. This whole prevents the tube from exploding when it is removed from the cryo-shipper.

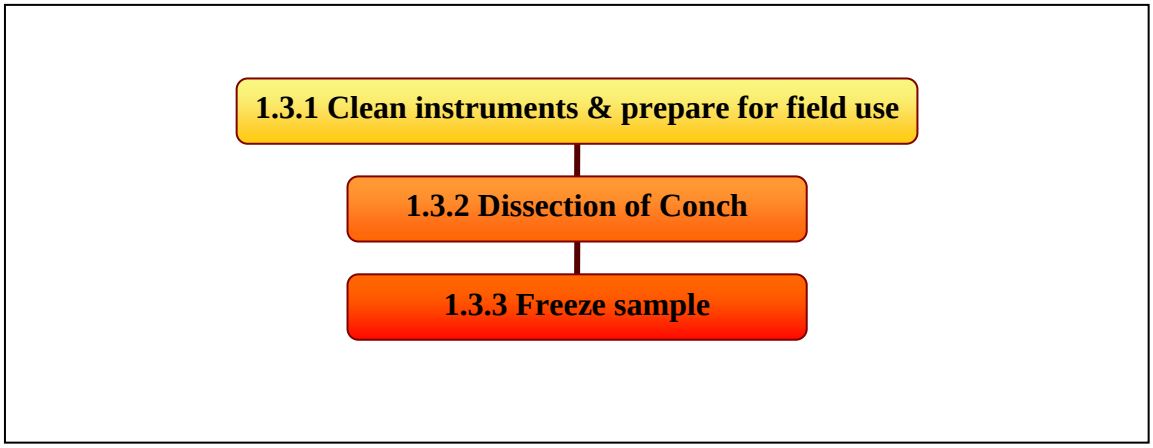
5. All six samples from a single site should fit into the single centrifuge tube. If worried about possible cross-contamination of target analytes if samples are placed in a single tube, then place samples in separate tubes.

6. Place the cap back onto the centrifuge tube, but only give the lid ¾ of a full rotation. An air-tight seal on the centrifuge tube could result in an exploding tube when the tube is removed from the cryo-vapor shipper.

1.2.4. Freeze Sample

1. Place the tube in the cryo-vapor shipper or in the Igloo Marine Cooler that contains dry ice.

1.3. Sample Preparation & Collection for Queen Conch



Materials

- Stainless steel hammer with a sparred end or stainless steel chisel
- Scalpel
- forceps
- Heavy-duty Aluminum Foil
- Oak Ridge Centrifuge tube, 30 mL
- Polypropylene Falcon Tube, 50 mL
- 5 mm Teflon Layflat bags
- Clip-n-seal, large
- Liqui-nox detergent
- Acetone
- Double Distilled water

If you have a stainless steel hammer with sparred end, you do not need the stainless steal chisel, and vice versa.

1.3.1 Clean instruments & prepare for field use

1. Wear nitrile gloves during the entire procedure.

2. Wash one side of a 30 cm x 30 cm piece of aluminum foil with acetone using the squirt bottle.

3. Allow sheet to air dry on the counter (15 minutes).

4. Wash the hammer/chisel, forceps and scalpel in 10% Liqui-nox detergent (dilute with double distilled water).

5. Remove all residual detergent on the instruments by rinsing the instruments with double distilled water using the squirt bottle.

6. Rinse instruments with acetone using the squirt bottle.

7. Place instruments on acetone-cleaned aluminum foil, allow to completely dry.

8. Cut aluminum foil into 30 cm x 20 cm pieces.

9. Wash one side of each piece of aluminum foil with acetone using the squirt bottle. Set the unwashed side face-down on a clean counter. Allow the foil to dry (15 minutes).

10. Place one hammer/chisel and one scalpel onto asingle 30x20 cm aluminum foil piece (on the side of the foil that was washed with acetone).

11. Wrap the instruments with the acetone-cleaned aluminum foil.

12. Place aluminum-covered instrument set into Teflon Layflat bag.

13. Seal the Layflat bag.

14. Acetone rinse 32 Oak Ridge 30 mL Teflon tubes/caps. Allow to air dry, then seal the tube.

15. Using a dremmel with a fine point or a knife, etch the site, species, and sample number designation onto the side of the tube. Each tube should have a different designation code.

1.3.2 Dissection of Conch

1. Once the conch has been collected, it can be placed in the cooler on dry ice or ice, or it can be dissected in the field.

2. Whether dissection occurs in the field or back in the lab, acetone clean one side of a 30 cm x 30cm piece of aluminum foil, and place the uncleaned side down on a clean benchtop or Teflon cutting board.

3. Wear nitrile gloves.

4. Position the conch shell on a clean surface and puncture or “crack” the shell with the stainless steel hammer or chisel at the location indicated in **Figure 5**.

5. With the scalpel, cut the retractor muscle off of the shell (**Figure 6**).

6. Pull the conch out of the shell.

7. Cut a 7 cm long x 1 cm in diameter swath of mantle tissue using the acetone-cleaned scalpel and forceps (**Figure 7**).

8. Place the mantel tissue into the labeled Oak Ridge Telfon 30 mL centrifuge tube that is appropriately labeled. Alternatively, wrap the tissue with an acetone-rinsed piece of aluminum foil; then place the tissue in a 50 mL polypropylene Falcon tube.

9. Be consistent with the area from which you dissect the tissue from one sample to another.

1.3.3 Freeze sample

1. Place the tube in the cryo-vapor shipper or in the Igloo Marine Cooler that contains dry ice.

Figure 5. Puncture or "crack" the shell at the location indicated in the figure. Use an acetone-cleaned stainless steel hammer with a spar or a stainless steel chisel.

Figure 6. Using the acetone-cleaned scalpel, cut the retractor muscle from the shell so that the conch can be removed easily from the shell.

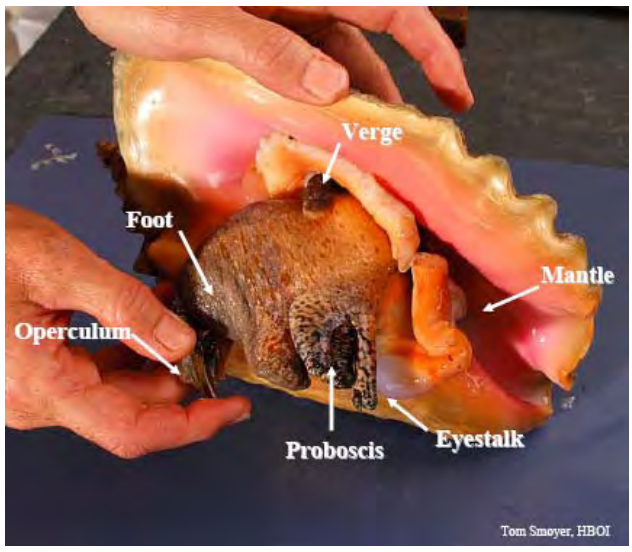
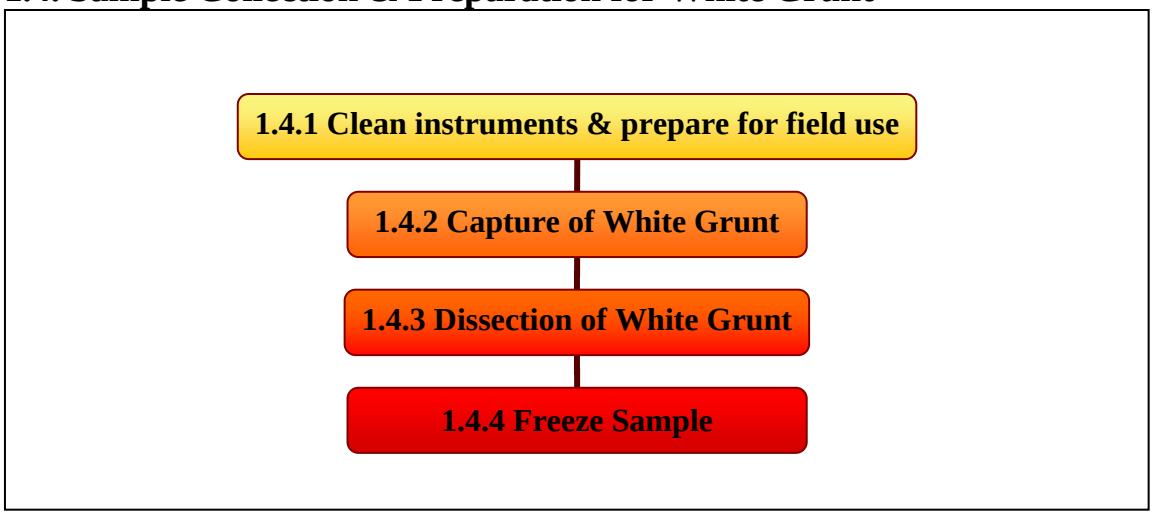


Figure 7. Cut a 7 cm long and about a 1-2 cm wide swath of mantle tissue using the acetone-cleaned scalpel and forceps.

1.4. Sample Collection & Preparation for White Grunt



Materials

- Fish cages
- Scalpel
- Forceps
- Surgical scissors
- Heavy-duty Aluminum Foil
- Oak Ridge Centrifuge tube, 10 mL
- Polypropylene Falcon Tube, 50 mL
- Teflon 12x12 cutting boards
- 5 mm Teflon Layflat bags
- Clip-n-seal, large
- Liqui-nox detergent
- Acetone
- Double Distilled water

1.4.1 Clean instruments & prepare for field use

1. Wear nitrile gloves during the entire procedure.
2. Wash one side of a 30 cm x 30 cm piece of aluminum foil with acetone using the squirt bottle.
3. Allow sheet to airdry on the counter (15 minutes).
4. Wash the surgical scissors, forceps, and scalpel in 10% Liqui-nox detergent (dilute with double distilled water).
5. Remove all residual detergent on the instruments by rinsing the instruments with double distilled water using the squirt bottle.
6. Rinse instruments with acetone using the squirt bottle.
7. Place instruments on acetone-cleaned aluminum foil, allow to dry completely.
8. Cut aluminum foil into 30 cm x 20 cm pieces.

9. Wash one side of each piece of aluminum foil with acetone using the squirt bottle. Set the unwashed side face-down on a clean counter. Allow the foil to dry (15 minutes).
10. Place one surgical scissors, forceps, and scalpel onto a single 20x20 cm aluminum foil piece (on the side of the foil that was washed with acetone).
11. Wrap the instruments with the acetone-cleaned aluminum foil.
12. Place aluminum-covered instrument set into Teflon Layflat bag.
13. Seal the Layflat bag.
14. Acetone rinse 32 Oak Ridge 10 mL Teflon tubes/caps. Allow to air dry, then seal the tube.
15. If only collecting samples for biomarker analysis, acetone rine 32 50 mL Falcon tubes/caps. Allow to air dry, then seal the tube.
16. Using a dremmel with a fine point or a knife, etch the site, species, and sample number designation onto the side of the tube. Each tube should have a different designation code.

1.4.2 Capture of White Grunt

1. Purchase bait from store.
2. Using an acetone-cleaned instrument, place approximately 5-10 grams of bait into a Oak Ridge Telfon 10 mL tube, and etch onto the side of the tube, "Fish bait." Freeze bait sample in -20C freezer or in the cryo-dry shipper.
3. When at the site location, place bait in trap. The fish-trap product suggested in this document was included because they were used in grunt studies in the Florida Keys. Other types of traps can be used, as long as they do not induce excessive stress on the fish. Excessive handling stress can cause artifactual results for some of the biomarker.
4. Have a diver set the trap at a location where a lot of white grunt are evident.
5. Allow trap to set for at least 30 minutes.
6. Seal entrance to trap, bring trap to surface.
7. Collect only White Grunts that are 25 cm and longer.
8. Wrap grunt in 36 x 36 cm aluminum foil square that has been acetoned-washed and labeled. Place Grunt directly over penciled label. Wrap Grunt in the aluminum foil square, making sure of creased edges and rolled-pinched seal.
9. Freeze same in Igloo Marine cooler with dry ice in it.
10. The fish will most likely exhibit intensive physical activity when you try to wrap the fish in foil, making it difficult and frustrating to carry out the procedure. There are a number of ways to reduce this effort. It is important to keep in mind that whatever method of reducing the physical exertion of the fish should be legally acceptable and institutionally approved. Placing the fish in an acetone cleaned tank with site water and a fish anesthetic may be the easiest and most socially acceptable method.

1.4.3 Dissection of White Grunt

1. Place acetone-cleaned 12 cm x 24 cm Teflon cutting board on a level and clean surface.
2. Partially thaw fish at room temperature (e.g., room temperature = 25°C-29°C).
3. Wear nitrile gloves.
4. Remove fish from aluminum foil covering and place on 12 cm x 24 cm Teflon cutting board.
5. Head of fish should be facing to your right, the tail facing to your left.
6. Make an incision with the scalpel that run from the dorsal edge to the bottom of the belly; the incision should be made in front of the pectoral fin (**Figure 8**).
7. Make a second incision that begins where the first incision ended at the fish's belly, and run along the belly to the vent (**Figure 8**; **Figure 9**). If it is easier for you, use the surgical scissors to make the cut.
8. Make a third incision from the vent across the side of the fish, ending the incision at the site of the beginning of the first incision (**Figure 8; Figure 10**).

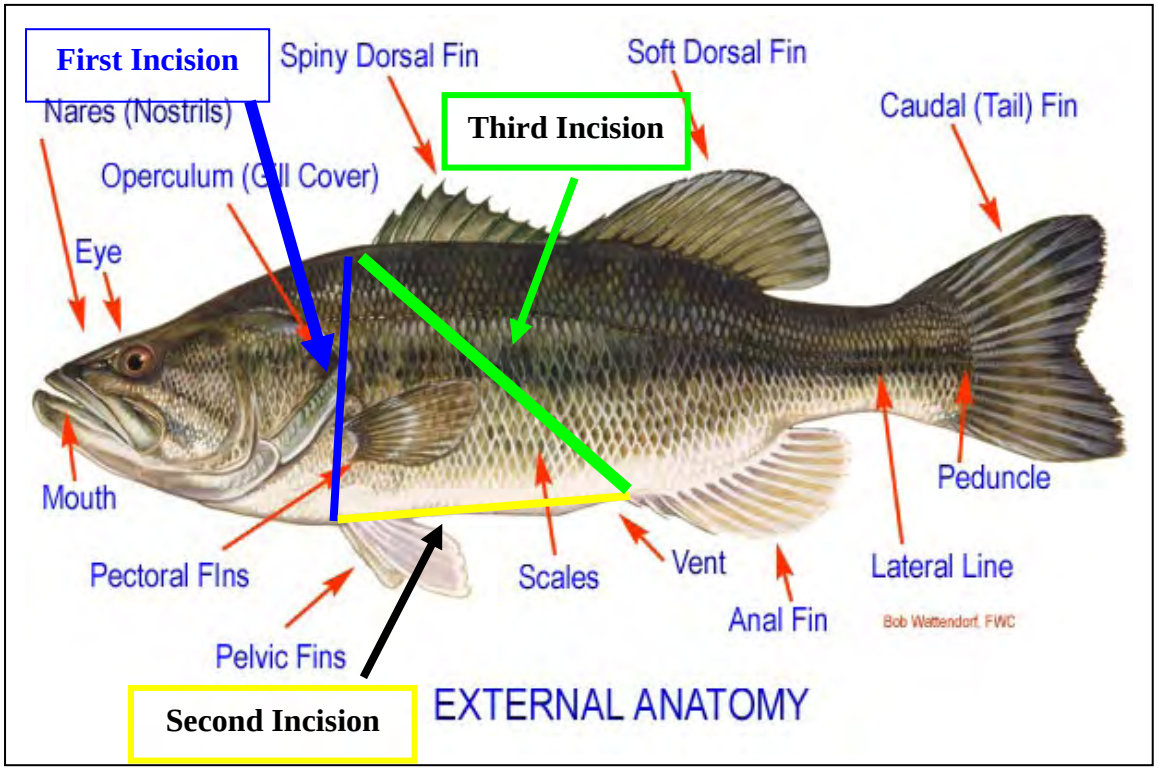


Figure 8. Make an incision along the blue line. The cut should only be deep enough to penetrate the muscle and break the gastrovascular fascia. DO NOT CUT into the organs. The yellow line is the second incision; again, penetrate the muscle and fascia, but do not cut into the organs. For the second incision, you may use your surgical scissors. The green line is the third incision; again, penetrate the muscle and fascia, but do not cut into the organs.

Figure 9. Second incision along the belly

Figure 10. Third incision along the side

9. Identify the liver. It should be dark-red in color, and near the gills and immediately below the stomach (**Figure 11**).
10. Remove the liver with forceps and scalpel.
11. Place liver in acetone-cleaner Oak Ridge Telfon 10 mL centrifuge tube. Cap the tube with the lid, making sure that the lid is NOT on tight. Alternatively, wrap the tissue in acetone-rinsed aluminum foil. Place the wrapped tissue in a 50 mL polypropylene Falcon tube.

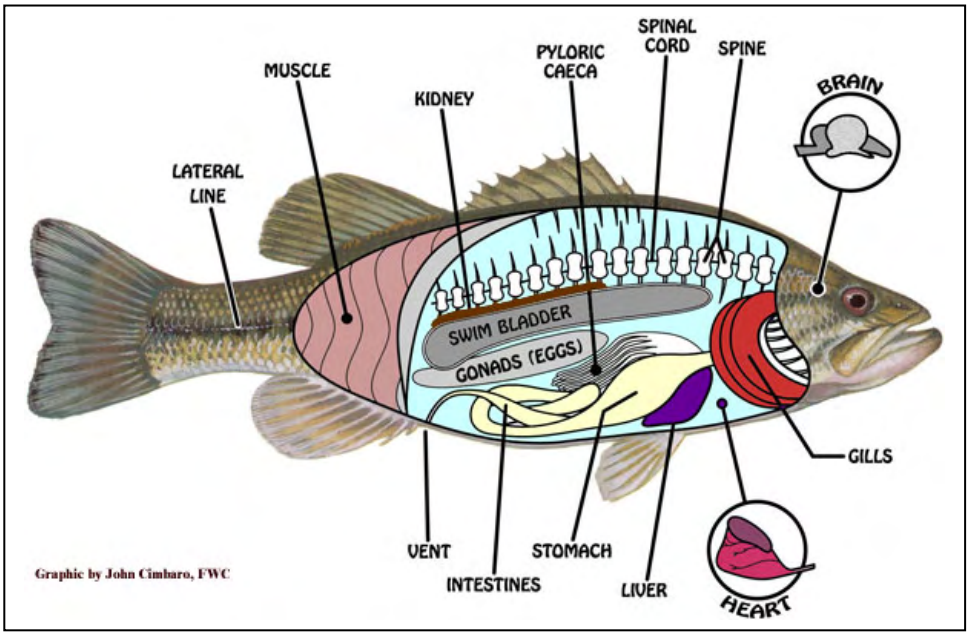


Figure 11. Liver is dark-red in color, and between the stomach and the gills

1.4.4. Freeze Sample

1. Place sample in cryo-dry shipper or in a -20C freezer. Samples can only remain at -20C for 28 days.

1.5. Sample Collection of Sediment for Organic Contaminant Analysis

Materials

- Sediment Jars, 500 mL

Collection Procedures

The particle composition and size of sediment may have an affect on the inferences that can be made from the contaminant chemistry data resulting from a sample site. The types of sediment at the sampling sites may vary from site to site. Oftentimes, inexperienced or uneducated sampling teams will sample sediments containing large sized stones (e.g., 1 centimeter or larger). Particulate size within a sediment sample should be, on average, smaller than two millimeters. Stones larger than 1 cm should be excluded from the sample. Exclusion of large stones requires that the sediment be resampled, and to not manually remove the stones from the sediment jar.

It is also suggested that the divers make note in the field book a description of the texture, color and scent of the matrix of each sediment sample.

1. At each sampling site, place six jars into mesh bag. Jars should have lid on them. If you do not dive deeper than 15 meters, the pressure on the jar should not break the jar. Do loosen the lid on the jar so that it can be opened easily underwater.
2. Diver should wear nitrile gloves.
3. At depth, open jar above sediment, and scoop the sediment into the jar using the lip of the jar. Only collect the top 1-2 centimeters of sediment.
4. Try to ensure that the jar is completely filled with sediment, and contains little residual seawater.
5. Cap jar with lid.
6. Once on deck, label the jar with a permanent marker or with laboratory tape, and chill the sample. Place jar in an Igloo cooler with normal ice – not DRY ICE.
7. If possible, open the jar and decant any excess seawater.
8. Once back in the lab, place the jar in a -20°C freezer.

If desired, grain size distribution for each sediment sample may be determined so that contaminants analysis results can be normalized against this grain size distribution. Grain size should be determined either by sieve fractionation or by gravimetric pipetting. The major fractions of particle distribution (based on the Wentworth scale) include the following classes:

- cobble (-6 phi and above)
- gravel (-2 phi to -5 phi)
- sand (+4 phi to -1 phi)
- combination of both silt and clay (+5 phi and below)

Most coastal marine systems have a diversity of sediment types, and hence, normalization against a single grain size distribution may be unrealistic and fallacious. This is not to say that this information might not be beneficial during the final analysis.

1.6. Option 1 – Short-term management of samples

Option 1 assumes that none of the samples will be archived or sent to a secondary analysis lab.

Samples from all three species will be in their capped, centrifuge tubes frozen in the cryo-vapor shipper.

1. Create a manifest of all contents in the cryo-vapor shipper.

2. Obtain the necessary export CITES permits.

3. Obtain the necessary import CITES permits.

4. DO NOT USE **DHL** as a courier service. Use air freight with an airline, FEDEX, or an air-freight service.

5. The day before shipping, make sure the cryo-vapor shipper is charged.

6. Notify the receiver five days in advance, then again at 48 hours in advance, and before the day the cryo-shipper is being sent to the receiver.

7. It is best that the receiver meets personally with the U.S Fish and Wildlife and the U.S. Customs inspection agents during the inspection of the cryo-shipper to expedite the processing and ensure that the cryo-shipper is delivered to the receiver in a timely fashion.

1.7. Option 2 - Long-term management of samples

Option 2 is a long-term management plan for samples collected as part of the Meso-American reef system. Option 2 is based on U.S. EPA's split-sample analysis inter-laboratory program. Samples are collected and prepared (as described in Section 1) and shipped to a central processing and storage facility. Samples are ground frozen to a fine powder, and aliquoted into three separate tubes. The purpose of each tube is as follows:

- Tube 1 is sent to the primary analysis facility.
- Tube 2 is archived for future reference.
- Tube 3 can be sent to the secondary analysis facility if there is a dispute, or for analysis of cellular end-points and contaminant target analytes that are not included in the primary biomarker and chemistry analysis.

Each tube will be given a new identification code that will ensure that all of the receiving facilities will be 'blind' to the true identification of the sample.

This Central Processing and Storage Facility is required to have the following items

- -80°C freezer or liquid nitrogen freezer storage
- Back-up power supply for cryo/freezer storage

- Secure entry
- System tracking of samples/identification
- Sample preparation equipment and supplies

Procedures for Option 2

Clean Instruments and prepare for use

1. Ship samples to Central Processing and Storage Facility as in Option 1.

2. Samples processed by ID input into data management system and stored either in a -80°C freezer or in a liquid nitrogen cryo-storage container.

3. Wear nitrile gloves for all instrument cleaning steps.

4. Mortar and pestles are washed in Liqui-nox detergent, rinsed in distilled water.

5. Optional: Mortar and pestles are set in a solution of 50% nitric acid for 2 hours, and then liberally rinsed in distilled water.

6. Mortar and pestles are rinsed with acetone.

7. Mortar and pestles are air-dried for five minutes, and then wrapped in acetone-cleaned aluminum foil for storage.

8. Stainless steel spatulas are washed with Liqui-nox detergent, rinsed with distilled water, then washed with acetone and air-dried. Wrap spatulas in aluminum foil for storage.

Sample preparation

1. Wear nitrile gloves.

2. Unwrap mortars, pestles, forceps, and spatulas from their aluminum foil covering and place on a clean lab bench.

3. In the three 1.8 mL cryo-vials, appropriately label the side of each tube with the Sample ID, and the storage tube Number (1-3). Labeling should be done with a black permanent marker or using printed cryo-tag labeling tape.

4. Place the three 1.8 mL cryo-vials into the tube racks, and place the racks in the ceramic ‘cool’ box with dry ice in the box. This is so that once you put the ground, frozen sample into each of the tubes, the samples do not thaw.

5. Place the 'cool' box with tubes onto a clean lab bench. It is assumed that the cool box and the tube racks have been cleaned with Liqui-nox detergent and rinsed in distilled water.

6. Fill cryo-dewar with liquid nitrogen.

7. Remove the samples from the cryo-storage container and place in a second 'cool' box that is filled with dry ice.

8. Set the second 'cool' box with the sample in it onto the lab bench.

9. Pour liquid nitrogen into a mortar that has the pestle in it. Fill the mortar to the rim, and allow the mortar to boil off (**Figure 12**).

10. Again, pour liquid nitrogen into mortar that has the pestle in it. Fill the mortar to the rim, and allow the mortar to boil off.

11. Rest the pestle on the lip of the mortar, and for the third time, pour liquid nitrogen into mortar (**Figure 13**).

12. As the liquid nitrogen is boiling in the mortar, remove the sample from its 3114 Oak Ridge Teflon Centrifuge tube with forceps, and place the entire sample into the mortar that has liquid nitrogen in it.

13. With the pestle, fracture the sample into smaller pieces before the liquid nitrogen completely boils off.

14. With 1-4 mL of liquid nitrogen remaining in the mortar, quickly grind the sample into the mortar applying significant pressure. Continue to do this until about 5-10 seconds after the liquid nitrogen completely boils off from the mortar.

15. Carefully add liquid nitrogen into the mortar, filling it to 1/3 to ¼ full.

16. Carefully grind the samples into a powder that is of a granulated consistency between ground sugar and finely milled flower (**Figure 14**).

17. With an acetone-clean, liquid-nitrogen cooled spatula, place contents of the mortar equally into the three cryo-vials that are in the 'cool' box that has dry ice in it (**Figure 15**).

18. Cap the samples, but do not make the seal air-tight, as nitrogen gas that is escaping from the sample can build up pressure within the tube and burst the vial.

19. Place sample in -80°C freezer or cryo-storage facility.

Figure 12. Pour liquid nitrogen into the mortar/pestle configuration and fill to the brim of the mortar

Figure 13. For the third filling of quid nitrogen into the mortar, remove the pestle and rest the pestle on the lip of the mortar.

Figure 14. Grind samples into a fine powder, making sure that the sample never thaws. Be careful when pouring liquid nitrogen into the mortar with granulized sample, as the liquid will sometime splash the sample out of the mortar and onto the bench.

Figure 15. While still frozen and in near liquid form, pour frozen, pulverized sample into a 1.8 mL cyo-vial that has been pre-chilled with liquid nitrogen. Using a liquid nitrogen or dry ice pre-chilled spatula will facilitate transfer of sample from the mortar to the vial.

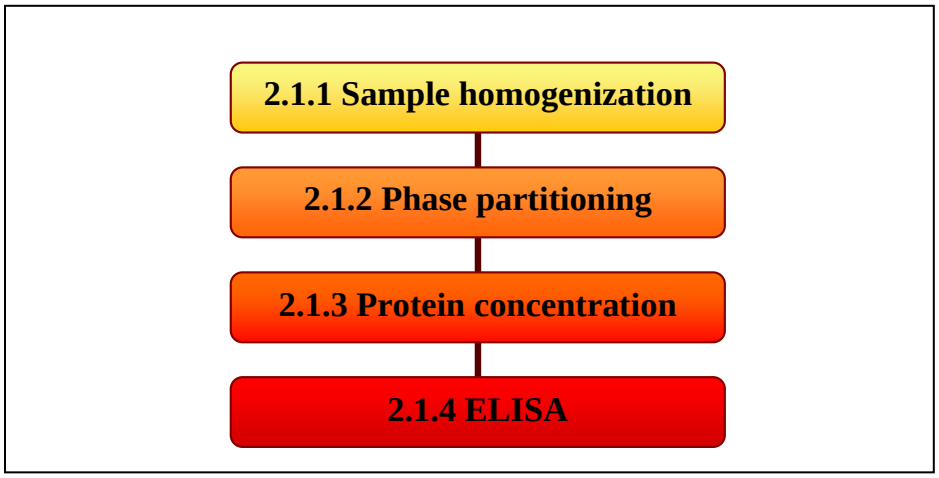
Some of the pulverized sample may escape from the mortar or cryo-vial and land on the lab bench, lab coat, etc. DO NOT place this piece of sample back into the mortar/cryo-vial with the remainder of the sample. This piece must be discarded.

Laboratory Safety

It is assumed (and strongly encouraged) that all technicians conducting laboratory preparation and assay protocols described in this document have taken a laboratory safety training course sanctioned by the laboratory's federal/state government and institution, and have read all Materials Safety Data Sheets for all of the chemicals used in the protocols. Special safety training will also be required for handling of liquid nitrogen and dry ice (solid carbon dioxide). The laboratory room where liquid nitrogen and dry ice are being handled should be well vented and precautionary measures should be taken to safeguard against asphyxiation. A number of safety guidelines, training documents, and information concerning specific laboratory activities can be found or requested at the U.S. Department of Labor Occupational Safety and Health Administration (www.osha.gov). It is the responsibility of the principle investigator and executives at the laboratory's institution to comply with all safety regulations indicated by institutional policy and federal/state laws.

Chapter 2:
Sample preparation and assays for biomarker analyses

2.1 Sample preparation and protocol criteria for ELISA



This document is not meant to introduce and instruct the novice laboratory technician. It is assumed that the technician has a minimal amount of education and training in biochemistry and molecular biology and has the ability to solve issues (trouble-shoot) concerning sample preparation and assay protocols. The purpose of Chapter 3 is to provide a basis for standardization of biomarker end-points used in the MAR study area as well as standardization of assay protocols. This document also assumes a level of competence in making diagnostic interpretations for the results of any of these biomarkers. Use of biomarkers should be conducted within a diagnostic context. It is beyond the scope of this document for the proper training and education in the theory of cellular diagnostics and biomarkers.

2.1.1 Homogenization of sample in Denaturing Buffer

1. Within two hours of commencing the homogenization of samples, prepare the Denaturing Buffer fresh, using the solid form of each ingredient, not a previous solubilized form of the ingredient.

2. All glassware, spatulas, and Teflon-coated magnetic stirrers should be cleaned with Liquid Nox detergent and thoroughly rinsed with distilled water.

3. In a 50 mL Pyrex bottle, make up a 100 mM stock solution of Disodium ethylenediaminetetraacetate (EDTA). First add 25 mL of distilled water to the vessel, then a teflon-coated magnetic stir bar. Then add 1.86 grams of disodium EDTA. Slowly titrate with 4 M sodium hydroxide (NaOH) and monitor the pH of the solution with a pH meter. The final pH of the solution when all of the EDTA is dissolved will be about 8.0. Solubilizing by titration for this amount of EDTA should take about 10 minutes. This solution of EDTA should be good for about two weeks if kept at 4°C.

4. In a 15 mL polypropylene Falcon tube, add 0.138 grams of salicylic acid. Then add 10 mL of distilled water to the tube, and mix until dissolved. This is a 10 mM solution of salicylic acid.

5. To a 100 mL Pyrex flask or Pyrex bottle, add 25 mL of distilled water.

6. To the vessel with water in it, add a small Teflon-coated magnetic stir bar. Place vessel on magnetic stirrer.

7. To the vessel, add 0.48 grams of tris base (also known as Trizma base).

8. To the vessel, add 8 mL of 100 mM EDTA solution to the vessel.

9. To the vessel, add 0.185 grams of fresh dithiothreitol (DTT).

10. To the vessel, add 800 microliters of 10 mM salicylic acid solution.

11. Once the tris, salicylic acid, and DTT have been dissolved, titrate the solution to pH 7.8 using 3 N hydrochloric acid (HCl).

12. Add 1.6 grams of sodium dodecyl sulfate from a bottle purchased within the last three months and has not been opened for more than five days.

13. To the vessel, add 800 microliters of dimethyl sulfoxide.

14. To the vessel, add 0.0015 grams of D-sorbitol.

15. If working with coral samples, add 2.4 grams of polyvinylpolypyrrolidone (PVPP) to the vessel.

16. Allow the solution to mix on the magnetic stirrer for about 15 minutes at a temperature above 23°C.

17. Label your locking 2.0 mL microcentrifuge with the appropriate sample identification.

18. Purchase a protease inhibitor cocktail solution from any reputable commercial source. The protease cocktail should contain the following ingredient and have a minimal stock concentration: 0.4 mM Bestatin, 0.1 mM E-64, 2 mM phenylmethylsulfonyl fluoride, 2 mM benzamidine, 5 mM a-amino-caproic acid, and 1 μg/100 μL pepstatin A.

19. Add 10-20 microliters of the protease inhibitor cocktail solution to the inside of the open lid that caps the microcentrifuge tube. This location is on the side of the lid that closes within the microcentrifuge tube.

20. For each species, the volume or weight of the frozen ground sample powder that will be homogenized in the microcentrifuge tube must be experimentally determined. The final total soluble protein concentration of the sample should not be more than 2 mg/ml and should not be less than 0.125 mg/mL.

21. Add the appropriate volume/weight of frozen powdered sample to the locking microcentrifuge tube using a pre-chilled spatula (**Figure 16**).

22. Add 1,700 microliters of fresh denaturing buffer in which the PVPP has been maintained in a equally distributed, suspended state in the buffer.

23. Close the lid on the microcentrifuge tube and lock the lid.

24. Vortex the tube with a mechanical vortex for about 20 seconds (**Figure 17**).

25. Incubate the tube in a temperature-controlled metal block or water bath that is set at 93°C for three minutes.

26. Vortex the sample tube for about 20 seconds.

27. Incubate the tube at 93°C for three minutes.

28. Set the tube out on the bench and allow cooling to room temperature (e.g., 25-28°C) for about 10 minutes.

Figure 16. Remove frozen, pulverized sample from cryo-vial with a pre-chilled spatula. Place sample on spatula into a locking microcentrifuge tube. Photograph courtesy of Phillip Dustan.

Figure 17. Before 93°C incubation and after the third minute of incubating at 93°C, vortex the sample for about 20 seconds, insuring thorough mixing of the sample with the Denaturing Buffer. Photograph courtesy of Phillip Dustan.

2.1.2 Phase partitioning of sample by centrifugation

1. Place the microcentrifuge tube into a microcentrifuge and centrifuge the tube at about 12,000 g or higher for 10 minutes.
2. Three phases will be evident after centrifugation: the bottom phase is the insoluble phase consisting predominantly of coralline skeleton, extra-cellular matrix, other insoluble tissue material and PVPP (**Figure 18**). The middle phase should be transparent, brownish (coral, conch) or reddish (fish) in color, and free of a whitish film that characterizes the top phase. The top phase is a very viscous matrix composed predominantly of cross-linked polysaccharides and fats.
3. Aspirate 200-300 µL of the middle phase; be careful not to collect any supernatant that may be contaminated with the whitish matrix that is the top phase.
4. Deposit the middle-phase supernatant into a new tube that is labeled with the same identification.

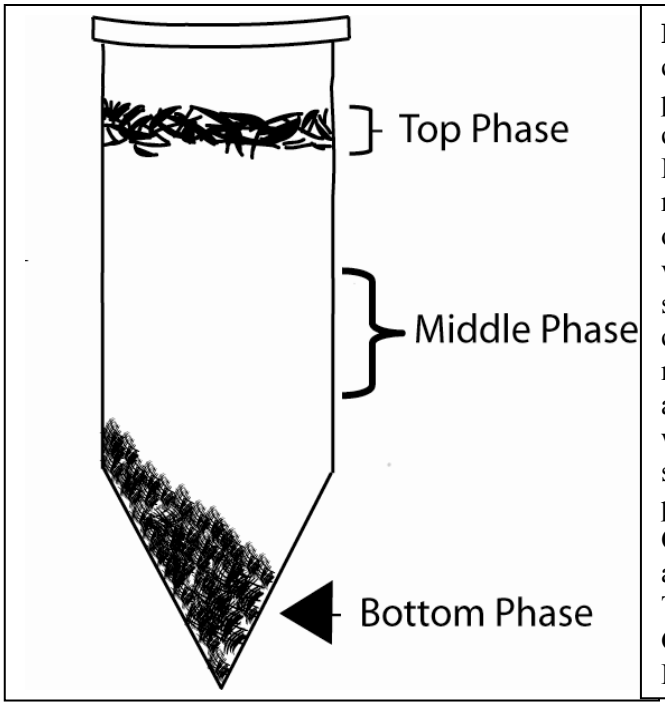


Figure 18. Three phases are formed after centrifugation of the sample. The bottom phase is insoluble debris, primarily calcium carbonate skeleton and insoluble PVPP. The middle phase should be relatively transparent and should be absent of residual mucus. It should be non-viscous. The top phase should be somewhat viscous and sticky, whitish in color. The demarcation between the middle and top phase is not always apparent, and care should be taken that when aspirating the middle phase, there should be no contamination from the top-phase matrix. From Downs, C.A. (2005) Cellular Diagnostics and its application to aquatic and marine toxicology. In: Techniques in Aquatic Toxicology, vol. 2: G. Ostrander (ed). CRC Press, Inc. Boca Raton, Florida. Pp 181-208.

2.1.3 Total soluble protein concentration determination of a sample

Lowry-based, bicinchoninic acid-based, and coomassie blue-based spectrophotometic protein concentration assays cannot be used to determine the protein concentration in the samples because the concentrations for many of the components in the Denaturing Buffer will cause significant artifact for these assays. An alternative assay platform was developed by Dr. Sibdas Ghosh in the late 1980s to overcome interfering substances from plants (e.g., chlorophyll, xanthophylls) that used cuvette-based spectrophotometric protocols. This assay was later modified by Ghosh and Downs in the mid-1990s to account for high concentrations of dithiothreitol and sodium dodecyl sulfate in the Denaturing Buffer which significantly interferes with both copper and silver dyes from binding to proteins.

1. Two solutions should be made: Stain Solution and a Destain Solution. The recipe for both solutions are:

   Stain Solution:
   - 200 mL of distilled water
   - 50 mL of glacial acetic acid
   - 250 mL of methanol
   - 4 g of Coomassie Blue RR 250

   Destain Solution:
   - 800 mL distilled water
   - 200 mL of glacial acetic acid
   - 1000 mL of methanol

   Make each solution in a pyrex bottle with a plastic lid. The staining solution has a shelf life of about 20 days. The destain solution has a shelf life of about four months. Be careful with both solutions and conduct this assay in a well-ventilated area or under a chemical hood. Methanol is a cumulative poison. Inhalation of the vapors of both solutions should be avoided.

2. Place clean lab mat down on in the area on the lab bench where you will be conducting the protein concentration assay.

3. Wearing latex or nitrile gloves, take a piece of Whatman #5 filter paper using forceps and the filter paper on the clean lab mat. Whatman filter paper disks that are 9 cm to 11 cm are the best to use.

4. With a #2 pencil, mark the filter paper indicating the location of the standards, placement of the samples, and the identification of the project and the date, similar to that in **Figure 19**.

5. Using a 1-20 uL pippettor, place 1 uL of sample and standard in an ordered fashion as indicated by the sample locations marked with pencil. Standards and samples should be spotted on the Whatman filter paper in triplicate (**Figure 19**).

The pipette tip should be changed for a new tip between spotting each sample and each standard. You can use the same tip for spotting the triplicate sample spots.

6. Allow the filter paper to air dry for about 20 minutes. You can accelerate the drying process by using a hair dryer to dry the filter paper. Use forceps to hold the filter paper in place while using the hair dryer. Do not use your fingers.

7. Once dried, place the filter paper in an incubation boat that contains enough Stain Solution to completely cover the filter paper.

8. Place the incubation boat on a rocker platform or hand agitate for 10 minutes (**Figure 20**).

9. After the 10 minute incubation, pour the Stain Solution back into its bottle.

10. Wash the filter paper with about 20 mL of Destain Solution. Decant the Destain Solution into the sink or into the proper waste receptacle.

11. Incubate the filter paper in about 30 mL of Destain Solution for about five minutes, and then decant the Destain Solution. Repeat this procedure until the non-spotted filter paper is white (**Figure 21**).

12. Gently wash the filter paper in distilled water, then allow to incubate in water for two minutes on the rocking platform or by hand agitation. This will remove the overwhelming smell of the acetic acid and allow the filter paper to be placed in the laboratory notebook.

13. Once the filter paper is dried, it can be scanned into a digital image by a scanner. Optical densities for each replicate can be determined using a densitometry program such as NIH Image developed at the U.S. National Institutes of Health and available on the Internet at http://rsb.info.nih.gov/nih-image/.

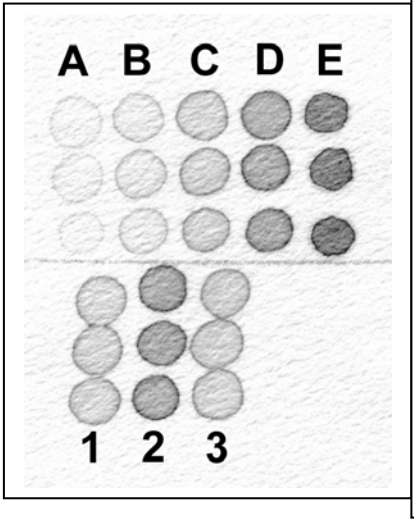


Figure 19. Protein Concentration Assay. Results of protein concentration assay using a modified method of Ghosh et al. (1988). Concentration calibrants are plated on the Whatman No. 5 filter paper as in Columns A - E. Column A = 0.125 µg/µL. Column B = 0.250 µg/µL. Column C = 0.5 µg/µL. Column D = 1.0 µg/µL. Column E = 2.0 µg/µL. Samples done in triplicate indicated in columns 1-3. All calibrants and samples are plated (hence assayed) on the filter paper in triplicate. Assay paper can be scanned by a scanner to create a digital image. Optical densities for each replicate can be determined using a densitometry program such as NIH Image developed at the U.S. National Institutes of Health and available on the Internet at http://rsb.info.nih.gov/nih-image/. From Downs, C.A. (2005) Cellular Diagnostics and its application to aquatic and marine toxicology. In: Techniques in Aquatic Toxicology, vol. 2: G. Ostrander (ed). CRC Press, Inc. Boca Raton, Florida. Pp 181-208.

Figure 20. Incubate the filter paper in an incubation boat. The boat can be anything: e.g., petri dish or weigh boat, and be made from plastic or glass. Stain solution should cover the filter paper either in its entirety or so that each rocking slant covers at least 50% of the filter paper in the Stain Solution.

Figure 21. There should be a distinct contrast between the blue of the sample and standard spots and the rest of the filter paper. The area of the filter paper that has not been spotted should be white. Be careful! It is possible to over destain the filter paper.

Once the protein concentration assay is done, Denatured Buffer-extracted samples can be frozen. The best temperature to preserve the samples is -80°C or colder. The samples can only be thawed once, so if you plan to conduct your ELISAs for more than a one-day time period, you need to aliquot the samples into new tubes so that a single tube can be removed from cold storage only once according to your work schedule.

2.1.4. Enzyme Linked Immuno-sorbent Assay (ELISA)

There are a number of different ELISA methods that can be used. This document does not advocate a specific method, but only methods that have a measure of validation and quality control. Before an ELISA is run on a sample or a set of samples, the antibodies and solution reagents need to be optimized and validated. This should include, at the very least, testing of the samples and the reagents using an SDS-polyacrylamide gel electrophoresis (PAGE) and western-blotting assessment system. A detailed description of SDS-PAGE and western blotting for validation of the ELISA system can be found in Downs, C.A. (2005) Cellular Diagnostics and its application to aquatic and marine

toxicology. In: Techniques in Aquatic Toxicology, vol. 2: G. Ostrander (ed). CRC Press, Inc. Boca Raton, Florida. Pp 181-208. Besides validation of the antibody and the ELISA reagents, SDS-PAGE/western blotting also helps in determining the integrity of the sample. Oftentimes, artifacts can befall a set of samples as a result of insufficient protease inhibition during the homogenization of the sample, freeze/thaw exclusion of SDS from proteins which results in protein aggregation, and adduction of target proteins with secondary compounds resulting in masking of epitopes and/or polymerization of heterogeneous protein species.

One of the least expensive methods to conduct an ELISA is a Dot-Blot/Direct ELISA method. A protocol for this method can be found Downs, C.A. (2005) Cellular Diagnostics and its application to aquatic and marine toxicology. In: Techniques in Aquatic Toxicology, vol. 2: G. Ostrander (ed). CRC Press, Inc. Boca Raton, Florida. Pp 181-208. This method requires a primary and secondary antibody. The secondary antibody can be conjugated to any number of different reporter enzymes that catalyze a colorimetric or chemiluminescent signal. Alternatively, the secondary antibody can also be conjugated with a fluorescent probe that can be used in a fluorescence detection system. The least expensive is a secondary antibody conjugated to either alkaline phosphatase or horseradish peroxidase that uses nitroblue tetrazolium and an electron donor compound. Samples and the standard calibrant curve should be replicated in triplicate (**Figure 22**). A five-point calibration curve should at least be used, especially when examining biomarkers such as heat-shock proteins and cellular damage products. These end-points can often have concentration differences of several fold to an order of magnitude.

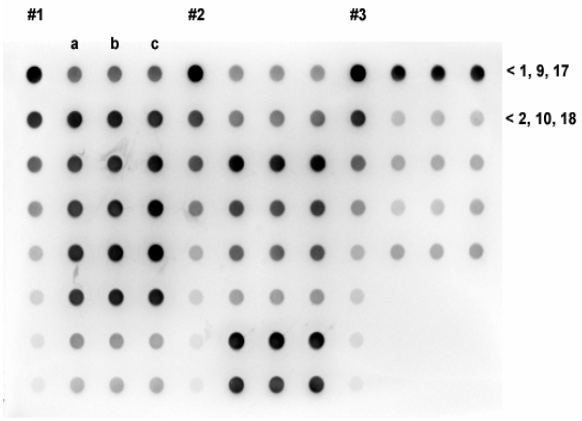


Figure 22. ELISA result using a 96-well dot blotter**.** # = calibrant standard curve. The calibrant with the highest concentration is plated in row 1, the calibrant with the lowest concentration is plated in row 8. Optimally, replicates of the standard curve should be evenly distributed across the dot blotter. In row 1, triplicate assays of sample 1, 9, 17. In row 2, triplicate assays of sample 2, 10, 19. In row 3, etc. In column ***a***, replicate one of sample 1, 2, 3, etc... are plated. In column ***b***, replicate two of samples 1, 2, 3, etc… are plated. In column ***c***, replicate three of samples 1, 2, 3, etc… are plated. Plate represents data for the chloroplast small heat-shock protein in samples of the hard coral, *Montastrea annularis*.

A second type of ELISA method uses a polystyrene, 96-well microtiter plate. This method often requires a microplate washer instrument and a microplate reader instrument. Samples and calibrant standards can be configured the same way as the dot-blot ELISA system (**Figure 23**). A good methodology resource for this ELISA method can be found in Crowther, J.R. (2001) The ELISA Guidebook: Methods in Molecular Biology. Humana Press. Totowa, New Jersey.

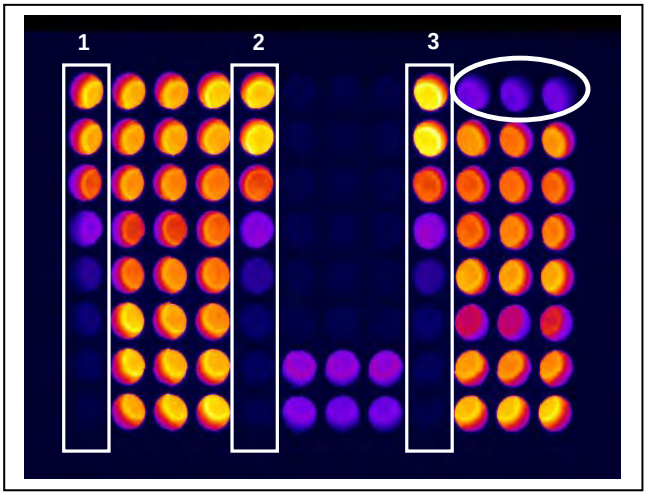


Figure 23. ELISA result using a 96-well microtiter plate**.** 1,2,3 = calibrant standard curve. The calibrant with the highest concentration is plated in row 1, the calibrant with the lowest concentration is plated in row 8. Optimally, replicates of the standard curve should be evenly distributed across the microtiter plate. The three wells that are circled are the triplicate of sample #17. The detection system used here is based on a chemiluminescent reporter system. This is the most sensitive detection system you can use; The lower calibrant-curve detection limits are often in the range of 1 to 400 picomoles for a target.

It should be recognized that ELISA is based on the kinetic characteristics of its components (e.g., binding of sample to solid phase, primary antibody binding to target protein, secondary antibody binding to primary antibody, washes, etc.). Because of the nature of this assay platform, conducting an ELISA should not be conducted like a "cook book" exercise. Each step requires optimization to ensure consistency in assay repetition, confidence in raw data generation, and consistency for inter-laboratory assessment and validation. This optimization can only be done experimentally.

2.1.5 ELISA end-points (biomarkers) for grunt, conch, and coral samples

The biomarkers in this section have been selected because changes in their concentration indicate a significant change in the physiological condition of an organism or a specific homeostatic response of that organism to environmental conditions. It must be cautioned that the life history of a specific organism/population must be considered when making a diagnostic interpretation using any of these biomarkers. For example, sampling during the reproductive season or mating season of an organism may produce a biomarker result that is determined, in part, not only by environmental conditions, but also because of life history conditions. The age of the organism may also influence biomarker results. A wise sampling assessment and monitoring design can overcome these hurdles: for example, collecting samples that are of the same age, or sampling a population outside of its spawning season.

Another important issue that must be addressed is establishing a normal range for a biomarker. A "normal range" can be defined as the concentration or activity of a biomarker that can be found in a population that is in a physiologically healthy condition, or a homeostatic condition that is not responding to a stressor. Determining and defining the "normal range" can be accomplished by incorporating a reference population within the assessment or monitoring design. Criteria for a reference population may be based on aspects of physiological performance and environmental conditions. For example, a potentially good candidate reference population should possess a level of reproductive fitness that can sustain the population. Disease incidence should be relatively low.

Environmental conditions should be consistent with a habitat that has historically sustained populations.

The ELISA biomarkers presented in this document include:

- Ubiquitin
- Multiple Drug/Xenobiotic Resistance Protein
- Cytochrome P450 2-class Proteins
- Invertebrate Small Heat-shock Proteins (for corals and conch)
- Fish Small Heat-shock Protein
- Metallothionein
- Cytochrome P450 6-class Proteins (invertebrates only)

A display in the levels of these biomarkers outside of their established normal range indicates a significant change in the physiological condition or homeostatic response of the organism/population. Any one of these biomarkers examined by itself, or with consideration of the any of the other ELISA-based biomarkers described in this section, is not meant to establish an etiology of pathology. These biomarkers are meant to be used as harbingers of physiological and population change if the organism/population remain in a persistent condition.

Ubiquitin – This end-point can be assessed in all three target species most likely using the same antibody source. This is because of the extreme conservation of this polypeptide and its ubiquitous presence and function in all eukaryotes. Ubiquitin is a 76-residue protein found in most phyla of life and used in a process for marking proteins for rapid degradation (Hershko and Ciechanover, 1998. The ubiquitin system. *Annu Rev Biochem* 67: 425-479.). Ubiquinated proteins are degraded by proteolytic enzymes known as proteosomes (Hershko and Ciechanover, 1998. The ubiquitin system. *Annu Rev Biochem* 67: 425-479.). Proteins, during stress, are targeted for degradation usually because these proteins have undergone an irreversible denaturation (Iwai, K. 1999. Roles of the ubiquitin system in stress response. *Tanpakushitsu Kakusan Kuso* 44: 759-765). Increases in ubiquitin levels are an indication of increased levels of protein degradation, and hence, increased protein turnover (Goff et al., 1988. Protein breakdown and the heat-shock response. In *Ubiquitin* (ed. M. Rechsteiner). New York, NY: Plenum Press: 207-238.). Consequently, to compensate for decreased functional protein levels due to stress, the cell will increase production of these same proteins (Iwai, 1999). Thus, measurement of levels of ubiquitin is an index of the structural integrity of the protein component of the superstructure of the cell (Mimnaugh et al., 1999. The measurement of ubiquitin and ubiquinated proteins. *Electrophoresis* 20: 418-428). Increased ubiquitin levels above a normalized range indicates: (1) a protein denaturing stress is occurring; (2) increased expenditure of energy is required to compensate for this stressed-induced protein turnover; and (3) in comparison to baseline data of this parameter for a particular species, may act as an indicator of individual fitness (Hawkins, 1991. Protein turnover: a functional appraisal. *Funct Ecol* 5: 222-233).

For this assay, it is important to use an antibody that can recognize the ubiquitin monomer and polyubiquinated chains. Without this type of recognition, detecting changes in ubiquitin equilibrium may not be possible. Antibody to ubiquitin and purified ubiquitin can be purchased from over half-dozen commercial sources (e.g., Sigma-Aldrich).

Multiple Drug/Xenobiotic Resistance Protein (ABC family of proteins) – This end-point will be measured in all three target species most likely using the same antibody source. This is because of the extreme conservation of this protein's primary structure, function and its ubiquitous presence and function in all eukaryotes. P-glycoprotein plays a role in removing xenobiotics and toxins from the cell by acting to transfer intracellular xenobitics and toxins across the cytoplasmic membrane. Sustained exposure to certain xenobiotics causes an increase in the cellular level of P-glycoproteins. Animals deficient in P-glycoproteins are viable and do not exhibit any obvious abnormalities. The pharmokinetic activity and relative toxicity of several compounds are, however, altered in these P-glycoprotein-deficient animals. For example, P-glycoprotein in mammals plays a significant role in preventing certain xenobiotics from crossing the blood-brain barrier: a decrease in P-glycoproteins would result in an increase in the amount of xenobiotics reaching the brain. P-glycoproteins are members of a superfamily of proteins called the adenosine triphosphate binding cassette that act as channels and transporters of solutes across membranes. Induction of certain P-glycoproteins indicates a response to xenobiotic exposure. See Ueda et al., (1999). Comparative aspects of the function and mechanism of SUR1 and MDR1 proteins. Biochem. Biophys. Acta 1461: 305-313; Borst et al., (1999). The multidrug resistance protein family. Biochem. Biophys. Acta 1461: 347-357; Bard (2000) Multixenobiotic resistance as a cellular defense mechanism in aquatic organisms: a review. Aqua. Toxicol. 48: 357-389. A simplified interpretation for this biomarker is that if levels of this protein increase, it may mean that the organism is responding to an exposure of a xenobiotic or a toxin. As always, there are a number of caveats: some xenobiotics do not elicit an increase in P-glycoprotein levels, such as mercury.

Cytochrome P450 2 homologue (CYP P450-2) – An antibody that cross-reacts with the mammalian homologue of cytochrome P450 2-class, but not CYP 1-class or CYP 3-class can be used to measure the accumulation of an antigenically similar CYPs in the three target species. Cytochrome P450 2-class enzymes are known to specifically oxidize ethanol to acetaldehyde via a monooxygenase mechanism, as well as other xenobiotics such as imidazole-based derivatives (Lieber, 1997. Cytochrome P-4502E1: its physiological and pathological role. *Physiol Rev* 77: 517-544). Cytochrome P450 2-class has both physiologically relevant oxidative and reductive reactions and is known to associate and catalyze as many as 60 xenobiotic-based substrates (Lieber, 1997). For example, it causes the demethylation of N, N-dimethylnitrosamine and the hydroxylation of p-nitrophenol and chlorzoxazone (Koop, 1992. Oxidative and reductive

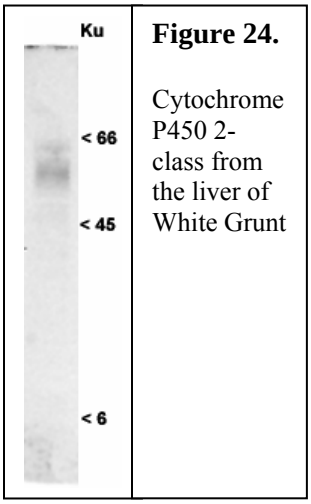


Figure 24. Cytochrome P450 2-class from the liver of White Grunt

metabolism by cytochrome P450 2E1. *FASEB J* 6: 724-730). Reduction reactions include reduction of a number of different lipid types. This enzyme homologue is conserved in all three target species, though the function may be less conserved. This enzyme is known to be induced in all three species by a variety of crop protection products. This is not to say that these enzyme homologues function by detoxifying these crop protection products, though in some species they may play a central role in Phase I of Xenobiotic Transformation (e.g., Hanioka, N., Jinno, H., Tanaka-Kagawa, T., Nishimura, T., Ando, M., and Ogawa, K. 1998. In vitro biotransformation of atrazine by rat liver microsomal cytochrome P450 enzymes. *Chem Biol Interact* 116:181–198).

Changes in the expression level from the nominal range for this biomarker indicate a changed physiological response, especially a changed endocrine and metabolic condition.

Antibody to cytochrome P450 2-class is readily available from a number of commercial sources. Alternatively, this enzyme can oftentimes be assessed by enzymatic activity. Several commercial sources provide protocols and kinetic assay kits to analyze enzymatic activity. In-house production for an antibody against CYP P450 2-class homologues is also straightforward since this enzyme has three evolutionarily conserved domains that define this class of enzyme.

Invertebrate sHsp (total small heat-shock protein isoforms) – This biomarker would only be used for the invertebrate target species, not for the grunt. αB-crystallin, Hsp22, Hsp23, Hsp26, and Hsp28 share domains of common homology to one another, but have different cellular functions (de Jong et al., 1993). In bivalves, as many as 5-6 major sHsp isoforms exist. Small Hsps from all phyla share a common motif near the carboxyl-terminal end of the protein, known as the "heat-shock domain" or α-crystallin domain (de Jong et al., 1993). Other areas of these proteins are not homologous and are specific to the sub-family of sHsps. In most cases, the small heat-shock proteins are not present during optimal growing conditions and are only elicited by stress (de Jong et al., 1993).αB-crystallin is a small heat-shock protein found only in the cytosol of animals, where it protects cytoskeletal elements during stress (Derham and Harding, 1999). Evidence indicates that Hsp22 localizes to neural-type cells and follicular cells in *Drosophila melanogaster*. Furthermore, this protein localizes to the mitochondria in arthropods and has been suggested to have a functional role similar to that of plant and mammalian mitochondrial sHsps (Downs & Heckathorn, 1998; Downs et al., 1999a). Thus, the presence and concentration of different small heat-shock proteins reflects the physiological status of several metabolic and structural pathways in the cell. In this study, it can be used as an indicator of a severe stress response. One caveat for this biomarker is that it has been shown to be expressed during spawning and at key

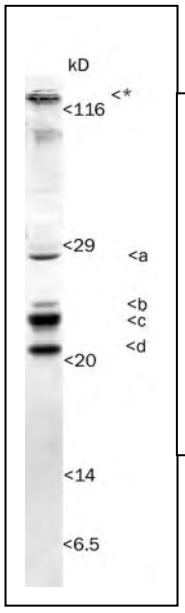


Figure 25. Invertebrate small heat-shock proteins

30 μg of total soluble protein from ribbed mussel
* = multimeric structure
a = Hsp28
b = Hsp25W or Hsp26
c = Hsp23
d = Hsp22

stages of early development – extremely stressful events in-and-of themselves. Care should be taken not to sample target species during these developmental stages.

Fish small heat shock protein – This biomarker could only be used for a fish species. Like the invertebrate small heat-shock proteins, this protein is usually induced only as a result of severe cellular stress. Less is known about the function of this protein as compared to other heat-shock proteins. Antibody for this protein will need to be manufactured "in-house" by the laboratory that is running this assay. The sequence to this gene is known from a number of species of fish and the epitope can be made against an evolutionarily conserved sequence in the carboxyl-terminal end of the protein known as the "crystalline" domain.

This protein is usually absent during normal physiological conditions and is usually induced under extremely stressed conditions. Detection or an increased accumulation of this protein may signify that the population/individual is under metabolic duress.

White CN, Hightower LE, Schultz RJ. 1994. Variation in heat-shock proteins among species of desert fishes (Poeciliidae, Poeciliopsis). Mol Biol Evol. 11(1):106-19.

Metallothionein – Metallothionein is often used as a biomarker of heavy metal exposure, though it is argued that this may be a misuse of this biomarker (*e.g.*, Aspholm and Hylland, 1998; Soazig and Mark, 2003; Galloway et al., 2004). In the context of cellular diagnosis, changes in metallothionein levels can be interpreted as an indicator of broad changes in mitochondrial functional equilibrium. This position is based on recent work demonstrating that metallothionein type 1 localizes to the inter-membrane space of mitochondria and can regulate oxidative phosphorylation (Simpkins et al., 1994; Ye et al., 2001). Studies showing the interaction of zinc, metallothionein, and mitochondrial function further support the role of metallothionein as a regulator of cellular energy production and redox state (Maret, 2000; Coyle et al., 2003; Maret, 2003). This interpretation is further justified by toxicology studies with cadmium and metallothionein that demonstrate the interaction between cadmium and zinc metallothionein and mitochondrial dysfunction (*e.g.*, Simpkins et al., 1998a; Klassen et al., 1999; Tang and Shaikh, 2001). Metallothionein can be induced by a number of different stressors, for example chronic oxidative stress; metallothionein gene expression in fish can be induced by exposure to chlorinated aromatic hydrocarbons (Gerpe et al., 1998).

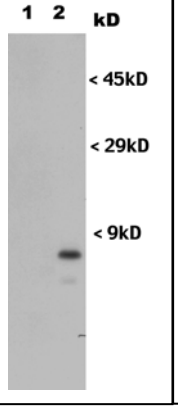


Figure 26. Metallothionein
Lane 1: 30 ug of total soluble protein from control *Mytilus edulitus.*
Lane 2: 30 ug of total soluble proteim from *Mytilus edulitus* exposed to 50 uM CdCl2 for eight hours. Two-three bands appear, depending on the type of metal exposure. Detects novel copper-inducible isoform.

Metallothionein gene sequences are known from a number of invertebrate species (including gastropods and cnidarians) and from more than 15 species of fish. Gene sequence can be aligned for the target phylum and be used to create an antigen that can be immunized into a host for antibody production (Figure 26).

A simplified interpretation for this biomarker is that levels of this protein outside the nominal range for this organism indicate a homeostatic response to maintain mitochondrial oxidative phosphorylation equilibrium. This marker should not be used as a biomarker of exposure to heavy metals.

Cytochrome P450 3 homologue (CYP P450-3) – An antibody that cross-reacts with the homologue of cytochrome P450 3, but not CYP 1A, CYP 2 or CYP 6 classes can be used to measure the accumulation of an antigenically similar CYP in all three target species. Cytochrome P450 3 homologues are known to play a role in steroidal biogenesis and porphryn metabolism. Induction of CYP P450-3 is oftentimes associated with cellular xenobiotic response. This may be true, but alterations in the accumulation and activity of this enzyme class can also result from changes in cellular demand for porphyrins and for steroid metabolism. The value of CYP P450-3 may not always be associated with it being a "biomarker of exposure", but as a biomarker of effect.

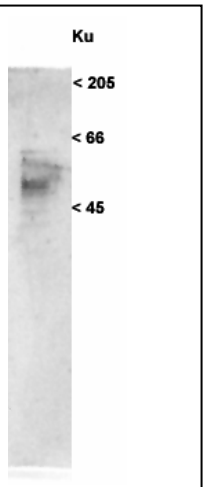


Figure 27. CYP P450-3 from liver of White Grunt

An antibody against CYP P450-3 homologues can be obtained from a number of commercial sources, but should be validated for each of the target species. Several polyclonal antibodies from at least three different commercial sources were tested by the author and found to work in all three of the target species.

A simplified interpretation for this biomarker is that if levels are beyond the nominal range, this indicates a change in the endocrine and metabolic condition of the organism. Oftentimes, an increase in the level of this protein is associated with an organic-based xenobiotic exposure.

Cytochrome P450 6 homologue (CYP P450-6) – This enzyme is specific to invertebrates and is recognized as a major contributor to insecticide resistance (Scott JG, Wen Z. 2001. Cytochrome P450 of insects: the tip of the iceberg. Pest Mang. Sci. 57:958-967). This class of CYP P450s is known to oxidize and be up-regulated by pesticides such as aldrin, dieldrin, diazinon, chlorpyrifos, deltamethrin, and a wide range of pyrethrin-like compounds. This enzyme has been used as both a biomarker of exposure and as a biomarker of effect. Assaying for this biomarker can only be done with coral and conch, not with White Grunt since vertebrates are not known to have this enzyme class.

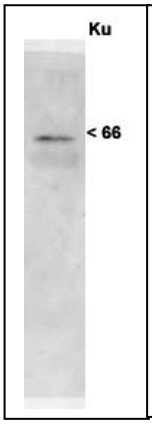


Figure 28. CYP P450 6 class.

From *Montastrea Annularis*

Courtesy: U.S. NOAA

A simplified interpretation for this marker is that if levels of this protein are higher than the nominal range, this organism is potentially responding to a specific class of pesticides. Decrease of this protein below the nominal range may indicate a compromised metabolic condition.

2.2. Non-ELISA-based Biomarker Assays

The following biomarkers are non-ELISA-based assays and will require additional equipment, different sample homogenization and preparation procedures, and different methods for detection. Like the ELISA-based biomarkers, these biomarkers display a dynamic quantitative range, and that the levels of these biomarkers outside of their established normal range indicate a significant change in the physiological condition or homeostatic response of the organism/population. Any one of these biomarkers examined by itself, or with consideration of the any of the other ELISA-based and non-ELISA-based biomarkers described in this section, is not meant to establish an etiology of pathology. These biomarkers are meant to be used as harbingers of physiological and population change if the organisms remain in a persistent condition.

2.2.1. Porphyria Species Assay

Materials

- Fluorescent 96-well microplate reader or a spectrofluorospectrophotometer
- Multichannel pipettor, 20-200 microliters
- Single channel pipettor set
- 3 N hydrochloric acid
- Black-walled 96-well microtiter plates
- Uroporhyrin standard (Porphyrin Products, Inc., Logan, Utah, U.S.A.)
- Ethyl acetate (99% purity)
- Sodium dodecyl sulfate
- Trizma base
- Sodium dodecyl sulfate

Porphyrins are prosthetic structures usually associated with proteins that contain a metal for functionality (**Figure 29**). A porphryin with an iron in it is heme. A porphyrin with a phytol chain and a manganese atom is chlorophyll. The porphyrin synthesis pathway begins in the cytosol and concludes within the mitochondria (**Figure 30**). At least six different enzymes are directly involved in the porphyrin synthesis pathway. Each one of these enzyme expresses differential sensitivity to the inhibitory power of environmental contaminants, such as heavy-metals, organochlorine compounds, organophosphorous compounds, and polycyclic aromatic hydrocarbons. A porphyrin synthesis enzyme inhibited by a toxicant results in the accumulation of precursor porphryn species. Accumulation of these precursors can lead to pathological effects - porphyria. Measurement of porphyria species is a classical clinical diagnostic test with straightforward diagnostic interpretation. Measurement of porphyrin-precursor (porphyria) species can be conducted in almost any coral reef species with little modification to the method. This method measures total porphyrin precursors and is unable to distinguish which porphyrin species is accumulating.

The method can be validly conducted using two protocols. The first method capitalized on the sample preparation conducted for ELISA. The second method can be employed on a sample independent of the ELISA-sample-preparation protocol. Both

methods should be conducted under dimmed light or a red light. Direct sunlight needs to be excluded from the laboratory.

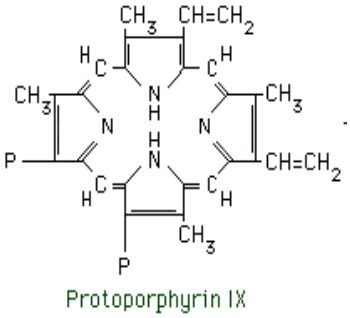


Figure 29. A precursor porphyrin species

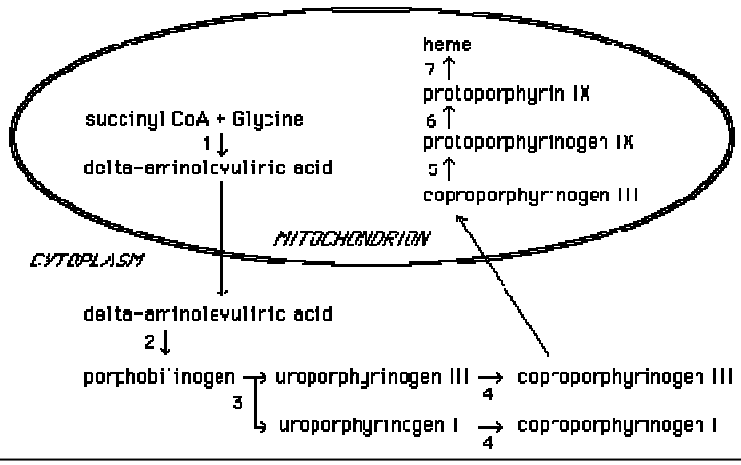


Figure 30. Schematic of the porphyrin/heme synthesis pathway. Courtesy of **medlib.med.utah.edu/ NetBiochem/hi3.htm**

Concentration of Total Porphyria Species using ELISA sample preparation

1. One-hundred and fifty micrograms of total soluble protein from sample supernatants prepared in Section 3.1.1. are diluted in a solution containing 1% SDS, Tris-HCl (pH 7.8), 5 mM EDTA into a volume of 310 microliters.

2. Dispense one-hundred microliter aliquots of each sample in triplicate to a clear-bottom with black walls 96-well microtiter plate.

3. Dispense 50 uL of 3 N hydrochloric acid into each sample well.

4. Place plate in a container that exclude light and allow incubation for fifteen minutes.

5. Mix the contents in each sample well by gently rocking the plate.

6. Uroporphyrin standards can be obtained from Porphyrin Products (Logan, Utah, U.S.A.), and diluted using an 8-point calibrant standard curve from 0 pmole of protoporphyrin to 1000 pmole of uroporphyrin. Dispense standard on the micro-titer plate in triplicate using a format similar to **Figure 23**.

7. Detect fluorescence signal using a fluorescent/luminescent microplate reader with the excitation filter set for 405 nm and the emission filter set for 610 nm. Band length for both excitation and emission filter should be less than ±20 nm.

Concentration of Total Porphyria Species using ethyl acetate extraction

1. Take about 40 microliters of frozen sample powder from the sample cryovial using a pre-chilled spatula and place into a locking microcentrifuge tube.

2. Add 700 microliters of 99% pure ethyl acetate.

3. Vortex sample for about two minutes until semi-homogenized.

4. Add 700 microliters of 3 N hydrochloric acid to the sample tube.

5. Vortex sample for about two minutes.

6. Incubate in dark for five minutes

7. Vortex sample for one minute.

8. Centrifuge sample at 12,000 *g* or higher for five minutes.

9. Aspirate the acidified phase from the tube and place in a new tube. This volume should be about 400 microliters. You will need to determine experimentally for your protocol which is the acidified phase. The acidified phase should be absent of any mucilage. Do not confuse the acidified phase with the ethyl acetate phase.

8. From the new tube, dispense one-hundred microliter aliquots of each sample in triplicate to a clear-bottom with black walls 96-well microtiter plate.

9. Uroporphyrin standards can be obtained from Porphyrin Products (Logan, Utah, U.S.A.), and diluted using an 8-point calibrant standard curve from 0 pmole of protoporphyrin to 1000 pmole of uroporphyrin. Dispense standard on the micro-titer plate in triplicate using a format similar to **Figure 23**.

10. Detect fluorescence signal using a fluorescent/luminescent microplate reader with the excitation filter set for 405 nm and the emission filter set for 610 nm. Band length for both excitation and emission filter should be less than ±20 nm.

2.2.2 Ethoxyresorufin-*O*-deethylase (EROD) activity assay

Materials

- Trizma Base
- EDTA
- Hydrochloric acid
- Ethoxyresorufin
- nicotinamide adenine dinucleotide phosphate, reduced form (NADPH)
- acetonitrile

- Fluorescent microplate reader or spectrofluorophotometer

This biomarker can represent a number of different assessment end-points. In the literature, this biomarker is predominantly used as an end-point that reflects a receptor-mediated induction of cytochrome P450 mono-oxygenase activity. This putative receptor is usually identified as the aryl hydrocarbon receptor. This biomarker is also used as a "response indicator" to contaminant uptake; the contaminant most likely a hydrocarbon-based compound or mixture of compounds. Another value of the EROD assay is associated with its decline-in-activity behavior. A number of environmental contaminants and conditions can either inhibit enzyme activity directly or depress gene expression, potentially reducing protein expression of this enzyme. One caveat with this assay is that induction of EROD activity should not be confused with it being a reflection of toxicity. Activity may increase without any pathological symptoms. The catalysis of ethoxyresorufin by a cytochrome P450 monooxygenase action results in the production of resorufin – a compound that can be detected through spectrofluorimetric means (**Figure 31**).

This biomarker should only be conducted in fish (White grunt). Though the assay has been tested in some invertebrate species, the EROD assay would need to undergo extensive validation in coral and conch.

To derive the greatest sensitivity for the EROD assay, most protocols recommend purification of the microsomal fraction via differential sub-ultracentrifugation or ultra-centrifugation methods. Unfortunately, the microsomal integrity has been compromised as a result of the pulverization of the fish liver sample using the liquid nitrogen grinding technique. EROD activity is often normalized against total soluble protein of the microsomal fraction. Since this cannot be accomplished as a result of the initial sample preparation, EROD activity will be normalized against total soluble protein of liver tissue.

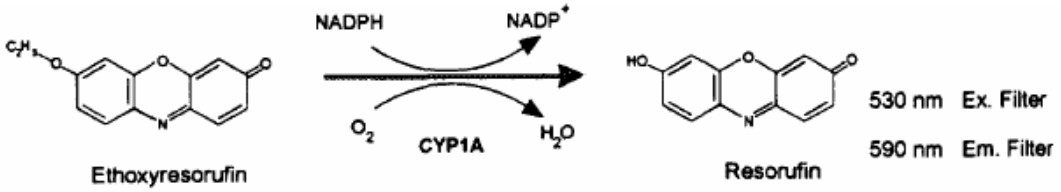


Figure 31. Mechanism of catalysis of ethoxyresorufin to resorufin by Ethoxyresorufin-*O*-deethylase activity.

Ethoxyresorufin-*O*-deethylase (EROD) activity assay protocol

Before conducting this protocol on the target species, the lab must conduct an optimization step before conducting this assay on field samples. Since the EROD assay is an enzymatic assay based on enzymatic kinetics, the Michaelis constant (K_m) and maximum velocity (V_{max}) must be determined for each species, since one cannot assume that the K_m of EROD is the same for every species. This can be determined by keeping the total soluble protein of the sample constant while varying the substrate (ethoxyresorufin and NADPH) concentration. Final concentration of both substrates

should be at least twice the V_{max} concentration to account for varying concentrations of the field sample starting material. Kinetic behavior determination and kinetic modeling for EROD can be determined following principles set forth in Segal, I.H. 1975. Enzyme Kinetics: Behavior and Analysis of Rapid Equilibrium and Steady-State Enzyme Systems. John Wiley & Sons, Inc: New York, New York.

1. Add about 30 microliters of pulverized fish liver sample into a microcentrifuge tube.

2. Add 500 microliters of EROD buffer with is a solution of 50 mM Trizma base and 20 mM EDTA that has been titrated to a pH of 7.8 with 1 M hydrochloric acid.

3. Vortex for 1 minute.

4. Add pre-determined volume of a fixed concentration of ethoxyresorufin solution to the sample.

5. Vortex for 20 seconds.

6. Add pre-determined volume of a fixed concentration of NADPH solution to the sample.

7. Vortex for 20 seconds.

8. Incubate for sample to the experimentally determined time that equals the catalysis of 25% of the available substrates.

9. Stop the reaction with 200 microliters of acetonitrile.

10. Centrifuge sample at 6,000 g for five minutes.

11. Aspirate one-hundred microliter aliquots of supernatant from each sample in triplicate to a clear-bottom with black walls 96-well microtiter plate.

12. Detect fluorescence signal using a fluorescent/luminescent microplate reader with the excitation filter set for 530 nm and the emission filter set for 590 nm. Band length for both excitation and emission filter should be less than ±10 nm.

2.2.3. DNA Abasic quantitative lesion assay

Materials:

- Multi-channel pipettor 20-200 microliter volume
- Single-channel piepptors, 20-200 microliter & 100-1000 microliter
- Double distilled water
- N’-aminooxymethylcarbonylhydrazino-D-biotin

- Streptavidin conjugated to horseradish peroxidase
- Luminol/hydrogen peroxide-based chemiluminescent solution or,
- Horseradish peroxidase nitroblue tetrazolium dye
- DNA AP quantitative standards
- 96-well microplates
- Spectrophotometric or luminescent/fluorescent 96-well microplate photometers

This system can also be purchased as a commercial kit for colormetric-based detection system from:

Dojindo Molecular Technologies, Inc.
211 Perry Parkway, Suite 5
Gaithersburg, MD 20877
Phone: 301-987-2667 Fax: 301-987-2687
E-mail: info@dojindo.com
Web site: www.dojindo.com

Dojindo Laboratories
Kumamoto Techno Research Park
2025-5 Tabaru, Mashiki-machi, Kamimashiki-gun
Kumamoto 861-2202, JAPAN
Phone: +81-96-286-1515 Fax: +81-96-286-1525
E-mail: info@dojindo.co.jp
Web site: www.dojindo.co.jp

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Oxidative damage to DNA is a result of the interaction of DNA with reactive oxygen species (ROS), in particular, the hydroxy radical which is converted from superoxide and hydrogen peroxide by the Fenton reaction. Hydroxy radicals produce a multiplicity of modifications in DNA. Oxidative attack by hydroxyl radical on the deoxyribose moiety will lead to the release of free bases from DNA, generating strand breaks with various sugar modifications and simple abasic sites (AP sites). In fact, AP sites are one of the major types of damage generated by ROS. It has been estimated that endogeneous ROS can result in about 2x105 base lesions per cell per day. Aldehyde Reactive Probe (ARP) reagent (N'-aminooxymethylcarbonylhydrazino-D-biotin, Fig. 33) reacts specifically with an aldehyde group which is the open ring form of the AP sites. This reaction makes it possible to detect DNA modifications that result in the formation of an aldehyde group. After treating DNA containing AP sites with ARP reagent, AP sites are tagged with biotin residues. By using an excess amount of ARP, all AP sites can be converted to biotintagged AP sites. Therefore, AP sites can be quantified using avidin-biotin assay followed by a colorimetric detection of peroxidase or alkaline phosphatase conjugated to the avidin (Fig. 34). **DNA Damage Quantification Kit** contains all the necessary solutions, enabling the determination of 1 to 40 AP sites per 1x105 bp.

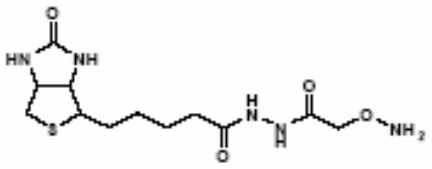


Figure 32. Aldehyde Reactive Probe

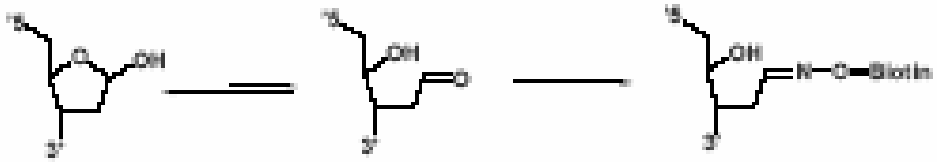


Figure 33. Reaction of ARP with AP site.

Purification and quantitation of genomic DNA

Several different methods and products are available for the isolation of genomic DNA from samples; such as the membrane binding method, the guanidine/detergent lysis method, and the polyelectrolyte precipitation method, to name just a few. Among these methods, the guanidine/detergent lysis method is simple, and it gives highly purified genomic DNA for the ARP-based abasic sites detection. During the purification process, avoid heating of the DNA solution.

Contamination of DNA by protein and other UV absorbing compounds (e.g., polyphenols) should be determined using the 260 nm absorbance/280 nm absorbance spectrophotometric assay. This ratio should be higher than 1.7.

The Absorbance 260nm method for determining DNA concentration is inaccurate and, thus, inappropriate to be used with the DNA AP site assay. A fluorescent-based method for determining double-stranded DNA concentration is much more accurate and precise. Double-stranded DNA quantification assay kits can be obtained from a number of commercial sources.

ARP reaction with sample genomic DNA

This method is based on the Dojindo AP assay kit system that uses a colormetric-based detection platform. If you use a chemiluminescent-based detection platform, the amount of DNA need per sample is three µg/mL for triplication (step 1 of section 3.3.2).

1) Mix 10 µl of purified genomic DNA solution (100µg/mL) and 10 µl of ARP Solution in a 0.5 ml tube, and incubate at 37°C for 1 hour.

2) Wash the inside of the Filtration Tube cup with 100 µl of TE twice.

3) Add 380 µl of TE to the reaction solution, and transfer the solution to the Filtration Tube.

4) Centrifuge the Filtration Tube at 2500 g for 15 min, and discard the filtrate solution.

5) Add 400 µl of TE to the Filtration Tube and resuspend the DNA on the filter with a pipette.

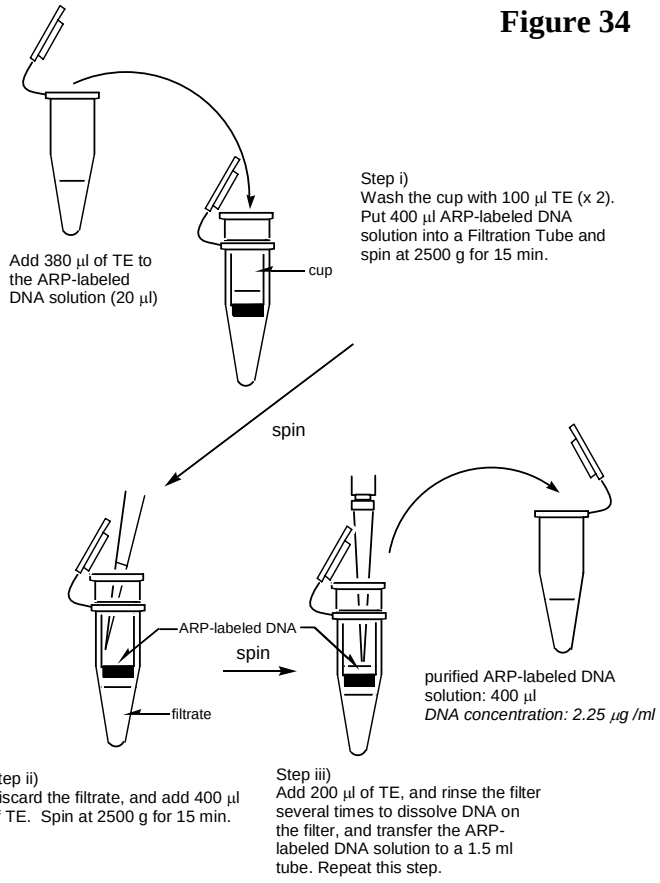
6) Centrifuge the Filtration Tube at 2500 g for 15 min.

7) Add 200 µl of TE to the Filtration Tube to resuspend the DNA on the filter with a pipette.

8) Transfer the DNA solution to the 1.5 ml tube, and add 200 µl of TE again to the Filtration Tube to transfer the ARP-labeled DNA on the filter completely to the 1.5 ml tube.

9) Store the ARP-labeled genomic DNA solution at 0°C to 5°C.

Figure 34



Day 1:

1) Dilute 90 µl of the ARP-labeled genomic DNA with 310 µl of TE.
2) Add 60 µl of Standard ARP-DNA Solution per well. Use three wells per 1 standard solution (use the same format as in **Figure 23**).

3) Add 60 µl of the diluted ARP-labeled genomic DNA solution per well. Use at least three wells per 1sample.

4) Add 100 µl of the DNA Binding Solution to each well, then allow the plate to remain at roomtemperature overnight.

5) Discard the DNA Binding Solution in the wells, and wash the well with 250 µl Washing Buffer 5 times.

6) Add 150 µl of diluted HRP-avidin solution to each well, and incubate the plate at 37°C for 1 hour.

7) Discard the solution in the well, and wash the well with 250 µl Washing Buffer 5 times. After discarding the solution, invert the plate and tap it on a paper towel several times to remove the solution completely.

8) Add 100 µl of Substrate Solution to each well, and incubate at 37°C for 1 hour.

9) Measure the O.D. at 650 nm within 1 hour after the incubation is finished, and prepare a calibration curve using the data obtained with standard ARP-DNA solutions.

10) Determine the number of abasic sites in the genomic DNA using the calibration curve.

2.2.4 Acetylcholinesterase activity assay

This assay can only be used on fish and conch. It will not work in corals. This protocol is a slight modification of the methods:

- Ellman, G. L., Courtney, K. D., Anders V., Jr., and Featherstone, R. M. (1961). A new and rapid coloremetric determination of acetylcholinesterase activity. Biochem. Pharmacol. 7, 88–95.
- Hamm, J. T., Wilson, B. W., and Hinton, D. E. (1998). Organophosphate induced acetylcholinesterase inhibition and embryonic retinal cell necrosis in vivo in the teleost (Oryzias latipes). Neurotoxicology 19, 853–869.

It should be noted that the Ellman method is very susceptible to artifact as a result of numerous factors. There are better, more accurate chemiluminescent-based and fluorescent-based assays that are commercially available.

Materials

- Dounce microcentrifuge tube homogenizer, 2 mL (Teflon pestle)
- Acetylthiocholine iodide
- 5,5'-dithiobis-2-dinitrobenzoic acid (DTNB)
- Tetra(monoisopropyl)pyrophosphor-tetramide (iso-OMPA)
- Trizma base
- Sodium chloride
- Dithiothreitol
- Disodium ethylenediaminetetraacetate (EDTA)

Fish sample preparation

1. Make up a Homogenization solution consisting of 50 mM Trizma base, 13 mM sodium chloride, 10 mM EDTA and 1 mM dithiothreitol. The solution should be titrated with 2 N hydrochloric acid for a final pH of 8.0.

2. Immediately prior to adding the pulverized fish sample, add 20 microliters of solution containing 0.4 mM Bestatin, 2 mM phenylmethylsulfonyl fluoride, and 1 µg/100 µL pepstatin A.

3. With a pre-chilled spatula, place about 100 microliters of frozen pulverized fish liver (from Section 2.2.2) into a microcentrifuge tube.

4. Add 1,200 microliters of homogenization buffer to the microcentrifuge tube.

5. Homogenize the sample using the Teflon homogenizer. Make sure that at the end of the homogenization, each sample has the same consistency. Close the lid on the microcentrifuge tube.

6. Centrifuge the microcentrifuge tube at 7,000 g for five minutes.

7. Aspirate 400 microliters of supernatant with a pipettor and place supernatant in a new tube.

8. Conduct protein concentration of soluble protein on each sample using the modified Ghosh method described in section 3.1.3.

9. Sample should be flash frozen, and can be stored until you are ready to commence the acetylcholinesterase activity assay.

Conch sample preparation

1. Make up a Homogenization solution consisting of 50 mM Trizma base, 10 mM EDTA, 13 mM sodium chloride, and 1 mM dithiothreitol. The solution should be titrated with 2 N hydrochloric acid for a final pH of 8.0.

2. Immediately prior to adding the pulverized conch sample, add 20 microliters of solution containing 0.4 mM Bestatin, 2 mM phenylmethylsulfonyl fluoride, and 1 μg/100 μL pepstatin A.

3. With a pre-chilled spatula, place about 100 microliters of frozen pulverized conch (from Section 2.2.2) into a microcentrifuge tube.

4. Add 1,200 microliters of homogenization buffer to the microcentrifuge tube.

5. Homogenize the sample using the Teflon homogenizer. Make sure that at the end of the homogenization, each sample has the same consistency. Close the lid on the microcentrifuge tube.

6. Centrifuge the microcentrifuge tube at 7,000 g for five minutes.

7. Aspirate 400 microliters of supernatant with a pipettor and place supernatant in a new tube.

8. Conduct protein concentration of soluble protein on each sample using the modified Ghosh method described in section 3.1.3.

9. Sample should be flash frozen, and can be stored until you are ready to commence the acetylcholinesterase activity assay.

Acetylcholinesterase activity assay

1. Dilute samples to a concentration of 1.0 microgram/microliter with Homogenization solution.

2. To each well in the 96-well microplate, add 10 microliters of 0.8 mM iso-OMPA. This compound inhibits non-specific cholinesterases.

3. Add 100 microliters of sample supernatant to a well in the 96-well microplate. Each sample will be triplicated, so you will need to add 100 microliters of sample to three well.

4. Incubate the microplate at 25°C for 15 minutes.

5. Add 100 microliters of a 300 μM of DTNB to each well with sample. Incubate the microplate for five minutes.

6. Add 50 microliters of 90 mM acetylthiocholine iodide

7. Measure activity for five minutes in a microplate spectrophotometer at 415 nm.

8. Divide final O.D. by five to calculate concentration on a per minute basis.

Chapter 3
Contaminant Chemistry Protocol

Contaminant chemistry analysis for both tissue and sediment is assumed to be conducted using gas chromatography (GC) with an electron-capture detector. Extraction procedures for both tissue and sediment can be done using standardized liquid-solid extraction methods, such as the Soxhlet Extraction method (EPA Method 3540) or an Accelerated Solvent Extraction (ASE) method (EPA Method 3545). Other extraction methods can also be used, such as Microwave Accelerated Extraction Method (EPA Method 3546) and Super-Critical Fluid Extraction Method. The Soxhlet and ASE methods seem to predominate in labs within the Meso-American Reef system and it is suggested that participating laboratories use the Soxhlet or ASE methods.

Samples will be normalized against wet weight and against lipid weight so that the data can be compared to the data in other studies.

3.1. Normalization

3.1.1. Gravimetric determination of lipid content of tissue sample

As noted by the below quote from the EPA document (Guidance for Assessing Chemical Contaminant Data for Use In Fish Advisories. Volume 1: Fish Sampling and Analysis - Third Edition), standardization of an extraction solvent is paramount. Based on current accepted methods in the literature, the broad array of difference extraction methods, and the availability of obtaining pesticide-grade solvents in the Meso-American Region, North America, and South America, it is recommend that all laboratories that participate in this study use dichloromethane mix as the initial extraction solvent (EPA Method 8290 and 1613).

It is recommended that a gravimetic method be used for lipid analysis. This method is easy to perform and is commonly used by numerous laboratories, employing various solvent systems such as chloroform/methanol (Bligh and Dyer,1959), petroleum ether (California Department of Fish and Game, 1990; U.S. FDA, 1990), and dichloromethane (NOAA, 1993a; Schmidt et al., 1985). The results of lipid analyses may vary significantly (i.e., by factors of 2 or 3), however, depending on the solvent system used for lipid extraction (Randall et al., 1991; D. Swackhamer, University of Minesota, personal communication, 1993; D. Murphy, Maryland Department of the Environment, Water Quality Toxics Division, personal communication, 1993). Therefore, to ensure consistency of reported results among fish contaminant monitoring programs, it is recommended that dichloromethane be used as the extraction solvent in all lipid analyses.

In addition to the effect of solvent systems on lipid analysis, other factors can also increase the inter- and intralaboratory variation of results if not adequately controlled (Randall et al., 1991). For example, high temperatures have been found to result in decomposition of lipid material and, therefore, should be avoided during extraction.

Underestimation of total lipids can also result from denaturing of lipids by solvent contaminants, lipid decomposition from exposure to oxygen or light, and lipid degradation from changes in pH during cleanup. Overestimation of total lipids may occur if a solvent such as alcohol is used, which results in substantial coextraction of nonlipid material. It is essential that these potential sources of error be considered when conducting and evaluating results of lipid analyses.

NOAA (National Oceanic and Atmospheric Administration). 1993c. Sampling and Analytical Methods of the National Status and Trends Program, National Benthic Surveillance and Mussel Watch Projects 1984-1992. Volume IV. Comprehensive Descriptions of Trace Organic Analytical Methods. NOAA Technical Memorandum NOS ORCA 71. Coastal Monitoring and Bioeffects Assessment Division, Office of Ocean Resources Conservation and Assessment, National Ocean Service, Silver Spring, MD. July.

Randall, R.C., H. Lee II, R.J. Ozretich, J.L. Lake, and R.J. Pruell. 1991.Evaluation of selected lipid methods for normalizing pollutant bioaccumulation. Environ. Toxicol. Chem. 10:1431-1436.

Due to the difference in laboratory equipment and extraction methods, a single standardized protocol may be difficult to implement. Instead, an example using a single method (one that is conducted in the author's laboratory) is provided that demonstrates the principle of obtaining the parameter of wet weight and lipid weight.

- Measure out five grams of fish on a pre-tared aluminum weight dish or in a pre-tared 250 mL pre-cleaned glass beaker.
- Add five grams of ASE prep material (dionex p/n 062819) to the 250 mL pre-cleaned glass beaker with the fish tissue in it.
- Place mix in microwave for 2.5 minutes (depends on moisture content of sample).
- Transfer dried sample to ASE extraction cell using acetone-cleaned stainless steel spatula.
- Conduct ASE extraction (dichloromethane, pressure at 1500 psi, 105 degrees Celsius).
- After ASE processing, transfer extract to 40mL pre-cleaned glass graduated vial
- Dry extract to 10mL, measure precisely using.
- Transfer 0.5 mL (10%) to pre-cleaned, pre-tared aluminum weighing dish.
- Dry 0.5 mL to dryness and weigh dish for 10% weight of lipids from this five gram sample.

3.1.2. Dry weight determination of tissue sample

The purpose of this procedure is to be able to normalize the concentration of contaminants against a parameter that has consistency from one sample to another.

All instruments and glassware should be cleaned with a phosphate-free micro-detergent, and acetone rinsed. Samples will be thawed, and using a cleaned spatula, one to three

grams of thawed material will be placed in a clean 10-25 mL beaker that has been pre-tared, and pre-dried (in the drying oven at the same temperature the samples will be dried at). The 'wet-weight' of the beaker is weighed, the amount recorded.

Samples are then placed in a drying oven and incubated to dryness. Drying oven temperature should be between 100°C and 115°C. The temperature should be consistent for all incubation of samples. Samples in beakers are weighed again, the amount recorded.

Ask for certification in the accuracy of all balances and thermometers used in this procedure. Accuracy of balances and thermometer should be checked before and after processing of the samples. Also ask for guarantee that the lab cleans all instruments and glassware appropriately so as prevent the occurrence of cross-contamination of samples.

Equation for calculating the percent dry weight of a sediment sample.

$$\text{Dry Wt.\%} = \frac{(\text{Beaker Wt.} + \text{Dry Wt.}_{\text{sample}}) - (\text{Beaker Wt.})}{(\text{Beaker Wt.} + \text{Wet Wt.}_{\text{sample}}) - (\text{Beaker Wt.})} \times 100$$

3.1.3. Dry weight determination of sediments

The purpose of this procedure is to be able to normalize the concentration of contaminants against a parameter that has consistency from one sample to another.

All instruments and glassware should be cleaned with a phosphate-free micro-detergent, and acetone rinsed. Samples will be thawed, and about one to two grams of tissue be homogenized in a homogenizer. Once homogenized, the homogenate is transferred to a clean 10-25 mL beaker that has been pre-tared, and pre-dried (in the drying oven at the same temperature the samples will be dried at). The 'wet-weight' of the beaker is weighed, the amount recorded.

Samples are then placed in a drying oven and incubated to dryness. Incubation should be between 24-36 hours. Drying oven temperature should be between 100°C and 115°C. The temperature should be consistent for all incubation of samples. Once samples are dried, they should be allowed to cool to room temperature. This should take less than one hour. Samples in beakers are weighed again, the amount recorded.

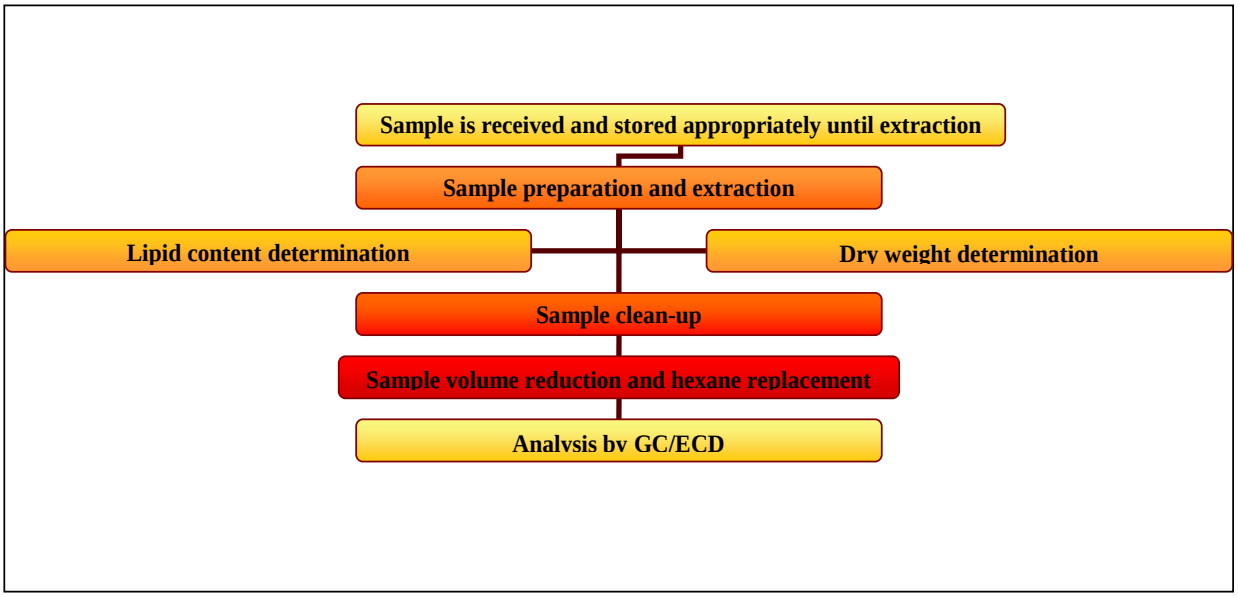
Ask for certification in the accuracy of all balances and thermometers used in this procedure. Accuracy of balances and thermometer should be checked before and after processing of the samples. Also ask for guarantee that the lab cleans all instruments and glassware appropriately so as prevent the occurrence of cross-contamination of samples.

Equation for calculating the percent dry weight of a sediment sample.

$$\text{Dry Wt.\%} = \frac{(\text{Beaker Wt.} + \text{Dry Wt.}_{\text{sample}}) - (\text{Beaker Wt.})}{(\text{Beaker Wt.} + \text{Wet Wt.}_{\text{sample}}) - (\text{Beaker Wt.})} \times 100$$

3.2. Example Protocol of Method

Because of the diversity of instruments and acceptable methods that can be used in the Analytical Laboratory for gas chromatography/electron capture detection, the document provides a single protocol for the extraction and detection of target analytes using a GC/ECD instrument. It can be used as a template for examining key attributes that any analytical laboratory's methodology should possess. The extraction method and the instruments used in this example *should not* be taken as that every analytical laboratory must use this method and this specific instrument. Coral will used as the sample example. The flow of the process is diagrammed below.



3.2.1 Sample Preparation and Extraction

1. Corals are ground in liquid nitrogen in a mortar and pestle as described in Section 2.2.2. of this document and it is assumed that this process is being done by a competent technician in a clean lab with clean instruments.

2. About one gram of frozen powder is transferred to a clean container using a frozen spatula for determination of dry-weight.

3. Frozen sample are then dried. This step can be done using a variety of methods, but most laboratories dry samples using Hydromatrix, a commercial chemical desscicant.

4. The dried sample is then loaded into a Dionex ASE (accelerated solvent extraction) cell and using dichloromethane as the extractant solvent. All samples, blanks, matrix spikes, and reference samples are prepared in the same fashion.

5. The ASE cells are closed and loaded onto the Dionex ASE extraction instrument.

6. Extracts are collected into extraction vials, and then evaporated to a volume of about 10 milliliters using a heating block or hot-water bath.

7. An aliquot of the sample is removed (usually 100 uL to 500 uL) to determine lipid content of the sample. The method for determining lipid concentration can be found in Section 3.1.1. of this document.

8. This extract is 'cleaned' of contaminating debris and lipid. Addition of samples with high lipid content onto the GC can create significant artifact. 'Clean-up' of samples can be done using a variety of methods, and even a combination of methods. For this sample example, clean-up is conducted using alumina/silica gel chromatography columns from a commercial source that comes pre-packed and pre-equilibrated in dichloromethane. Columns are washed with a 1:1 solution of hexane:dichloromethane. The elutant is collected, and its volume reduced via evaporation. The final sample is diluted to 0.5 milliliters with hexane.

9. The sample is then transferred to a one milliliter vial and stored at -80°C until analysis.

3.2.2. Sample Analysis

Samples are loaded unto an autosampler that is attached to the gas chromatograph. The autosampler will inject a designated volume of a sample into the gas chromatograph. Besides the target samples, the autosampler will also inject method blanks, calibrant standards, matrix standards, internal standard, and the surrogate spiked standard in a single run. A run is defined as a set of samples and standards that are loaded onto the instrument over a discrete amount of time (usually 36 hours).

3.3. Standards

There are four different standards that any analytical laboratory must have in their methods. These four standards are necessary to provide a reasonable level of confidence in the data generated for the samples.

3.3.1. Internal Standard

This standard is added to all samples and quality control samples and is used to provide a reference for the calculation of analyte concentrations. Most often, the internal standard is a 1 nanogram/microliter concentration of tetrachloro-m-xylene. This compound can be obtain from a number of commercial sources and is certified/designated for use as an internal standard in contaminant chemistry analysis.

3.3.2. Surrogate Spiking Standard

This standard is used to determine the efficiency of analyte recovery of the method used in the analytical laboratory. The surrogate spiked standard *cannot* be a target analyte (e.g., PCB 105), and can be compounds such as 4,4,'-dibromooctoflurobiphenyl, tetrachloro-m-xylene, and 2,2',4,5',6 pentachlorobiphenyl. This compound can be obtain from a number of commercial sources and is certified/designated for use as a standard in contaminant chemistry analysis.

3.3.3. Calibration Standards (aka working standards)

The purpose of Calibration Standards is to calibrate the instrument and to determine the range of linearity for the instrument. These standards are purified/known concentration of the target analytes. They are obtained from a commercial source and are certified/designated for use as calibrant standards. The calibrants are actually a series of dilutions of a mastermix of target analytes are loaded directly into the GC-ECD instrument. Calibrants for each target analyte may range from 1 to 500 picograms/microliter. For organochlorine analysis that is usually analyzed in most U.S. EPA survey programs, the calibrant mastermix should contain the following target analytes:

1,2,4,5-tetrachlorobenzene	2,4'DDD	dieldrin
1,2,3,4-tetrachlorobenzene	4,4'DDD	endrin
hexachlorobenzene	Heptachlor	mirex
α-HCH	Heptachlor epoxide	endosulfan II
β-HCH	Oxychlordane	endosulfan sulfate
γ-HCH	α-chlordane PCB66	PCB8
δ-HCH	PCB101	PCB18
pentachlorobenzene	PCB105	PCB52
chlorpyrifos	PCB118	PCB170
pentachloroanisole	PCB128	PCB180
2,4'-DDE	PCB138	PCB187
4,4'DDE	PCB153	PCB195
2,4,'DDT	γ-chlordane	PCB206
4,4,'DDT	trans-nonachlor	PCB209
	cis-nonachlor	PCB28
	aldrin	PCB44

3.3.4. Matrix Spike Standard

The purpose of the matrix spike standard is to determine the efficiency of the recovery of target analyte from an actual sample. To conform to U.S. EPA methods, a matrix spike duplicate should be included in the analytical laboratory's methodology. The matrix spike duplicate is used to determine the precision of matrix recovery. These matrix spike standards can be obtained from a commercial source and are certified/designated for use as standards. The concentration of analytes in the matrix spike solution should be about 10 times greater the concentration of the methods detection limit. The matrix spike standards are added to a sample. The matrix spike solution usually contains the same target analytes found in the working standard solution or a subset of those target analytes.

3.3.5. Blanks

Included in the Analysis Laboratory's methodology should be a number of Laboratory Method Blanks. This blank, actually a set of blanks, includes components used for analysis. For example, one blank should include the analysis of the dichloromethane and hexane from the original reservoir. Glassware used during the extraction should also have a blank. The Teflon sample containers, and ever the aluminum foil used to contain some samples should have blanks of their own. To counter possible criticism, the the Hydrosorb wipes should be used to on 'clean' Teflon cutting boards, dissecting instruments, and counter-tops to determine the extent of possible sample preparation contamination.

3.3.6. Standard Reference Material

Standard reference material is usually obtained from a government repository or some other certified source whose sample and sample matrix is similar to the samples. This material is processed through the entire extraction method, determined for lipid content and dry weight, and analyzed with the samples usually in the same batch of samples that are loaded onto the analytical instrument.

3.4. Quality Control/Quality Assurance Parameters

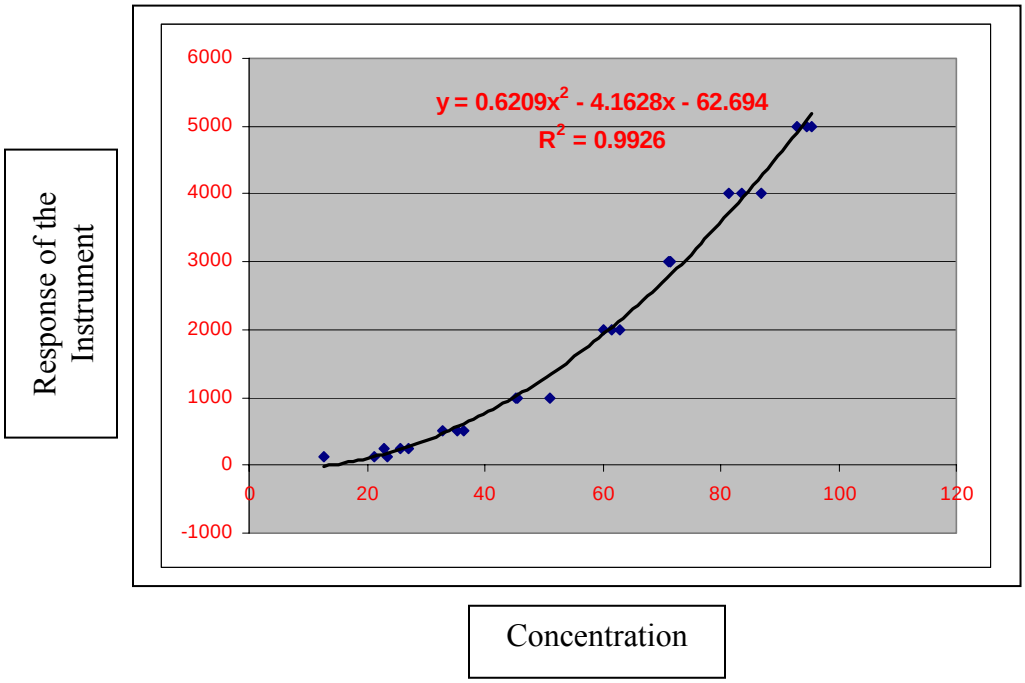
Whatever laboratory is responsible for conducting the contaminant analysis for your samples, it should have a Quality Assurance (QA) program in place that meets the demands of specific Quality Control (QC) criteria. Quality Assurance is a 'management strategy' that meets the demands of the study for a level of confidence in the validity of the data being generated.

As part of the Quality Assurance Program for the analysis laboratory, the laboratory should be able to provide you (on demand) documentation that addresses the following items (which is what expected as part of an US EPA QA/
QC program and is copied almost verbatim from Guidance for Assessing Chemical Contaminant Data for Use In Fish Advisories. Volume 1: Fish Sampling and Analysis - Third Edition appendix I):

1. Detailed descriptions of laboratory procedures for sample receipt, storage, and preparation.
2. Detailed descriptions of the analytical methods used for quantitation of target contaminants, dry weight of sample, and percent lipid determination.
3. Detailed descriptions of methods routinely used to assess data accuracy, precision, and completeness.
4. Detailed descriptions of preventive maintenance procedures for sampling and analysis equipment.
5. Detailed descriptions of calibration procedures for all measurement instruments, including specification of reference materials used for calibration standards and calibration schedules.
6. Detailed descriptions of procedures for internal QC performance and/or systems audits for sampling and analysis programs.
7. Detailed descriptions of procedures for external QA performance and/or systems audits for sampling and analysis programs, including participation in certified QA proficiency testing or interlaboratory comparison programs

Every analysis laboratory should be able to meet five separate QC criteria. They can present their QC in different ways, but you should be able to feel satisfied that they have met these criteria.

1. Demonstration of capability – The laboratory must demonstrate that all of the instruments are in sound working order, that the technicians are competent, and that the lab has a quality assurance plan in place.
2. Laboratory background contamination – the laboratory must demonstrate that benchtop, the sample preparation instruments, solvents, the analytical instruments are free of traces of target analytes. The lab should provide method blank data and nonzero blanks for both sample analysis and analyte percent recoveries.
3. Determining surrogate and targeted analyte recovery – the laboratory must demonstrate that the surrogate and targeted analytes can be recovered within an acceptable range by the methods preparation in that laboratory. It is beyond the scope of this Protocol, but an excellent review for theory and application of surrogate and targeted recovery can be found in Loconto, P.R. (2005) Trace Environmental Quantitative Analysis: Principles, Techniques, and Applications, 2nd edition. CRC Press. Boca Raton. Pp 82-91. What you need to understand from the analytical laboratory is the range of recovery of a target analyte using the laboratory's methods, and what you require to be an acceptable range of %recovery.
4. Experimental calibration and the range of linearity - The analytical laboratory will provide you with data that has quantitative units. There is a method for which they determined concentration of each target analyte. That method includes the addition of known concentrations of a target analyte that is analyzed by the analytical instrument. This data represent two characteristics: (1) the response of the instrument and (2) concentration of the analyte. This data can be represented as a relationship (quadratic relationship).



The correlation coefficient, ***r***, of 0.9990 is the goal to achieve between the instrument response and the amount of analyte. The coefficient of determination, r^2, is the measure of the variation of the instrument response (dependent variable) that can be accounted for by the concentration of the target analytes (independent variable). These two coefficients are necessary to determine the range of linearity and the goodness of fit in the calibration of an instrument for measuring the target analytes. The lab should establish what the linear dynamic range of their instrument is for a target analyte, whether the linear range be determined by a first-order least squares regressions or a second order least-squares regression (polynomial), you should understand that for your sample to have a validly determined concentration of a target analyte, the instrument's response for your sample's target analyte must fall within the linear range of the calibration curve. If your sample's target analyte falls outside the linear range of the calibration curve, it produces an increased level of uncertainty in measuring accurately the true concentration of the analyte in that sample.

5. Precision and Accuracy – The laboratory should provide you documentation of the precision of the method/instrument in measuring the target analyte in each sample, and the accuracy of the measurement. Precision can be evaluated by conducting replicate measurements on the same sample for the same target analyte. Most assays are conducted in triplicate so that a meaningful standard deviation can be determined for you sample, as well as determining the %coefficient of variation.

Accuracy can be determined by the use of a known, certified, reference standard. Your sample's response/calculated concentration can be compared to the reference standard, and a standard error determined. The accuracy should be reported as a "% standard error."

%Error=[Xi(unknown) – Xi(known)]/Xi(known)

3.5. Reports of contaminant chemistry analysis

Following U.S. EPA suggestions for data reporting of contaminant chemistry analysis, documentation of analytical data for each sample or batch of samples should include the following information:

1. Study identification (e.g., project number, title, phase).
2. Description of the procedure used, including documentation and justification of any deviations from the standard procedure.
3. Method for the detection and quantitation limits for each target analyte.
4. Method for the accuracy and precision for each target analyte.
5. Discussion of any analytical problems and corrective action taken.
6. Sample identification number.
7. Sample weight (wet weight).
8. Lipid content (as percent wet weight).
9. Final dilution volume/extract volume.
10. Date(s) of analysis.
11. Identification of analyst.
12. Identification of instrument used (manufacturer, model number).
13. Chromatograms for each sample analyzed by GC/ECD.
14. Raw data quantitation reports for each sample.
15. Description of all QC samples associated with each sample (e.g., reference materials, field blanks, rinsate blanks, method blanks, duplicate or replicate samples, spiked samples, laboratory control samples) and results of all QC analyses. QC reports should include quantitation of all target analytes in each blank, recovery assessments for all spiked samples, and replicate sample summaries. Laboratories should report all surrogate and matrix spike recovery data for each sample; the range of recoveries should be included in any reports using these data.
16. Analyte concentrations with reporting units identified (as ppm or ppb wet weight **and** ppm or ppb lipid weight; two significant figures unless otherwise justified). **Note:** Reported data should not be recovery-corrected or blank-corrected.
17. Data qualifications (including qualification codes and their definitions, if applicable, and a summary of data limitations).

Mesoamerican Reef Alliance, ICRAN-MAR Project

Land use change modelling for three scenarios for the MAR region

Technical Report

Technical report on the collection of geographic data, the regression analysis of explanatory factors of land use patterns, the development of a set of three alternative scenarios, and the modelling of land use changes using the CLUE-S model. This work was carried out as part of the ICRAN-MAR project's sub-result 1.2, "Trends in land use integrated with spatial, hydrological and oceanographic models for use in modelling".

Joep Luijten, Lera Miles and Emil Cherrington

UNEP World Conservation Monitoring Centre

5 October 2006

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Summary

Mesoamerica – the region in which the Mesoamerican Barrier Reef Systems fall – is recognized internationally for its biodiversity. For example, Conservation International has identified the area as a biodiversity hotspot, with a high proportion of endemic species (Myers *et al*. 2000). The area's natural ecosystems are also recognized to be threatened. The World Bank-funded Central America Ecosystems Mapping Project, which concluded in 2002, estimated that 49% of Central American land had been converted to agriculture (Vreugdenhil *et al*. 2002).

With a focus on the Mesoamerican Reef, the International Coral Reef Action Network's Mesoamerican Reef Alliance (ICRAN-MAR) project is focusing its attention on how changing land use affects the health of the region's reef ecosystems. The project region includes southern Mexico, and all of Belize, Guatemala, and Honduras.

This report details the steps undertaken to map current and potential future land cover for this ICRAN MAR region. Geographic data was collated, three alternative land cover scenarios for 2005 to 2025 were developed, a regression analysis was undertaken to identify the strength of different factors affecting land use patterns and land use changes under these scenarios were modelled.

The land cover maps for the present day and for 2025 were used as a key input to a hydrological model of watersheds discharging adjacent to the Mesoamerican Reef, prepared by the World Resources Institute (WRI). A hydrologic modelling report is also available on this CD.

A workshop was held in August 2006 to disseminate project results and to provide training in the use of the models. A preliminary version of this report was distributed to workshop participants.

1 Data collection and preparation

1.1 Outline of methodology and preparation steps

To identify drivers of deforestation, a regression analysis was undertaken in SPSS. The method involves a comparison of land use with the explanatory factors on a cell-by-cell basis within a raster map. Consequently, it is important that all raster data associated with the explanatory factors are prepared consistently: all raster maps must have exactly the same extent, same cell size, and the same numbers of grid cells that are not Null (NoData). A difference of just one cell will cause an offset in the order in which the statistical analysis are carried out and results will be meaningless.

To assure consistency across the raster inputs, the same preparation and conversion procedure was applied to every dataset. The data preparation involves two stages as follows.

1.1.1 Stage 1: Creation of ASCII grids with identical number of value cells

Stage 1 involves the creation of the raster datasets in Arc/Info ASCII format so that they can be used (i) by the CLUE-S model and (ii) for the subsequent Stage 2 processing steps.

1. Identify and acquire the best available and most suitable data, in vector or raster formats. Different data from different sources will be used.
2. Review the quality of the dataset, and edit the dataset to resolve any data errors or other problems (areas with missing data; non-adjacent polygons; misclassification of data). If necessary reclassify the data into a more appropriate system.
3. Create any derived datasets, if applicable. An example of this is the creation of a dataset for the number of dry months from monthly precipitation data.
4. Convert vector data or resample raster data to the same raster grid resolution and spatial extent (see Section 1.2).
5. Apply a focal mean filter (continuous data) or a focal majority filter (categorical data) to fill any occasional *Null* cells[1] and "add a few grid cells width" of data on the edges of the maps. This critical step ensures that when data are clipped in the next step, there are absolutely no Null cells within the watershed boundaries. An Avenue script was developed for use in ArcView 3.3 (Appendix 1).
6. Clip all rasters to the MAR extent, and then clip them further to the individual extents of the countries (Table 1-1). This step can be carried out using the *Raster Calculator* in ArcMap.
7. Export all data from GRID to ASCII text format. This can be carried out using the conversion tools in ArcToolBox (Conversion Tools > From Raster > Raster to ASCII[2])

[1] IThe conversion of vector data to raster data sometimes results in *Null* cells where they would not be expected. This reason for this appears to be non-adjacency of polygons in the vector data. Grid cells are assigned as *Null* when their centre points fall in the empty area between the two polygons.

[2] Step 7 – 10 required several Gigabytes of disk space because the ASCII files were quite large and there were many of them.

1.1.2 Stage 2: Conversion to a text file for use by SPSS regression module

Stage 2 involves the further processing of the output datasets from stage 2 into a number of different formats to obtain plain text files that can be imported by SPSS. The CLUE-S user manual and exercises (Verburg 2004, Verburg *et al*. 2004), offer a more detailed explanation.

8. Separate grids must be created for every land cover type because binary logistic regression analysis is used. This can be carried out using the *Raster Calculator*. For the ICRAN MAR region, there were 4 countries * 10 land use types = 40 different grids. Each grid is then converted to ASCII format, as in step 7.
9. Using the *File Converter* program that is supplied with CLUE-S, convert the ASCII grids to text files in which all raster values are listed in a single column, with no header. This must be undertaken for all land use types and all explanatory factors, creating a large number of files. For example, for 10 land use types and 15 explanatory factors, there are 4*(10+15) = 100 single-column files. A consistent file naming convention should be used to avoid confusion and mistakes.
10. Copy the contents of the single-column files into an overall file that can be loaded in SPSS (this file is called stats.txt by the CLUE-S *File Converter*). The total number of columns in this file must equal the sum of the number of land use types and the total number of explanatory factors. This file was created using the TextPad text editor (the option to create this file using the CLUE-S *File Converter* resulted in a runtime error, possibly as a result of the large grid size. Record the order of the data columns.

1.2 Grid extent and grid resolution

1.2.1 Creation of watershed boundaries shapefile

WRI provided a base watershed boundaries shapefile. This illustrates that not all the watersheds in the four MAR countries drain to and have a direct impact on the Mesoamerican Reef[1], and is a vital component in analysing the impacts of land cover change on the reef system. A version delineated from the 90 m DEM was completed on 4 August 2005 and a version based on the 250 m DEM on 24 January 2006. Neither shapefile was readily usable in this exercise because WRI had removed watersheds less then 80 ha in size. This had resulted in an erratic boundary that did not correctly represent the water/land boundary. Furthermore, to retain flexibility in the final resolution used for modelling, it was considered undesirable to restrict the boundaries to a particular DEM extent.

Several edits were carried out to create an improved and more flexible boundaries shapefile for preparation of data for the regression analysis and the land use modelling. The overall area of WRI's 90 m and 250 m shapefiles (for inland boundaries) was combined it with the best land/water/country boundary shapefile (*land_country_20july05.shp*, used for the mask's coastline). Next, the combined shapefile was improved in January 2006 by extensively editing the coastline of Mexico and Honduras so that it better matched the coastline from the Ecosystem map and the Landsat TM colour composites. The final MAR watershed shapefile **`MAR_BASIN_3B_RECLASSMASK_5FEB06.SHP`** was created.

The shapefile was converted to a raster at 250 m resolution as **`BASIN250`**. This raster has *NoData* values outside the catchment area and has four different grid values: 1 for Mexico, 2

[1] GIS analysis (using the WRI watershed delineations and the administrative boundaries provided by CCAD) reveals that all of Belize's six districts, fourteen of Guatemala's twenty-two departments, sixteen of Honduras' eighteen departments and three of México's thirty-two states possess lands in the hundred or so watersheds draining to the reef.

for Belize, 3 for Guatemala and 4 for Honduras. These values are used later on in the modelling process.

1.2.2 Conversion to raster masks

As mentioned above, it is critically important that all input data associated with the land use and the explanatory factors are prepared consistently, meaning that all grids must have the same extent, cell size and NoData area. A difference of just a single cell will render the results of the statistical analysis meaningless.

In cooperation with the hydrological modeller, a grid cell size of 250 m was chosen[1]. The extent of the grids for the MAR watershed and every country is given in Figure 1-1.

Figure 1-1: Spatial extents and data area for raster datasets for the counties within the MAR region.

The regression analysis was carried out at 250 m. It should be noted that explanatory factors of land use changes can be scale dependent. That is, certain spatial relationships that may be observed (i.e., are statistically significant) at a certain scale, but may be less or not all significant at other scales. However, Kok and Veldkamp (2001) and Kok (2004) have concluded that changing the spatial resolution does not lead to major changes in the set of variables composing the equation that explain land use patterns in Central America.

Table 1-1: Spatial extents for the raster datasets, by country. The coordinates are based on Universal Transverse Mercator (UTM) projection for zone 16 with the NAD 1927 Central American datum.

Country	West (xmin)	East (xmax)	South (ymin)	North (ymax)	# Rows	# Columns	# Cells (not Null)
All of MAR	40 000	794 000	1 519 000	2 390 000	3 484	3 016	3 046 407
Belize	261 500	412 500	1 757 500	2 045 250	1 151	604	349 762
Mexico	213 250	528 750	1 971 250	2 389 750	1 674	1 262	886 433
Guatemala	41 250	368 750	1 596 500	1 972 250	1 503	1 310	542 309
Honduras	260 250	793 000	1 521 000	1 772 250	1 005	2 131	1 267 903

[1] A minimum polygon size of about 150 ha was applied during the creation of the 2003 Central American Ecosystem map, and a minimum of 10 ha was used for the more detailed 2004 Ecosystem Map for Belize. A resolution of 250 m (6.25 ha grid cell) is thus small enough to preserve the data resolution.

From the raster **BASIN250,** a separate raster mask was created for each of the four countries. This involved three steps:

1. Set the appropriate analysis extent and cell size in the Spatial Analyst options menu. Use the values as specified in Table 1-1.
2. Use the raster calculator and the expressions below:

   For MX, `Con([basin250] == 1, 0 ,setnull([basin250]))`
   For BZ, `Con([basin250] == 2, 0, setnull([basin250]))`
   For GT, `Con([basin250] == 3, 0, setnull([basin250]))`
   For HN, `Con([basin250] == 4, 0, setnull([basin250]))`
3. Save the output of the raster calculator permanently, using the names: **MASK_MX_250, MASK_BZ_250, MASK_GT_250** and **MASK_HN_250.** Each of these grids only has zero values and can be used as analysis mask for further data preparation.

1.3 Land use/land cover classification

1.3.1 Reduced number of land cover classes

A reduced land cover classification with ten classes (Table 1-2) was developed for use by the CLUE-S land use model and the scenario analysis. The need for such a classification was outlined early in the project and a proposed classification in principle agreed upon during a conference call on 16 September 2005. The dataset was derived from the 2003 Ecosystem Map dataset for Central America and the 2004 update for Belize. Appendix 4 gives the legend used for the original and reduced classifications.

Table 1-2: Land use classes used for the land use change modelling. The original Ecosystem Map dataset had a more detailed classification that was reduced.

0 – Other/Unknown[1]	5 – Savanna
1 – Broad-leaved forest	6 – Wetland/Swamp
2 – Pine forest	7 – Mangroves
3 – Agriculture/Pasture	8 – Urbanized
4 – Scrub	9 – Water

The ten land use classes represent different production systems that are distinctly different in terms of (i) natural and spectral characteristics, (ii) relevant national policies and key drivers of land use change in the past and future, and (iii) management practices and possible changes in those practices as they relate to the overall objective of the project.

The proposed classification changed over time, during a total of four revisions:

- In September, a seven-class system was proposed: Forest, Pasture, Scrub, Cropland/Agriculture, Wetland, Savanna, and Other (includes urban, water bodies).
- During the 16 Sept 2005 conference call we agreed that mangroves should be added as a separate class and that forest should be split in two forest types (broad-leaved and pine forest). This brought the total to nine classes.

[1] The "Other/Unknown" land use class includes any land cover types that cannot be reclassified as any other types. For the scenario simulations it is assumed that "Other/Unknown" remains constant over time (i.e., neither the total area, nor the spatial distribution changes over time. The Other and Water classes were not included in the statistical analysis of land use factors and the associated areas were not changed by the CLUE-S model.

- During the creation of the first reclassified raster, it was noticed that neither the 2003 Ecosystem Map nor the 2004 Belize Ecosystem map contained pasture as a separate category. Pasture may be included within the agricultural land class. Pasture was therefore dropped from the classification, resulting in a total of eight classes.
- Having reviewed the first reclassified dataset, Lauretta Burke suggested that urban and water should be included as two separate classes rather than be grouped in the "other" class. The final version is therefore composed of ten classes.

Table 1-3: Total area (km^2) of each land cover type in the reclassified and rasterized Ecosystem map data (final version 4 created on 6th February 2006)

	Mexico	Belize	Guatemala	Honduras
0. Other/Unknown	251.7	13.5	8.3	232.9
1. Broad-leaved forest	31 760.9	12 684.2	17 322.6	20 555.3
2. Pine forest	0.0[1]	771.8	840.4	12 198.9
3. Agriculture/pasture	3 398.0	4 235.1	10 505.9	43 720.4
4. Scrub	14 990.6	274.8	4 292.3	151.6
5. Savanna	62.3	1 886.4	0.3	1 114.7
6. Wetland/Swamp	1 921.0	931.8	13.4	472.1
7. Mangroves	2 316.8	720.0	0.8	82.7
8. Urban	145.4	189.4	118.3	130.5
9. Water	555.4	153.2	792.2	584.8
TOTAL	*54 402.06*	*21 860.13*	*33 894.31*	*79 243.94*

1.3.2 Sources of land cover data

For Mexico, Honduras and Guatemala, data were derived from the revised 2003 Ecosystem Map. For Belize: data were derived from the revised 2004 Ecosystem map for Belize.

Both datasets contain a mangrove class. Emil Cherrington shared a separate mangrove dataset for Belize that is arguably more up-to-date. While this dataset appears more detailed (there are many more smaller polygons), it does not include all the mangrove areas within the 2004 Ecosystem map. As substituting the mangroves from the 2004 Ecosystem map with the improved mangrove data would result in data gaps, for which the land cover is unknown, this has not been undertaken.

The 2003 Ecosystem map had various data quality problems, in particular non-adjacent polygons along the Belize/Mexico and Belize/Guatemala border and in locations where rivers form national boundaries. For example, an area of about 75 km long and just 400 m wide along the straight border was not classified. This resulted in some visible reclassification errors and gaps in the first version of the reclassified land cover raster.

The 2003 Ecosystem map was extensively edited to fix these errors and improve polygon adjacency with the 2004 Belize ecosystem data (which was not edited). After review, it appeared that the second reclassified land dataset still contained errors, mostly in the form of single NoData cells. The original 2003 Ecosystem map was extensively edited (half a day) to fix these remaining problems via: better edge-matching of polygons along rivers; addition of numerous missing water bodies, particularly along the Mexican coastline; development of a script in Avenue to iteratively apply a 3x3 neighbourhood majority filter (Appendix 1). This script was applied to the ecosystem raster dataset, prior to clipping.

[1] Total absence of a particular land use type, here pine forest in Mexico, is a special case that requires some tweaks/workarounds in the CLUE-S model to avoid runtime errors. See section 4.2.6 for details.

The known unresolved data quality issues with the land cover map are as follows:

1. In the 2003 ecosystem map, a very large part of Honduras has been classified as '*Sistemas agropecuarios'*, and in the 2004 Belize dataset there is a class '*Agricultural uses*'. As this is likely to be a mixture of cropland and pasture, this class has been named "*Agriculture/Pasture*" to avoid confusion.
2. The errors that could be observed near the Belize/Mexico border in the first reclassified raster have been fixed. However, some other abnormalities in the Mexican Yucatan —the sudden land use changes at the 19th and 20th parallel and the 90th meridian— have not been resolved as these are problems with the source data, not the reclassification.

1.3.3 Output extent and cell size

A cell size of 250 m was chosen. Earlier in the project, it had been assumed that the entire country of Honduras would be included. WRI's latest watershed shapefile (*mar_basin_3b.shp*, 4 August 2005) showed that not all of this country would be included, so the raster analysis extent was adjusted to avoid unnecessarily large grids. The final analysis extent is:

```
West:  40 000 (no changes)
East:  794 000 (was 920 000 but eastern part of Honduras now excluded)
North: 2 390 000 (was 2 400 000)
South: 1 519 000 (was 1 430 000 but southern part of Honduras now excluded)
```

1.3.4 Reclassification methodology using ArcGIS

1.3.4.1 Step 1: Creation of clip/mask shapefile and grid

An overall MAR watershed shapefile **MAR_BASIN_3B_RECLASSMASK_4FEB06.SHP** was created, based on the WRI version. It includes both sets of watershed boundaries that WRI delineated from the 90 m and 250 m DEM, which were completed on respectively 4th August 2005 and 24 January 2006, and also all smaller watersheds excluded by WRI. The coastline has been extensively edited to better match the coastline from the Ecosystem map data and the Landsat colour composites.

The shapefile was converted to a raster at 250 m resolution: **BASIN250**, as described in section 1.2.1. This raster has *NoData* values outside the catchment area, and values inside the catchment area according to country: 1 for Mexico, 2 for Belize, 3 for Guatemala and 4 for Honduras.

1.3.4.2 Step 2: Creation of land cover reclassification tables

Two reclassification tables (dbf files) were created for the ecosystem datasets: **ECOMAP2003_RECLASS.DBF** (Table 1-4) and **ECOMAP2004BZ_RECLASS.DBF** (Table 1-5).

1.3.4.3 Step 3: Reclassification & rasterization of the Ecosystem Map data

The two reclassification tables were linked to their corresponding vector datasets in ArcMap. Next, the *Feature to Raster* tool was used to rasterize the ecosystem data (see Fig. 1-2).[1]

1.3.4.4 Step 4: Combining the rasterized 2003 and 2004 Ecosystem datasets

The next step was the combination of the two grids created in the previous step in such a way that the **ECOMBZ04_V3** values takes priority over **ECOMAP03_V3**. This was carried out using the following *Raster Calculator* expression, and the result saved as grid **COMBRAW_V3**.

```
Con(IsNull([ecombz04_v3]),[ecomap03_v3],[ecombz04_v3])
```

Table 1-4: Reclassification table for the 2003 Ecosystem map using field DESCRIPTIO

DESCRIPCIO (ecomap2003_reclass.dbf).	**NEWCLASS**	**NUM**
Arbustales de coniferas	Scrub	4
Arbustales de latifoliadas	Scrub	4
Arbustales mixtos	Scrub	4
Arbustales xeromorficos subdeserticos	Scrub	4
Areas con escasa vegetacion	Other	0
Arrecifes coralinos	Other	0
Bosques deciduos de latifoliadas	Broad-leaved forest	1
Bosques manglares	Mangroves	7
Bosques semideciduos de latifoliadas	Broad-leaved forest	1
Bosques semideciduos mixtos	Broad-leaved forest	1
Bosques siempreverdes de coniferas	Pine forest	2
Bosques siempreverdes y semisiempreverdes de latifoliadas	Broad-leaved forest	1
Bosques siempreverdes y semisiempreverdes mixtos	Broad-leaved forest	1
Cuerpos de agua	Water	9
Otros	Other	0
Pantanos y humedales	Wetland/Swamp	6
Plantaciones forestales	Broad-leaved forest	1
Paramos	Other	0
Sabanas	Savana	5
Sin datos	Other	0
Sistemas agropecuarios	Agriculture/Pasture	3
Sistemas productivos acuaticos (camaroneras, salineras)	Other	0
Urbano	Urbanized	8

Table 1-5: Reclassification table for the 2004 Belize Ecosystem map using field ECOSYSTEM

ECOSYSTEM (ecomap2004bz_reclass.dbf)	**NEWCLASS**	**NUM**
Agricultural uses	Agriculture/Pasture	3
Coral reef[2]	Water	9
Lowland broad-leaved dry forest	Broad-leaved forest	1
Lowland broad-leaved moist forest	Broad-leaved forest	1
Lowland broad-leaved wet forest	Broad-leaved forest	1
Lowland pine forest	Pine forest	2
Lowland savanna	Savanna	5
Mangrove and littoral forest	Mangroves	7
Open sea	Water	9
Seagrass	Water	9

[1] It should be noted that these conversions could not be successfully completed in ArcGIS 9 (it hung the application). The reason for this is unknown. ArcView 3.3 was used instead.

[2] Coral reef, sea grass and open sea are included in the original source data and were reclassified as *Water*, but these ecosystem types are not relevant to the land cover change analysis.

Shrubland	Shrub	4
Sparse Algae	Other	0
Submontane broad-leaved moist forest	Broad-leaved forest	1
Submontane broad-leaved wet forest	Broad-leaved forest	1
Submontane pine forest	Pine forest	2
Urban	Urban	8
Water	Water	9
Wetland	Wetland/Swamp	6

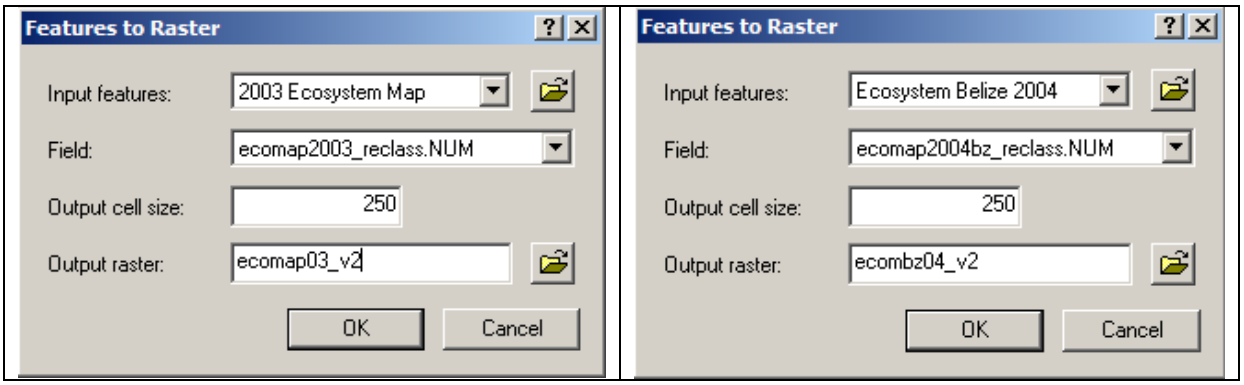

Figure 1-2: Rasterization of the Ecosystem map vector data on linked field NUM for the 2003 Ecosystem Map data (left) and the 2004 Belize Ecosystem Map (right)

1.3.4.5 Step 5: Application of a hole-filling majority filter

The raster **ECOMRAW_V3** had some imperfections. First, some apparently randomly located grid cells were Null where they would not be expected to be Null. This was traced back as the result of non-matching polygons in the original vector data, where the centre point of the grid cells fell exactly in the empty area between the two polygons. Even a grid cell that had >95% of its area covered by the vector data could still become NoData in this way. Second, the coastline of the Ecosystem Map dataset did not exactly match the coastline of the clip/mask shapefile. For the statistical analysis it is crucial that all datasets contain exactly the same number of value grid cells (not NoData cells).

A hole-filling Avenue script (GRIDTOOLS, *Fill NoData Holes in Grid*) was used. This iteratively applies a majority filter. This script not only fills any single NoData cells, but also buffers the raster as described in section 1.1.1. A 1-cell thick buffer is added in each iteration and a total of five iterations were carried out. The resulting dataset was **ECOMFILTER_V3**.

1.3.4.6 Step 6: Clip to the watershed extent and coastline

Lastly, the **ECOMFILTER_V3** was clipped to the extent of the watershed using the mask grid **BASIN250** and the result saved as **ECOMAPFINAL_V4**. This is the final land cover grid.

```
Con(IsNull([basin250]), SetNull([ecomfilter_v3]), [ecomfilter_v3])
```

1.3.5 Calculation of area by country and land cover type

This was easily carried out in the Raster Calculator using **BASIN250** and **ECOMFINAL_V4**. Recall that **BASIN250** has four different values for each country values (1=MX, 2=BZ, 3=GT and 4=HN) and the final land cover grid has values from 0 to 9. The expression below produces a grid that has unique values for each land cover type in each country.

```
([basin250] * 10) + [ecomfinal_v4]
```

The resulting grid was saved as **CLS4CNTRY_V4**. This grid's attribute table lists the number of cells per land cover per country (Table 1-1). The grid values range from 10 (Other/Unknown in Mexico) to 49 (Water in Honduras). As each grid cell is 250 m, the area in km^2 was calculated by dividing the Count value by 16.

1.3.6 Land cover for use in N-SPECT

The combined & reclassified land cover grid **ECOMFINAL_V4** was developed for use as the "current" land cover by both the CLUE-S model and the N-SPECT model. It is important that the same land cover grid is used in by both models to allow accurate evaluation of the impacts of the land cover change simulated by CLUE-S on the results of the N-SPECT model. For N-SPECT, it is necessary to reclassify/remap the 10 different land cover types to 10 corresponding ones from the set of 22 land cover types supported and hard-coded into the N-SPECT model.

1.4 Explanatory factors of land use patterns

A set of potential explanatory factors was compiled on the basis of a literature review and other knowledge about the dominant factors that have affected the directions of land use changed in the past and/or affect the prevailing land use patterns. CLUE-S operates by extrapolating the current land use pattern and driving forces of change to the future (Kok & Veldkamp 2001, Wassenaar *et al*. 2005, Kok & Winograd 2002, Kok 2004, Cherrington 2005). Table 1-7 lists the factors that have been identified and for which data are available at this time.

Each location factor is represented in the form of a grid that is clipped to the boundaries of the country based on the extents listed in Table 2. There is a separate grid for each country because the regression analysis and CLUE-S model runs are performed on a country basis. The main categories of explanatory factors are described below. It has been assumed that only factors on this list have to be accounted for; on the other hand, some of these factors may not be significant.

1.4.1 Topographic factors - elevation and slope

1.4.1.1 Data source

The Shuttle Rader Topography Mission (SRTM) data provided the most consistent and highest resolution elevation data for Central America. CIAT has processed the original 90 m resolution STRM data to fill any *NoData* holes using digitized contours from topographic maps and other elevation products. These processed data were used in this project.

1.4.1.2 Data processing

CIAT data were available in 5 x 5 degree tiles. A total of eight tiles covering 10-25N and 80-95 W (Fig. 1-3) were required to cover the entire MAR catchment .These were merged into a seamless mosaic, **SRTMFULL**, in geographic coordinates and WGS-1984 datum. This DEM was projected to UTM zone 17 using a modified Raster Project tool to a 250 m DEM, **SRTM250_BL_CC**. This name reflects the discovery that the bilinear and cubic convolution resampling methods both gave the same result as the grid resolution was increased from

0.0008333° (approximately 90 m) to 250 m. The factor grids for elevation and slope (degrees) were computed from this DEM.

In the early stages of the project, a comprehensive accuracy assessment of the SRTM data was conducted along with a review of relevant geographic transformations and tools for projecting raster datasets in ArcGIS. The out-of-the-box Raster Project tool in ArcToolbox is that it cannot perform geographic transformation of raster datasets. This is a known issue with ArcGIS 9.0/9.1. Consequently, a modified, functional version of that tool was developed by Joep Luijten.

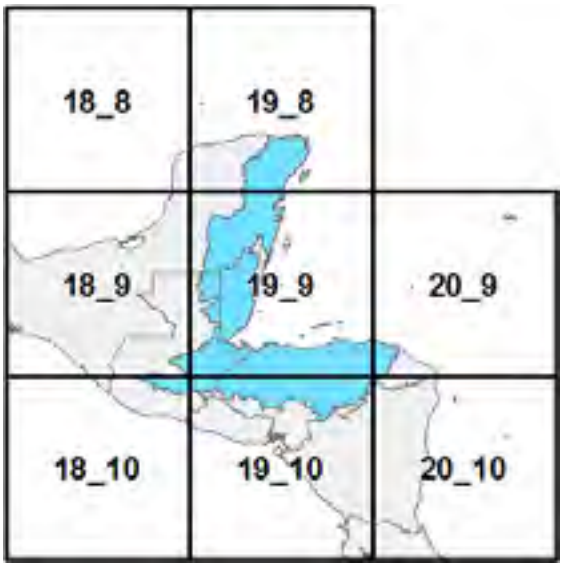

Figure 1-3: SRTM tile numbers that were downloaded. Tile 20_10 was included as the earlier versions of the watersheds boundaries indicated that it extended more to the east and southeast.

Table 1-6: Potential explanatory factors that will be included in the regression analysis and simulated of land use changes. The number (#) has been used for numbering of the CLUE-S regression results parameter files and therefore starts at 0. Cost of access to roads was eventually left out from the analysis because it is strongly correlated to cost of access to markets. There weare no categorical explanatory factors.

#	Explanatory factor	Data source	Reference/suggested by	Type	Dynamic	File prefix
	Demographic					
0	Population density	GPW v3, CIAT LAC	Kok & Veldkamp 2001, Wassenaar 2005	Float	Likely	POPDEN
	Soil / geology					
1	Soil depth	SOTER LAC	Wassenaar 2005, Kok & Veldkamp 2001	Float	No	SDEPTH
2	Soil drainage	SOTER LAC	Wassenaar 2005, Kok & Veldkamp 2001	Float, 0-1	No	SDRAIN
	Climate					
3	Mean annual rainfall	CIAT WorldClim database	Wassenaar 2005, Kok & Veldkamp 2001	Int	No	RAINYR
4	Length dry period (consecutive months with < 60 mm rain)	Derived from Worldclim	Wassenaar 2005, Kok & Veldkamp 2001	Int (0-7)	No	DRYMON
	Topography					
5	Altitude	SRTM DEM	Kok & Veldkamp 2001	Int	No	ELEVAT
6	Slope	SRTM DEM	Wassenaar 2005; Kok & Veldkamp 2001	Float	No	SLPDGS
	Contextual					
7	Cost of access to markets (cities with population > 10 k)	Friction surface	CIAT; Kok & Veldkamp 2001	Float	Possibly	ACSMKT
~~8~~	~~(Cost of) distance to roads~~	~~Friction surface~~	~~Wassenaar 2005, Cherrington 2005~~	~~Float~~	~~Possibly~~	~~ACSRDS~~
9	Coastal, tourism hotspots	Selva Maya; WWF experts	Cherrington 2005; http://www.selvamaya.org	Int (0/1)	Likely	TOURIS
10	Protected areas (full protection)	WDPA (Jan 06)	Wassenaar 2005, Kok & Veldkamp 2001	Int (0/1)	Possibly	WDPAR1
11	Protected area (partial protection)	WDPA (Jan 06)	Wassenaar 2005, Kok & Veldkamp 2001	Int (0/1)	Possibly	WDPAR2

1.4.2 Demographic factors – population density

1.4.2.1 Data sources

There was a choice of two population density datasets, as follows: (i) CIAT and colleagues completed the third version of the Latin American and Caribbean (LAC) Population Database in March 2005 (CIAT *et al*. 2005). It contains vector population maps (population per administrative unit) and raster surfaces created with an accessibility model; (ii) CIESEN released the latest Gridded Population of the World (GPW) database v3, together with the Global-Rural Urban Mapping Project (GRUMP) data (Balk *et al*. 2004) in December 2005. A third dataset, Landscan 2004, was produced by the Oak Ridge National Laboratory, USA, but the project team was not able to obtain this dataset.

When overlaying on a Landsat image, the LAC dataset is visibly less accurate than GPW v3. GPW's actual population density for 1990, 1995 and 2000, estimated density for 2005, 2010 and 2015, and population density grid appears more accurate. This may be because CIAT used comparatively coarse road maps and urban areas data for population modelling. However, the GPW data do not show much spatial variation in population density in Belize, and to a lesser extent in the Mexican Yucatan. Belize City does not stand out at all in the GPW dataset, probably because population densities are averaged across administrative areas, of which there are only six in Belize (compared to 3 696 in Honduras). The LAC dataset is slightly better for Belize, although it still does not look accurate in the vicinity of Belize City.

1.4.2.2 Data processing

The LAC dataset was selected for Belize and Mexico, and the GPW v3 dataset for Guatemala and Honduras. The original data at 1-km resolution were resampled to 250 m. No other processing was carried out. For actual (1990-2000) population data, the GPW3 "**AG**" grids (adjusted population density to match UN totals) were used.

1.4.3 Demographic factors – location of settlements

1.4.3.1 Data source

As there was no available consistent urban point dataset with associated population information, a dataset was pieced together from four different sources data. Many of these were identified by Emil Cherrington. For Honduras, a dataset (**HN_SETTLEMENTS_IGN-CCAD.SHP**) from CCAD was used. For Belize a dataset (**BZ_SETTLEMENTS_BTFS.SHP**) from the Belize Tropical Forest Studies was used. For Mexico and Guatemala the settlements from the Selva Maya CD (see Table 1-6) were used (**BZ-GT-MX_SETTLEMENTS_SELVA_C2000.SHP**). El Salvador was included because it closely borders the MAR catchment; the GRUMP v1 settlement data were used here, even though they were not very accurate.

1.4.3.2 Data processing

Each dataset was projected to UTM16 and the fields in the attribute table that contained the city/settlement name and population size were renamed, respectively, NAME and POPSIZE. The datasets were then merged. The Selva Maya data appeared quite inaccurate and so, where possible, alternative data were used. Guatemala City was missing and was added manually, with its location based on the ESRI and GRUMP settlements and ESRI world cities. The resulting shapefile **MAR_SETTLEMENTS_POP.SHP** has a field SOURCE that indicates were the point features originated from. It should be noted that the GRUMP dataset

is very small scale, but was useful for comparison to indicate whether any key cities are missing, rather than for precise pinpointing of locations.

1.4.4 Soil and geology factors

1.4.4.1 Data source

The highest quality consistent soil dataset for Central America is the 'Soil and Terrain database for Latin America and the Caribbean' (SOTERLAC) and its associated SOTER-based soil parameters estimates (version 1). Both datasets were downloaded from http://www.isric.org/UK/About+Soils/Soil+data/Geographic+data/Regional/. The soil parameters dataset contained everything that was needed - shapefiles, legend files and a large MS Access database that contained all parameters for every soil profile ID (*PRID*) and unique SOTER unit (*NEWSUID*).

1.4.4.2 Data processing

Essentially, the entire area has been characterized using 1585 unique SOTER units, corresponding with 5855 polygons, and the soils described using 1660 profiles. Each SOTER unit is associated with one or more profiles, each given a relative weight and totalling 100%. Each profile and its soil parameters are specified by up to five different layers (*D1* = 0-20 cm; *D2* = 20-40 cm; *D3* = 40-60 cm; *D4* =60-80 cm and *D5* = 80-100 cm), but the deepest layers can be less than 20 cm thick. The soil parameters vary between soil profiles. The attribute data of the shapefiles only contained the soil parameters for the top layer (*D1*).

To calculate the average soil depth and average drainage (over all soil layers), an aggregation had to be made across soil profiles and soil layers, as follows:

For soil depth and drainage:

- Opened **SOTWIS_SOTERLAC_1.MDB** and exported table *SOTERsummaryFile* to a **SOTER_SUMMARY_FILE.DBF**.
- Edit **SOTER_SUMMARY_FILE.DBF** and add a field *ProfDepth* (Number, 2 decimal places) to store the effective depth of that profile within a SOTER unit.
- Calculated the *ProfDepth*, in cm, as: `0.01 * ([BotDep] – [TopDep] * [Prop]`.
- Added a field *ProfDrainage* (Number, 4 decimal places) to store the effective drainage rates of that profile within a SOTER unit.
- Calculated the ProfDrainage, in cm, as: `0.01 * [Drain2] * [Prop]`.
- Summary on the *Newsuid*, taking the Sum of *ProfDepth* (which will be in between 0 and 100 cm) and the Average of *ProfDrainage* (which will be in between 0 and 1). The file was saved as **CUMULATIVE_BY_NEWGUID.DBF.**
- Linked **CUMULATIVE_BY_NEWGUID.DBF** to **SOTERLAC2_SOTWIS.SHP** and created a legend based on the cumulative soil depth (*Sum_Cum_Depth*).
- Convert feature to raster on the cumulative depth field and drainage field. The resulting grids were saved as **SDEPTH** and **SDRAIN**.
- Applied the majority filter 20 times to each grid (so many times to fill major gaps near the islands) and saved grid as **SDEPTHFT20** and **SDRAINFT20**.

◊ Mask and clipped a total of 8 grids using the raster calculator:

`Con([BASIN250] == 1, [SDEPTHFT20])`	Saved as **MXSDEPTH**
`Con([BASIN250] == 1, [SDRAINFT20])`	Saved as **MXSDRAIN**
`Con([BASIN250] == 2, [SDEPTHFT20])`	Saved as **BZSDEPTH**
`Con([BASIN250] == 2, [SDRAINFT20])`	Saved as **BZSDRAIN**
`Con([BASIN250] == 3, [SDEPTHFT20])`	Saved as **GTSDEPTH**
`Con([BASIN250] == 3, [SDRAINFT20])`	Saved as **GTSDRAIN**
`Con([BASIN250] == 4, [SDEPTHFT20])`	Saved as **HNSDEPTH**
`Con([BASIN250] == 4, [SDRAINFT20])`	Saved as **HNSDRAIN**

1.4.5 Climate factors - precipitation and length of dry season

1.4.5.1 Data source

CIAT's WorldClim database (http://biogeo.berkeley.edu/worldclim/worldclim.htm) was used. The database contains grids of monthly mean temperatures and precipitation in several resolutions (30 degree-seconds and 2.5, 5 and 10 degree-minutes). The finest resolution, 30 degree-seconds (about 1-km x 1-km), was considered more than sufficient for land use modelling.

1.4.5.2 Data processing

WorldClim data at 30 degree-seconds resolution were downloaded for tiles #22 and #23 (the MAR catchment covers a small part of each tile). These monthly grids were mosaicked and stored as **PREC_1, PREC_2, …, PREC_12.** Each grid was then projected to UTM 16 NAD 1927 and clipped to the extent of the MAR. A bilinear interpolation was used. The resulting grids are stored as **PRECIP1, PRECIP2, …, PRECIP12.** A grid of annual precipitation **ANNUALRAIN** was computed by adding the 12 grids.

The calculation of dry season length was more complex. Based on existing literature, a month with less than 60 mm of precipitation is considered a dry month. An inspection of the range of values of the monthly grids showed that November through May are generally the drier months. While the minimum value in both July and August is also below 60 mm, the much shorter period and very few grid cells with a value < 60 makes this insignificant compared to the other seven months.

A short Avenue script was written as follows, to calculate a grid that indicates whether each of these seven months is a dry month. Note that the script is hard-coded to use the precipitation grids from months 11, 12, 1, 2, 3, 4 and 5.

```
theProj = av.getProject
theView = theProj.finddoc("view1")

r1 = theView.FindTheme("precip1").getGrid
r2 = theView.FindTheme("precip2").getGrid
r3 = theView.FindTheme("precip3").getGrid
r4 = theView.FindTheme("precip4").getGrid
r5 = theView.FindTheme("precip5").getGrid
r11 = theView.FindTheme("precip11").getGrid
r12 = theView.FindTheme("precip12").getGrid

' Only Nov-May are potentially dry months so leave out other months.
g = 20000000.asgrid +
  (((r11 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 1000000) +
  (((r12 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 100000) +
```

```
        (((r1 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 10000) +
        (((r2 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 1000) +
        (((r3 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 100) +
        (((r4 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 10) +
        (((r5 < 60.asgrid).Con(1.asgrid,0.asgrid)) * 1)

    gthm = gtheme.make(g)
    theView.addTheme(gthm)
```

The output grid has 8-digit numbers only. The first digit is always 2 and has no meaning: it exists solely to make sure that the first digit is not a 0 (resulting in a number less than 8 digits long). The 2nd through 8th digit indicate whether, in exactly the following order, the month of November, December, January, February, March, April, and May is a dry month (value=1) or not (value=0). A reclassification table was manually created (Table 1-6).

Note that the number *Dry_Months* is the number of consecutive dry months. For example, a value of 20101010 is reclassified as 1 because there is a maximum of just one consecutive dry month (albeit it occurs three times), not three consecutive dry months. The resulting grid was saved as **DRYMONTHS** (Table 1-7).

Table 1-7: Grid reclassification (resampling) scheme for the number of dry months.

Value	Count	DryMonths
20000000	59136	0
20000010	10397	1
20000011	104	2
20000100	18129	1
20000101	142	1
20000110	42598	2
20000111	187	3
20001000	2164	1
20001010	4224	1
20001100	5290	2
20001110	67622	3
20010110	25	2
20011000	14	2
20011100	1320	3

Value	Count	DryMonths
20011110	34593	4
20011111	6	5
20101000	2	1
20101010	4	1
20101100	10	2
20101110	4406	3
20111000	57	3
20111100	6604	4
20111110	61067	5
20111111	29	6
21111100	10403	5
21111110	114659	6
21111111	6930	7

Next, the majority filter was applied five times and the grids saved as **ANNUALRAINFT** and **DRYMONTHSFT**. Lastly, the grids were clipped using the raster calculator

`Con([BASIN250] == 1, [DRYMONTHSFL])`	Saved as **MXDRYMON**
`Con([BASIN250] == 1, [ANNUALRAINFL])`	Saved as **MXRAINYR**
`Con([BASIN250] == 2, [DRYMONTHSFL])`	Saved as **BZDRYMON**
`Con([BASIN250] == 2, [ANNUALRAINFL])`	Saved as **BZRAINYR**
`Con([BASIN250] == 3, [DRYMONTHSFL])`	Saved as **GTDRYMON**
`Con([BASIN250] == 3, [ANNUALRAINFL])`	Saved as **GTRAINYR**
`Con([BASIN250] == 4, [DRYMONTHSFL])`	Saved as **HNDRYMON**
`Con([BASIN250] == 4, [ANNUALRAINFL])`	Saved as **HNRAINYR**

1.4.6 Contextual factors – protected areas

1.4.6.1 Data source

The World Dataset of Protected Areas (WDPA) that is maintained by UNEP-WCMC has been used. Initially the 18-May-2005 WDPA version was made available. A comparison with similar data from both CCAD and MesoStor showed major discrepancies, in particular for Honduras. There were obviously missing data in the WDPA dataset. Revisions were started during Emil Cherrington's visit in December 2005 and an improved dataset for MX, GT, BZ and HN was made available in January 2006. A further revision was completed in May 2006, along with a hypothetical future protected area dataset for the scenarios. The only key difference between the Jan and May versions was the inclusion in May of a large area in Belize (Gallon Jug Estate). Table 1-8 lists the prevailing WDPA types in the four countries along with the number of polygons of each type.

1.4.6.2 Data processing

The WDPA dataset contains protected areas with different types of designation (national parks, biological reserves, etc.). For the regression, the degree of protection from land use change is important. The IUCN category (IUCN 1994) was used to generate an estimate of protection level.

The following assumptions were made.

◊ The areas are legally protected from land use change if they are in IUCN Categories I to IV. There are some exceptions for category III (Natural Monument), but this general rule will be used in the CLUE-S model.

◊ The areas may be subject to some level of change (but certainly not complete change) if they fall in IUCN categories V and VI.

◊ Any area that does not have a category assigned (115 areas for the MAR countries), was treated as if it was fully protected from change.

Data processing steps:

◊ Two new fields named **PROTECTED1** and **PROTECTED2** were added to the WDPA shapefile **WDPA_MAR_SUBSET_UTM16.SHP**. The field were of type integer.

◊ All polygons of the categories I to IV and the "unset" ones were given a value of 1 for **PROTECTED1** (full protection). All polygons in categories V and VI were given a value of 1 for **PROTECTED2** (partial protection).

◊ The shapefile was rasterized on both fields and the resulted grids saved under the same name as the fields, **PROTECTED1** and **PROTECTED2**. Note that these grids have values only for the WDPA area, not for the entire country.

◊ Lastly, the following equations were used to created the final clipped grids:

`Con(isNull([protected1 – protected1]),0,[protected1 – protected1])`, saved as **WDPAR1**

`Con(isNull([protected2 – protected2]),0,[protected2 – protected2])`, saved as **WDPAR2**

Table 1-8: Prevailing designation types of WDPA areas in Mexico, Guatemala, Honduras and Belize.

Designation Type	Areas [1]
Anthropological Reserve	1 (1)
Archaeological Reserve	12 (12)
Archaeological Site	2 (1)
Area de Protección Especial	13 (5)
Biological Reserve	12 (8)
Biosphere Reserve	47 (15)
Biosphere Reserve Core Zone	89 (8)
Bird Sanctuary	7 (3)
Crocodile Reserve	1 (0)
Cultural Monument	7 (3)
Fisheries No Take Zone	11 (1)
Flora and Fauna Protection Area	402 (4)
Forest Reserve	18 (17)
Mangrove Reserve	1 (0)
Marine National Park	1 (0)
Marine Reserve	29 (4)
Multiple Use Area	10 (5)

Designation Type	Areas
Multiple Use Reserve	1 (1)
National Park	121 (40)
National Park - Buffer Zone	1 (1)
Natural Monument	10 (3)
Natural Resources Protection Area	2 (0)
Nature Reserve	4 (4)
Private Natural Reserve	53 (16)
Private Reserve	18 (18)
Protected Biotope	6 (4)
Regional Park	20 (8)
Reserva de Manantial	2 (2)
Sanctuary	28 (1)
Wildlife Refuge	20 (11)
Wildlife Sanctuary	9 (8)
Zona de Amortiguamiento	27 (6)
Zona de Veda Definitiva	24 (4)
Area Productora de Agua	1 (0)

1.4.7 Contextual factors – access to roads and markets

The accessibility of transportation links and markets are important explanatory factors of land use patterns and how land use changes. Accessibility is more than a measure of distance. It has been described as the ease with which a location may be reached from another location. The concept of accessibility has been used in rural development policy as an indicator or rural deprivation and as a variable in location analysis.

Farrow and Nelson (2001) and Nelson (2000) developed a raster GIS-based methodology for calculating accessibility grids using cost-distance functions. The same methodology was used here for calculating accessibility of roads and markets.

1.4.7.1 Data source and data processing - roads

Numerous roads datasets of varying quality and ground year were identified (Appendix 2). The best quality regional dataset was the one from MesoStor (**`RED_VIAL_LINE.SHP`**). In addition, other datasets, thought to be more accurate, were available for Belize. A national map was created by Jan Meerman, as an update of the Land Information Centre's (LIC) roads dataset, using 2000-03 Landsat Imagery. Furthermore, Emil Cherrington made available a 2005 road dataset for southern Belize.

The processing of the road data was cumbersome for several reasons. First, while all three datasets included a road classification, these classifications were different and needed to be reconciled. Second, overlaying the data for Belize showed that they were all different, though no single dataset seemed superior to the others. Some existing roads were missing in the MesoStor data included in the more recent Meerman data, but the opposite was true for other roads. The Belizean datasets were also most detailed, including many tracks.

[1] Total number of WDPA areas in Mexico, Guatemala, Honduras and Belize. The number between parenthesis is the number of areas that are wholly or partially within the MAR catchment boundaries.

Thus, reconciling these differences and the creation of a single combined dataset was the first processing step. QuickBird Satellite imagery, viewed through Google Earth, was used to resolve discrepancies about the existence or precise location of roads. The combined dataset **MAR_ROADS_MODELLING.SHP** has the fields *TYPE* and *SOURCE*. The former field is used for symbology. For consistency between countries, tracks were omitted. The *SOURCE* field shows from shapefile each road originated.

1.4.7.2 Data source and data processing - markets

It was assumed that markets exist in the larger cities, so a dataset of settlement locations with population data was needed. No such single dataset for the entire MAR or Central America existed, however, several other datasets that covered a country where available. The settlements data from the Selva Maya CD provided good coverage in Mexico, Belize and all but the southern part of Guatemala. Better data for Belize were available from the Belize Tropical Forest Studies project (http://www.green-hills.net/btfs/). Several datasets were available for Honduras and the one from IGN/CCAD was the most complete. The datasets were merged and reviewed, resulting in the combined dataset **MAR_SETTLEMENTS_POP.SHP**.

1.4.7.3 Data processing - accessibility

The methodology described by Farrow and Nelson (2000) was followed, although their accessibility wizard (an Arcview GIS 3.2 extension) was not used, to retain control over all processes. Several new grids were prepared as an input to the cost-distance functions.

- ◊ To avoid edge effects that may be caused by the exclusion of roads that are just outside the MAR boundary, the catchment extent was buffered at 50 km and rasterized. This raster **MASK50K** was used as a temporary analysis extent (Xmin=-10 000; Xmax=844 000; Ymin=1 469 000, Ymax=2 440 000).
- ◊ The land cover raster was recreated to include the 50 km buffer zone. The resulting grid had the same 10 classes (Table 1-9) and was saved as **ECOMAP50K.** A value of 0 (unknown) was assigned to those areas that fall in the buffer zone and that do not have land. Note that the precise value doesn't matter.
- ◊ Slope affects travel time. Slope in degrees was calculated from the DEM. Any areas not covered by the DEM and oceans were assigned a slope of 0. Again, the precise value of the additional areas in the buffer zone doesn't matter. The resulting grid was saved as **SLOPE50K.**
- ◊ Roads were rasterized using four classes: 1=paved roads; 2=major roads; 3=major roads dry season only; 4=other roads (Table 1-10). Tracks were omitted. The source grid **SRC-ROADS** was reclassified to contain only zeros, **SRC_ROADS_0**.
- ◊ Settlements with a population of at least 5 000 and 10 000 were selected from **MAR_POP_BUF_75KM.SHP** and rasterized to **SRC_POP5K** and **SRC_POP10K**. The only grid value is 0.
- ◊ Next the friction surface was created. As the cell size is 250 m, friction values were expressed in seconds. This was a two-step process. First, three input grids (slope, land cover and roads) were reclassified to their friction values (see Tables 1-9 to 1-11), resulting in **FRIC_ROADS**, **FRIC_SLOPE** and **FRIC_LAND**.
- ◊ Next, the three reclassified "semi-friction" grids were combined into a single surface using the following expression. The output was saved as **FRICTION**, and had friction values from 8 to 2 700 seconds, indicating difficulty of passing through a 250 m grid cell.

```
FRICTION250 = ([fric_roads].isnull.Con([fric_land] *
[Fric_slope],[fric_roads] * [Fric_slope]))
```

The same friction surface, but expressed per map unit passed through:

```
FRICTION = FRICTION250 / 250
```

Accessibility in terms of travel time, in hours, was calculated using ArcView 3, as:

```
ACCESS_ROADS = [Src_roads_0].costdistance([friction],nil,nil,nil) /
3600
ACCESS_POP5K = [Src_pop5k].costdistance([friction],nil,nil,nil) /
3600
ACCESS_POP10K = [Src_pop10k].costdistance([friction],nil,nil,nil) /
3600
```

◊ Because of the strong interdependence between access to roads and access to market, only one of these factors (**ACCESS_POP10**) was ultimately included in the regression analysis. Lastly, the **ACCESS-POP10K** grid was masked and clipped to create four country-scale grids in the final format, using the raster calculator:

`Con([BASIN250] == 1, [ACCESS_POP10K])`, Saved as **MZACSMRK**
`Con([BASIN250] == 2, [ACCESS_POP10K])`, Saved as **BZACSMRK**
`Con([BASIN250] == 3, [ACCESS_POP10K])`, Saved as **GTACSMRK**
`Con([BASIN250] == 4, [ACCESS_POP10K])`, Saved as **HNACSMRK**

Table 1-9: Friction values for land cover with 250 m grid cells. On land cover, average walking speed was estimated at 4km/hr, but reduced to 3 km/hr in forest and increase to 5 km/hr in urban areas.

Land cover type	Speed (km/hr)	Friction value (sec per 250 m)
0. Other/Unknown	4	225
1. Broad-leaved forest	3	300
2. Pine forest	3	300
3. Agriculture/pasture	4	225
4. Scrub	4	225
5. Savanna	4	225
6. Wetland/Swamp	1	900
7. Mangroves	1	900
8. Urban	5	180
9. Water	0	10000

Table 1-10: Friction values for different road type with 250 m grid cells.

Road type	Speed (km/hr)	Friction value (sec per 250 m)
1. Paved road	110	8
2. Major road	60	15
3. Major road (dry season only)	50	18
4. Other road	30	30

Table 1-11: Friction multipliers for slope. There is no accounting for slope direction; it is assumed that travelling both up-slope and down-slope incurs a reduction in travel speed.

Slope		**Friction value multiplier**
0 – 5 degrees		1
5 – 10 degrees		2
10 – 20 degrees		3
> 20 degrees		5

1.4.8 Contextual factors – tourist hotspots and areas of coastal development

1.4.8.1 Data source

The most relevant dataset was the tourism threat layer from the Selva Maya data CD, covering the Yucatan, Belize and the Peten region of Guatemala (the northern half). It is composed of hexagonal polygons of 100 ha, with an attribute "Qualification" (*Calificacia*) that indicates what part of the polygon is under threat. Nearly all of the areas under threat are predominantly mangroves. In addition, WWF (email from Melanie McField) supplied the approximate location of tourism hotspots, drawn on maps in a PowerPoint file. This confirmed the accuracy of the Selva Maya dataset, though Honduras was not covered by either. The two main tourist areas on mainland Honduras are the cities of La Ceiba and Trujillo. These cities were added to the Selva Maya dataset.

While there is general consensus that urban development near tourist hotspots is a major threat to the land in those areas, its use as an explanatory factor in the statistical analysis difficult, because the impact of tourism is highly localized, whereas the statistical analysis and subsequent modelling is carried out at a national level.

The problem can be split in two. First, coastal development can never be an explanatory factor for (urban) developed land that is not near the coast, particularly in Honduras, which has major urban areas inland. Second, the available data for tourism hotspots point out the areas that are under the greatest pressure, rather than actual areas of tourism-induced urban development. Overlaying the Selva Maya tourism threat layer with the ecosystem map land cover data shows that nearly all of the areas under threat are mangroves.

Consequently, it is likely that a regression analysis between the land cover data and tourism hotspots will not show a significant relationship. However, the areas under threat from coastal development were included in the statistical analysis in order to confirm this suspicion.

1.4.8.2 Data processing

- ◊ A field named *RECLASS* was added to the Selva Maya shapefile and all polygons with a qualification > 100 (out of 1000) were given a value of 1. All other polygons were given a value 0. The shapefile was rasterized on the field and the resulted grid saved as **COASTD**.
- ◊ The following equation was used to created the final clipped grid:

  `Con(IsNull([coastd]),0,[coastd])`, saved as **TOURIS**.

2 Analysis of drivers of land use change

2.1 Land Use Change Adjacent to the Mesoamerican Reef

This section reviews literature on land use changes in the project region over the past twenty or so years. It was originally released as a working document entitled “Drivers of Land Use Change Adjacent to the Mesoamerican Reef: A Preliminary Review, by Emil Cherrington, Coastal Zone Management Institute, Belize City, in August 2005.

The individual Annotated Bibliographies compiled for the FAO’s 2000 Forest Resource Assessment for México, Belize, Guatemala and Honduras provide a great deal of additional insight into country-level environmental landscape changes in the respective countries (FAO 1999, FAO 2000a, FAO 2000b, FAO 2000c).

2.1.1 Mexico

The states of Campeche, Quintana Roo and the Yucatan fall in the MAR project area. . While national-level statistics are readily available on land cover change, GIS analysis is required to quantify changes within the project area. Considerable work on the drivers of land use change has been carried out for part of this area by the Southern Yucatan Peninsular Region (SYRP) project, a joint initiative between Mexico’s ECOSUR and the USA’s Harvard Forest (Harvard University) and Clark University.

Land use change can be summarized over the past thirty years as the result of an expansion of agricultural activities and rapid increase in population. Change seems to have reduced in light of the Mexican government’s promotion of the regional Mundo Maya archaeo-ecotourism initiative, which has also seen the designation of a number of protected areas in the project region since the late 1980s. It is acknowledged that even ecotourism will continue to affect the local environment.

2.1.1.1 Historical Land Use Change

Following a forestry (selective logging)-dominated period for the first half of the twentieth century which went bust by the late 1960s due to international market conditions, the Mexican government sought to use its southern frontier “as a release valve for land stress elsewhere in Mexico.” Peasant farmers were drawn to the area due to readily accessible land in the form of communally-owned *ejidos*, “the primary form of land tenure in Mexico,” created by Article 27 of the 1917 Constitution (Merrill 1996).

Infrastructural development, such as the completion of Highway 186 in 1970, which connected the capitals of Campeche and Quintana Roo to the rest of the nation, also encouraged land use change. Emphasizing agriculture, Mexican governments of the 1970s and early 1980s sought to “[reshape the] forest frontier into a rice and cattle producing area.” Seasonal wetlands known as *bajos* were converted to large-scale rice paddies, but poor practices led to failure of this venture. The land has since been used for pastureland. Other agricultural activities include cattle ranching, fruit orchards, and the cultivation of chilli peppers, corn and beans.

Trade liberalization in the 1990s accompanied land reforms in which farmers received formal title to *ejidos*, allowing them to sell and lease plots (if this is agreed to by their communities). Subsidies and price controls were eliminated, as was further distribution of land.

Mexican participation in the regional Mundo Maya initiative is currently being promoted by the government, which is seeking to capitalize on the region's rich history. A number of protected areas have hence been designated since the late 1980s. According to WRI (2004), coastal development is a major issue due to resort developments, particularly on the Caribbean coast of Mexico.

2.1.1.2 Explicit / Implicit Drivers

As indicated above, in the recent past, government agricultural policies in the form of subsidies, price controls and ready distribution of land encouraged deforestation in southern Mexico. These have been discontinued with trade liberalization and a new emphasis on tourism. However, even with nature-based tourism, in the archaeologically-rich inland and in coastal areas, a demand is placed on land resources.

It remains to be seen how poverty and population growth also affect land use change in southern Mexico, although discontinued distribution of lands may lead communities to encroach on protected areas. The effort at making *ejidos* transferable by sale and lease is aimed at improving the economic situation of peasant farmers by proving them with access to credit. The elimination of subsidies for export crops should not impact demand in local markets for food, especially given steady population growth.

Regional influences, such as Plan Puebla-Panama, are explored in section 2.1.5.

2.1.2 Belize

Land use change over the past twenty plus years of Belize's history can be summarized as the continuous expansion of agriculture (including aquaculture), and infrastructural expansion driven by population growth (including immigration) and tourism. These changes have occurred after Belize's attainment of independence from Great Britain in 1981. Despite a rapidly changing natural environment, deforestation was not acknowledged as an issue until resource assessments of the mid- to late-1990s which indicated that deforestation was occurring at rates of roughly 24 280 ha a year in the early 1990s (FAO 2000a). Whereas in the 1980s, Belize boasted 97% forest cover, the most recent (2004) assessment indicates that forest cover is closer to 63%, down from 72% in the beginning of the 1990s (DiFiore 2002, Fairweather & Gray 1994, Meerman 2005).

2.1.2.1 Historical Land Use Change

For most of the past three hundred and fifty years of Belize's history, forestry was the mainstay of the territory's economy. Colonial masters intentionally suppressed agriculture to maintain forest resources, even as already-independent neighbouring republics had begun their phase of agricultural development. The 20th Century saw a gradual decline of forestry due to depressed prices on the world market, and the rise of a national economy founded on the export of agricultural and marine products. Passage of the Land Reform Ordinance in 1962 further shifted emphasis to agriculture, and between 1971 and 1982, 212 465 ha of land were transferred farmers. Plummeting prices for Belize's agricultural exports starting in the late 1970s, even further spurred agricultural expansion and made once-independent subsistence farmers even more dependent on international market forces.

The mid-1960s also saw the gradual establishment of a tourist industry based largely on the territory's offshore attractions though the industry, did not really take off until the post-Independent 1980s, following the creation of a Ministry of Tourism & the Environment whose efforts centred on marketing the nation as a Caribbean tourist destination (McMinn & Cater 1998). By the late 1990s, tourism began to displace agriculture as the major engine of economic growth, averaging 20.2% of GDP per year between 1997 and 2001 (GOB 2002). Although tourism relies on Belize's natural assets, the industry has exerted its own impact on the national landscape, particularly in coastal areas, where the most rapid changes are believed to be occurring.

2.1.2.2 Explicit / Implicit Land Use Policies

The Belizean Government continues to be the largest landowner in Belize, and almost 37% of the country's land is vested in protected areas. Only a few of these are privately-owned. The government encourages small and large-scale enterprises in tourism or agriculture, in the face of ever-mounting foreign debt and continuing trade deficits. The implicit government policy has been support for the agricultural, aquacultural, and tourism sectors (over say forestry) because of the revenues and contribution to GDP generated.

The main export crops include citrus, bananas, and sugarcane, while locally-consumed crops include beans, rice and corn. With regard to the export crops, sugarcane is cultivated mostly in the north of Belize, while citrus and bananas are cultivated in the centre and south of the country. In the 1970s, for instance, revenue from sugar exports accounted for roughly 70% of export revenue (Merrill 1992). While there was no formal agriculture policy until 2003, agriculture was and still is widely promoted, though there are questions as to the impact of trade liberalization. Traditionally there have been price guarantees for Belizean crops in the American and European markets, even though such support is now waning.

Boles (2005) cites poverty as a significant driver of land use change, indicating that it has driven deforestation in southern Belize via slash and burn *milpa* agriculture. Some speculate that integration of Belize into the Caribbean Single Market & Economy (CSME) initiative may mean increased immigration from the Caribbean and hence greater demand for land.

Belize has one of the most extensive protected areas systems in the world, and almost one protected area has been added to the national list each year. Nevertheless, there have been de-gazettements of protected areas and sections thereof in recent years. The ongoing National Protected Areas Policy & System Plan (NPAPSP) project seeks to define a national policy on protected areas, and to rationalize their future existence.

The lack of an overarching, explicit land use policy and plan has resulted and continues to result in haphazard development. The National Lands Act encourages prospective landowners to 'develop' the land, whereby development is defined as modification of the land's original cover. There is a continued outlook in some quarters that natural habitat as 'useless' land to be 'developed,' irrespective of its biophysical potential. Due to the continued importance of coastal areas to tourism, a continuous, largely unregulated development in coastal areas (on the coastal mainland and on offshore islands) led to the establishment both of a national Coastal Zone Management Authority and, more recently, guidelines for development in coastal areas. Some institutional weakening of the Coastal Zone Management Authority has, however, occurred since its initial sponsorship through the UNDP-GEF and EU ran out in mid-2004.

A project in the pipeline through the UN Convention to Combat Desertification, includes the preparation of a national land use plan to guide future development efforts. An ongoing land titling initiative is occurring through the Land Management Programme, which is conducting cadastral surveys in the northern half of Belize. The LMP is intended to stimulate economic

growth through secure land tenure. It remains to be seen if the end result will be further emphasis on productive enterprises such as agriculture.

In light of the above analysis, it seems that population growth, migration, coastal development, and agricultural / aquacultural expansion will be the main factors driving land use change in Belize in the near future.

2.1.3 Guatemala

While eight of Guatemala's southern Pacific states[1] fall outside in the MAR project area, most of the information available covers the whole country. The National Institute of Forestry (INAB) reports that in the 1980s, deforestation occurred at a rate of roughly 60 000 ha per year, while in the 1990s, the rate was roughly 90 000 ha per year (FAO 1999). This change seems to have driven jointly by agricultural expansion and human population dynamics, including migration to the largely forested eastern highlands of the Petén in northern Guatemala (FAO 1999). FAO (1999) further states that forest policy had changed three times over the twenty-year period, and that there has been competition between the forest and agricultural sectors, though since the 1990s, forestry has played a larger role in the economy.

2.1.3.1 Historic Land Use Change

Large areas of land were converted to agriculture from the early 20th century onwards. Around the middle of that century, Guatemalan governments promoted agriculture as the major avenue of economic growth. Government policy was that the wide expanses of forest were essentially "useless" and should be converted to "productive" uses. In reality, some of the areas where such land conversion occurred, such as the Petén, are infertile. Land was openly distributed to peasant farmers, and promotion of agricultural activities took the form of subsidies, price guarantees and laws encouraging development via land conversion.

Commercial, export-oriented agriculture has been practiced mostly in southern Guatemalan states (most of which fall outside of the project area), while shifting cultivation, cattle ranching (and illegal logging) have predominated in the Petén (FAO 1999). Shriar (2002) cites the Petén as being 70-80% forested in 1970, but only 50% forested by the late 1990s.

The late 1980s through the mid-1990s saw the establishment of various protected areas such as the Maya Biosphere Reserve in the Petén, and institutional changes empowering the national Commission on Protected Areas (CONAP) and the INAB. The role of forests in the national economy has likewise changed, with the introduction of market incentives to prevent deforestation, including concessions, and exploration of carbon sequestration as options for revenue generation.

FAO (1999) recognizes the increasing role of managed forests in the Guatemalan economy, but notes that there is a national debate as to whether agriculture has stabilized or will continue to expand, and on the effectiveness of protected areas in maintaining forest resources. CONAP has delegated management duties of various parks to NGOs.

2.1.3.2 Explicit / Implicit Drivers

Shriar (2002) points to a growing population in areas such as the Petén, while FAO (1999) discusses the significance of "migration, colonization and dependency" on change. FAO

[1] These are Escuintla, Huehuetenango, Jutiapa, Quezaltenango, Retalhuleu, San Marcos, Santa Rosa, and Suchitepequez. According to FAO (2001), these areas produce sugarcane, cotton and cattle for export.

(1999) also points to the emergence of forestry as a major player in the Guatemalan economy as being able to drive sustainable use of forests, particularly because of economic incentives coming from the government. Other factors mentioned by both Shriar (2002) and FAO (1999) are the availability of land (even despite protected area designations), and the incidence of rural poverty, which limits communities' options economically.

2.1.4 Honduras[1]

While the other nations of the project area are acknowledged to be underdeveloped, Honduras is one of the few Highly Indebted Poor Countries in Latin America (Jansen *et al*. 2005). The nation has a more diverse topography than the rest of the region, with a large mountainous area and largely infertile soil (Merrill 1993). As with the other nations, agriculture is a major contributor to GDP. The World Bank figures cites the nation's population growth at 2.6% per annum (World Bank 2004c).

2.1.4.1 Historical Land Use Change

Martinez *et al*. (1999) indicate that almost half of the forests that existed in 1965 had been converted to other uses by 1992. FAO (2000b) and Merrill (1993) also indicate that large areas of forest land were converted to agriculture in the latter half of the twentieth century, continuing into the late 1980s. Farmers focused on the production of livestock, and the cultivation of coffee, bananas, sugar, and basic grains. Despite the poor soil of the nation's mountainous landscape, agriculture has mainly expanded, rather than intensified, and resulted in the erosion of an estimated 2.3 million ha (FAO 2000b). In the 1990s, following trade liberalization, commercial agriculture declined.

Other factors contributing to continuous land conversion have been population growth, and the incidence of natural disasters. Hurricane Mitch in 1998 had substantial impacts on both natural forests and human-dominated landscapes (FAO 2000b).

2.1.4.2 Explicit / Implicit Drivers

The major cited drivers of deforestation have included expansion of agriculture & cattle-ranching, population growth & colonization, land tenure, energy production needs, competition between forestry and agricultural policies, forest fires, crop disease and natural disasters such as hurricanes (FAO 2000b).

According to Jansen *et al*. (2005: 18), trade and market liberalization in the 1990s saw the discontinuation of "land distribution and rural credit provision," agricultural extension services, consumer subsidies and guaranteed prices. In theory, this should have discouraged the expansion of export-based agriculture. The authors suggest that increased emphasis should be placed on intensification of existing agriculture as a means of poverty alleviation. They also recommend putting measures in place to limit population growth.

Bonta (2005: 95) states that "by 2000, Honduras alone possessed over 100 protected areas…including 37…'cloud forests' that had been set aside by presidential decree in 1987". He suggests that many Honduran protected areas are protected merely on paper.

2.1.5 Regional Synthesis

Certain cross-cutting themes seem to emerge from the four countries, including:

[1] Only the southern departments of Choluteca and Valle are excluded from the project region.

(i) A strong emphasis on agricultural activities in the last few decades, at the expense of forest land. In the case of both Belize and Honduras, it appears that agriculture is expanding rather than intensifying

A former emphasis on forest management (excluding Honduras), faltering in the mid-20th Century due to the international market

(ii) An expansion of road networks and settlements driven by population dynamics of both growth and migration

2.1.5.1 Future Land Use Change

A number of factors operating at national and regional scales can be expected to influence future land use changes. For one, each of the countries of the region are the signatories to some form of trade liberalization agreement, whether it be the *Free Trade Agreement of the Americas*, the *Central America Free Trade Agreement* or the *Caribbean Single Market and Economy*. The conventional wisdom is that these will discourage agricultural expansion by removing subsidies and price guarantees

Other sources indicate that such liberalization will instead encourage agricultural expansion, because countries will have to export more products to maintain previous levels of revenue. Plan Puebla-Panamá can be expected to open up previously inaccessible areas to development. The regional fisheries & aquaculture policy advocated by the PREPAC project may in turn lead to increased aquacultural activities in coastal areas.

Population growth and migrations will themselves exert pressures on national land resources. Such migrations may be within individual countries, or between nations in the region, such as expected to impact Belize through the CSME initiative. Tourism is expected to continue to grow, with a proportionate increase in demand for land in coastal areas and offshore islands. The influence of climate change on land suitability will also become increasingly important in the future.

While the list of possible future causes of land use change can only go on, with regard to spatially explicit causes, infrastructural development and expansion of both settlements and roads, and expansion (rather than intensification) of agriculture and aquaculture seem like the most plausible factors.

2.2 Statistical analysis of explanatory factors for land use patterns

2.2.1 Methodology

One set of parameters for the CLUE-S land use change model is derived from regression equations that describe the relationship between each individual land use type and a relatively small but diverse number of “explanatory factors” or “location factors”. The regressions attempt to quantify the relationships between the location of all land cover types (dependent variables) and a set of explanatory factors (independent variables).

These regression equations are used to compute the relative suitability of a particular location for each of the possible land use types during a simulated future scenario. The regression coefficients are then input as model parameters. The regression analysis is one of the most critical and comprehensive tasks during the preparation of the CLUE-S model.

The regression analyses were completed using the statistical program SPSS v 11.5. A binomial (binary) logistic regression was used, as is appropriate when the dependent variable is a dichotomy (i.e. 0/1 values for each land cover class). Unlike OLS (ordinary least squares) regression, logistic regression does not assume linearity of the relationship

between the independent variables and the dependent, does not require normally distributed variables, does not assume homoscedasticity[1], and in general has less stringent requirements. It does, however, require that observations are independent and that the logit (effect) of the independent variable is linearly related to the dependent.

The spatial relationships between land use and the selected set of variables were quantified in a two-step procedure using binary logistic multiple regression analysis. Independence between variables is a prerequisite for this method. The use of a stepwise regression procedure solves multi-collinearity problems. In step one, significantly contributing variables were selected with a stepwise forward regression, using the 0.05 significance criterion. In step two, this set of variables was used to construct multiple regression equations.

The regression analysis was performed separately for every land use type and stratified by dividing the study region into the four countries (or parts thereof).

The CLUE-S user's manual (Verburg 2004) and the associated exercise 4, "*How to do the statistical analysis*" (Verburg *et al*. 2004) explain how to conduct these analyses in SPSS. The guidelines provided in these documents provided the basis for the analysis, though additional online information proved useful.[2]

2.2.2 Evaluating statistical significance and goodness of fit

The output of a logistic regression in SPSS includes various statistics on the significance of the individual regression coefficient and the overall fit of the regression equation. These are found in the "Variables in the Equation" section of the output. The final regression model is the last step model for which adding another variable would not improve the model significantly.

2.2.2.1 Regression coefficients

The standard regression coefficients (standardized betas) are used to indicate the relative importance of individual variables in a given equation. Note that you cannot compare the various coefficients for the partial factor across rows. That is, the absolute value of a regression coefficient is meaningless if it is not considered within the context of the total number of significant factors and their respective importance.

2.2.2.2 Wald test

The Wald test is used to test the statistical significance of individual logistic regression coefficients (β coefficients) for each independent variable, i.e., to test the null hypothesis that a particular logit (effect) is zero. A Wald test calculates a *Z* statistic, which is B / SE. Values greater than zero indicate that their effect is not significant, and these independent variables may well be dropped from the model.

Initially, all explanatory factors were included in the regression. When the results indicated that a factor(s) was not statistically significant, the insignificant factor(s) was specifically removed (i.e., not selected as an independent variable) and the regression analysis was repeated. This process was iterated until all Wald values were zero or near-zero.

[1] Homoscedasticity = constancy of the variance of a measure over the levels of the factor under study.

[2] Other useful sources included http://www2.chass.ncsu.edu/garson/PA765/logistic.htm and http://www.ats.ucla.edu/stat/spss/topics/logistic_regression.htm

2.2.2.3 R-squared

The adjusted coefficient of determination (R^2), reported in the SPSS regression output, serves as a measure for the amount of variation in the dependent variable that is explained uniquely or jointly by the independents. However, note that it is a pseudo-R^2 that is not equivalent to the R^2 found in Ordinary Least Squares (OLS) regression. Hence, this R^2 statistic should be interpreted with great caution.

2.2.2.4 Relative Operating Characteristic (ROC)

The ROC characteristic is a measure of the goodness of fit of a logistic regression model, similar to the R^2 statistic in Ordinary Least Squares regression. A completely random model gives a ROC value of 0.5; a perfect fit results in a ROC of 1.0. The ROC was calculated only for Belize and Guatemala as these datasets are relatively small. Attempts to calculate the ROC for Mexico and Honduras resulted in the computer being locked for hours on end. The ROC values should also be interpreted with care. For example, the equation for savanna in Guatemala has an ROC of 1.0, which seems excellent, but is meaningless because the area of Savanna is extremely small, so the regression equation and ROC are not significant.

2.2.3 Regression results

The statistically significant regression coefficients along with the total number of significant location factors (NF) and the ROC statistics are listed in Table 2-1 to 2-4. The default number of decimal values in the SPSS output was increased from 3 to 4 because some coefficients – in particular for elevation and annual precipitation, which are relatively large numbers--- are significant only at the third or fourth decimal.

There are no results for Water, because the regression analysis was not conducted for this land cover type. Also, note that the results for mangroves and savanna in Guatemala are not significant because the area of these land cover types is very small (respectively 0.8 and 0.3 km^2). These data should be ignored, but are included here because the CLUE-S model requires regression coefficients for all land use type present.

*Table 2-1: Summary of the logic regression analysis for **Belize**. For each dynamic land use, the regression coefficients for all statistically significant explanatory location factors are listed, with the four most significant ones in bold. Note that the absolute value of a regression coefficient is no indicator of its level of significance, so even relatively small values may be in the top four.*

	0	1	2	3	4	5	6	7	8	9
	Unknown	B.L. Forest.	Pine forest	Agr/Pasture	Scrub	Savanna	Wetland	Mangroves	Urban	Water
Constant	22.3069	-1.4571	-5.8352	-2.5870	-5.1061	-4.0898	+1.3174	-5.2436	-5.4260	-3.1271
0. POPDEN	**-0.1271 (2)**	+0.0078	-0.0400	**-0.0782 (2)**	-0.0210	+0.0241	-0.0262	-	+0.0060	-0.0470
1. SDEPTH	-	+0.0112	+0.0422	+0.0309	+0.0189	+0.0477	-0.0124	+0.0046	-	-0.0167
2. SDRAIN	-13.0878	+3.0685	**-24.843 (4)**	+2.6108	+0.0003	**-21.904 (2)**	-0.4416	-8.0568	-1.9926	-
3. RAINYR	**-0.0138 (1)**	**-0.0004 (4)**	+0.0010	+0.0005	-	+0.0011	**-0.0008 (3)**	**+0.0015 (3)**	**+0.0024 (3)**	**+0.0017 (2)**
4. DRYMON	-0.9545	-0.1538	-	+0.1446	**-0.3929 (3)**	+0.0993	-	**+0.6580 (4)**	+0.1273	-
5. ELEVAT	**-0.2195 (3)**	-0.0002	**+0.0081 (1)**	-0.0003	**-0.0017 (4)**	**-0.0186 (3)**	**-0.1676 (1)**	**-0.1927 (1)**	-	**-0.0258 (4)**
6. SLPDGS	+0.4280	**+0.0811 (3)**	+0.0140	-	**0.0829 (2)**	**-0.7204 (4)**	+0.4240	+0.0975	-0.0594	+0.2321
7. ACSMKT	-	**+0.3888 (1)**	**-0.9785 (2)**	**-0.8834 (1)**	**-0.2993 (1)**	**-0.4508 (1)**	**+0.2888 (2)**	**+0.3880 (2)**	**-3.7940 (1)**	**-2.0572 (1)**
8. ACSRDS										
9. TOURIS	**-5.0293 (4)**	-0.4248	-	-1.4025	-	-1.1697	-0.5085	+0.7488	**+2.3536 (2)**	**+2.0064 (3)**
10. WDPAS1	-	**+1.1660 (2)**	+1.1161	**-2.1446 (3)**	+0.1790	+0.2115	**+0.8526 (4)**	-	**-1.5865 (4)**	+0.9016
11. WDPAS2	-	+0.6111	**+1.5436 (3)**	**-1.9867 (4)**	+0.3019	+0.9286	-0.7365	+0.1544	-	-0.6708
Final N.F. (significant number of location factors)	7	11	9	10	9	11	10	9	8	9
ROC (relative operating characteristic)	0.986	0.790	0.914	0.856	0.746	0.877	0.944	0.949	0.930	

*Table 2-2: Summary of the logic regression analysis for **Mexico**. For each dynamic land use, the regression coefficients for all statistically significant explanatory location factors are listed, with the four most significant ones in bold. Note that the absolute value of a regression coefficient is no indicator of its level of significance, so even relatively small values may be in the top four.*

	0	1	2	3	4	5	6	7	8	9
	Unknown	B.L. Forest.	Pine forest	Agr/Pasture	Scrub	Savanna	Wetland	Mangroves	Urban	Water
Constant	+6.8517	+0.7725		+3.3490	-4.3477	-1.4840	-0.3299	+2.4059	-0.5279	+3.9652
0. POPDEN	-0.0087	-0.0037		-0.0044	+0.0038	-0.0080	+0.0004	-0.0006	**+0.0032 (2)**	-
1. SDEPTH	+0.0931	**-0.0363 (1)**		**+0.0368 (4)**	+0.0277	-	-0.0360	**+0.0465 (2)**	-0.0183	-0.0135
2. SDRAIN	**+8.1756 (2)**	+0.7826		+1.1185	+0.7621	-1.5481	**-3.3492 (3)**	**+2.3327 (4)**	-	-3.2865
3. RAINYR	**-0.0096 (3)**	+0.0006		**-0.0049 (2)**	+0.0008	**-0.0025 (4)**	+0.0007	-0.0026	-	-0.0028
4. DRYMON	**-1.0723 (4)**	**-0.2020 (4)**	NOT	+0.0315	**+0.4965 (2)**	**-0.3356 (3)**	**-0.3577 (4)**	**-0.5768 (3)**	**-0.1976 (4)**	-0.1971
5. ELEVAT	**-0.2035 (1)**	**+0.0032 (3)**	PRESENT	+0.0004	**+0.0082 (3)**	**-0.0061 (2)**	**-0.1152 (1)**	**-0.2902 (1)**	**+0.0134 (3)**	-0.1682
6. SLPDGS	-0.3045	+0.0376		-0.1887	-0.1187	**+0.3921 (1)**	+0.3671	+0.0974	-0.4270	+0.9935
7. ACSMKT	-0.1832	**+0.1108 (2)**		**-0.8789 (1)**	**-0.5194 (1)**	-0.0998	**+0.1687 (2)**	+0.0558	**-3.8397 (1)**	-0.8043
8. ACSRDS										
9. TOURIS	-0.3411	-0.1851		-0.8338	-4.4556	-	-1.0558	+0.3901	-	+0.3677
10. WDPAS1	-2.5142	-1.9277		-3.9602	-	-	-	+1.5087	-	+1.5022
11. WDPAS2	+1.4217	-0.3500		**-1.2475 (3)**	**-1.1183 (4)**	-	+0.4964	-	-	+1.1391
Final N.F. (significant number of location factors)	11	11		11	10	7	10	10	6	10
ROC (relative operating characteristic)	0.960	0.643		0.772	0.755	0.696				

*Table 2-3: Summary of the logic regression analysis for **Guatemala**. For each dynamic land use, the regression coefficients for all statistically significant explanatory location factors are listed, with the four most significant ones in bold. Note that the absolute value of a regression coefficient is no indicator of its level of significance, so even relatively small values may be in the top four.*

	0	1	2	3	4	5	6	7	8	9
	Unknown	B.L. Forest.	Pine forest	Agr/Pasture	Scrub	Savanna[1]	Wetland	Mangroves[1]	Urban	Water
Constant	47.3927	-1.0271	-12.2485	-0.9537	-5.4976	-18.2304	-11.4624	-53.4470	-17.7335	+9.9883
0. POPDEN	**+0.0550 (2)**	+0.0004	**-0.0016 (3)**	-0.0004	-0.0019	-	**+0.0063 (3)**	**-0.5870 (3)**	**+0.0013 (1)**	-0.0565
1. SDEPTH	-	-0.0037	**+0.0998 (4)**	**+0.0213 (4)**	+0.0287	-	+0.0388	-	+0.1074	-0.0300
2. SDRAIN	-	**+1.3851 (4)**	-1.3376	-0.2118	-1.5277	+5.5433 (2)	**-7.7154 (4)**	-	+1.3544	-
3. RAINYR	**-0.0325 (3)**	-0.0004	**-0.0016 (2)**	-0.0001	+0.0006	-	-	-	**+0.0033 (3)**	-0.0011
4. DRYMON	**+0.7634 (4)**	-0.0506	-0.2201	-0.1077	**+0.3530 (2)**	-	-	-	+0.3273	-0.8731
5. ELEVAT	**-0.1978 (1)**	-	**+0.0025 (1)**	-0.0002	**-0.0009 (1)**	+0.0030 (1)	**-0.0183 (1)**	-	**-0.0016 (4)**	-0.0349
6. SLPDGS	-	-0.0016	-0.0079	-0.0172	**-0.0497 (4)**	-	-	-	-0.3538	-0.9330
7. ACSMKT	-	**+0.3799 (1)**	-0.0819	**-0.3457 (1)**	-0.0578	-	**+0.5710 (2)**	**-1.6120 (2)**	**-6.5289 (2)**	-1.6897
8. ACSRDS										
9. TOURIS	-	-	-	-	-	-	-	-	-	-
10. WDPAS1	-	**+1.9105 (2)**	-	**-1.3588 (3)**	-2.2227	-	+2.0176	**+6.6210 (1)**	-	+0.4520
11. WDPAS2	-	**+1.3967 (3)**	+0.1446	**-1.1538 (2)**	**-1.1085 (3)**	-	+2.1844	-	-	-
Final N.F. (significant number of location factors)	4	9	9	10	10	2	7	3	8	8
ROC (relative operating characteristic)	1.000	0.787	0.906	0.748	0.755	0.972	0.963	1.000	0.993	0.994

[1] Results for savanna and mangroves are not significant and unreliable because the area of these land cover types in Guatemala is nil (respectively 0.3 and 0.8 km^2).

*Table 2-4: Summary of the logic regression analysis for **Honduras**. For each dynamic land use, the regression coefficients for all statistically significant explanatory location factors are listed, with the four most significant ones in bold. Note that the absolute value of a regression coefficient is no indicator of its level of significance, so even relatively small values may be in the top four.*

	0	1	2	3	4	5	6	7	8	9
	Unknown	B.L. Forest.	Pine forest	Agr/Pasture	Scrub	Savanna	Wetland	Mangroves	Urban	Water
Constant	-10.2362	-2.4795	+1.5916	+1.4693	+15.7990	-14.6541	+5.2971	-6.0420	-5.8989	-14.8752
0. POPDEN	-0.0007	-	**-0.0095 (4)**	-	-0.0074	**-0.1154 (2)**	-	-0.0150	**+0.0026 (1)**	-0.0059
1. SDEPTH	+0.0511	+0.0177	-0.0059	-0.0089	-	+0.0573	-	-	-0.0165	-0.0295
2. SDRAIN	**+1.8542 (4)**	-0.5031	+1.5214	-0.7989	-1.6502	+2.3869	-1.0514	-	**-2.9412 (4)**	+0.6983
3. RAINYR	+0.0009	**-0.0010 (4)**	**-0.0026 (1)**	**+0.0007 (3)**	**-0.0105 (1)**	**+0.0039 (3)**	**-0.0031 (2)**	**+0.0020 (4)**	+0.0016	**+0.0066 (1)**
4. DRYMON	-0.1531	**-0.7078 (2)**	+0.0444	**+0.2402 (2)**	**-1.2983 (3)**	-0.7053	**-0.8714 (3)**	-0.8990	-0.2122	**+1.5561 (3)**
5. ELEVAT	**-0.0192 (2)**	**+0.0017 (3)**	**+0.0010 (2)**	**-0.0011 (1)**	-0.0009	+0.0027	**-0.0332 (1)**	**-0.1165 (2/3)**	**+0.0025 (3)**	**-0.0064 (4)**
6. SLPDGS	-2.6805	+0.0476	+0.0048	-	**-0.2143 (4)**	**-0.5584 (4)**	-0.1944	-	-	-0.1983
7. ACSMKT	**-0.1011 (1)**	**+0.2286 (1)**	-0.0208	-0.2079	-0.4109	**-0.2150 (1)**	**+0.0625 (4)**	**-0.2285 (1)**	**-9.8104 (2)**	**-0.2251 (2)**
8. ACSRDS										
9. TOURIS	-	-	-	-1.4446	-	-	-	-	+1.0999	-
10. WDPAS1	**+1.1004 (3)**	+1.5334	**-1.5463 (3)**	**-0.6011 (4)**	**+2.8179 (2)**	-6.3652	-1.4120	**+1.6109 (2/3)**	-	+0.5007
11. WDPAS2	-	-	-	-	-	-	-	-	-	-
Final N.F. (significant number of location factors)	9	8	9	8	8	9	7	6	8	9
ROC (relative operating characteristic)										

3 GEO-4 scenarios and the ICRAN MAR project

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3.1 Scenario summaries

Four scenarios for the 'Latin America and the Caribbean' UNEP region have been drafted in preparation for the publication of Global Environment Outlook 4 (GEO-4) in 2007. These narratives were developed by the LAC scenarios working group for GEO-4. The scenarios envisage differing social, political and economic trajectories, emphasising outcomes for the environment and human well-being. Three of the four draft scenarios have been selected for exploration of possible futures for land cover change within the ICRAN MAR project; the fourth scenario (Security First) is not presented here.

The GEO scenarios consider the period from 2007 through to 2050 for the whole of Latin America and the Caribbean, and encompass the overall interaction between human development and the environment. The ICRAN MAR project considers the period up to 2025, for the watersheds draining directly onto the reef and focuses on the impact of land cover change on coral reefs. This chapter summarises and adapts the GEO scenarios with a focus on this topic and timescale. The scenarios published in GEO 4 and in the forthcoming GEO-LAC will therefore differ in many respects from those presented here.

It is assumed that climate change and variability is not susceptible to further human influence up to 2025 – the change will occur has already been set in train. Changes in climate are therefore identical throughout the scenarios; what varies is the resilience and response of societies within each of the scenarios. For example, coral bleaching events can be expected to increase in frequency in every scenario; but the approach to and coordination in tackling the issue varies.

A comparison of modelled population and land cover changes up to 2025 for the scenarios follows the narrative description; the methods are described in Sections 3.2 and 3.3.

3.1.1 About the GEO-4 scenarios

UNEP is working on the fourth *Global Environment Outlook* (GEO-4), for release in 2007, 10 years after the first GEO, and 20 years after the Brundtland report (WCSD, 1987). The Global Environment Outlook process was initiated by UNEP for global environmental assessment and reporting process, in response to several Decisions of the UNEP Governing Council. The aim is to ensure that environmental problems and emerging issues of wide international significance receive appropriate, adequate and timely consideration by governments and other stakeholders. Projects are undertaken under the GEO programme at global, regional and local scales.

There are seven GEO regions, each divided into subregions for finer scale analysis and reporting. The Latin America and Caribbean (LAC or ALC) region is composed of the Caribbean, Meso-America and South America regions. The Meso-America subregion is the one relevant to the ICRAN MAR project, being composed of Belize, Costa Rica, El Salvador,

Guatemala, Honduras, Mexico, Nicaragua and Panama. Many GEO processes have been undertaken in the LAC region. The most relevant for the ICRAN MAR project are *GEO LAC 2000*[1], *GEO LAC 2003*[2], *Caribbean Environmental Outlook (1999, 2005)*[3] (includes Belize), *GEO Centroamerica 2004*[4], *GEO Biodiversidad (Centroamerica) 2003*[5], *GEO Guatemala 2003*[6], *GEO Honduras 2005*[7] and *GEO México 2004*[8].

GEO-3 presented a set of divergent global scenarios running from 2002 to 2032: Markets First, Policy First, Security First and Sustainability First (UNEP, 2002). These scenarios are being updated and extended to 2050 for GEO-4, with the global narratives being based on the work of seven regional working groups. Each regional scenario focuses on regional priorities defined by contributors to the GEO process. The LAC group met first as part of the global scenarios meeting in Bangkok, September 2005, and then in a follow-up meeting in Trinidad & Tobago, in February 2006. Each meeting included representatives from throughout the LAC region. In addition, feedback has been sought from a broader group including the regional team working on the state and trends section of GEO-4.

The narratives will be represented in the GEO-4 report alongside a set of quantitative outcomes. A process of reconciliation of the assumptions made in the different regional scenarios and by the modelling team is currently underway, with the first order draft of GEO-4 being circulated for review in May 2006.

It is anticipated that the adaptation of the GEO scenarios for the ICRAN MAR project will render the project outcomes more immediately accessible to policy makers who have already encountered the GEO work through UNEP's outreach efforts. It also allows the ICRAN MAR project to benefit from the substantial amount of work undertaken through GEO, including the modelling of regional scale land-cover change within an integrated modelling framework. The MAR project has discarded the Security First scenario, which results in a level of land cover change in between those of Markets and Policy First.

In the following sections, the global overview of each scenario is presented as described in GEO-3, and is followed by a regional summary based on the draft for GEO-4.

3.1.2 Markets First

3.1.2.1 GEO-3 scenario overview

"*Most of the world adopts the values and expectations prevailing in today's industrialized countries. The wealth of nations and the optimal play of market forces dominate social and political agendas. Trust is placed in further globalization and liberalization to enhance corporate wealth, create new enterprises and livelihoods, and so help people and communities to afford to insure against — or pay to fix — social and environmental problems. Ethical investors, together with citizen and consumer groups, try to exercise growing corrective influence but are undermined by economic imperatives. The powers of state*

[1] http://www.unep.org/geo/regreports.htm

[2] http://www.unep.org/geo/regreports.htm

[3] http://www.unep.org/geo/regreports.htm

[4] draft pdf obtained

[5] pdf obtained

[6] http://www.pnuma.org/dewalac_ingles/guatemala03_i.htm

[7] http://www.serna.gob.hn/documentos/GEO_Honduras_2005.pdf

[8] http://www.ine.gob.mx/ueajei/publicaciones/consultaPublicacion.html?id_pub=448

officials, planners and lawmakers to regulate society, economy and the environment continue to be overwhelmed by expanding demands." (UNEP, 2002).

3.1.2.2 MAR region summary (based on GEO-4 draft)

Economy and governance

- Public policy is geared towards supporting **commercial interests** and promoting the open exchange of goods and services. Social and environmental policies receive little attention or financial support; it is assumed that economic growth is in itself a sufficient route to progress.
- **Remittances** (funds sent home by migrant workers) are more important than foreign investment or aid; this is especially valuable for Mexico's economy.
- New **industrial parks** are built to entice national and foreign investment.
- **Tourist visits** to the MAR region increase until around 2025. With limited regulation, the impact of tourism on coastal ecosystems also increases. Visits then start to drop off as a result of deteriorating habitats and increasing pollution.

Population and standard of living

- **Populations increase**, but the growth rate slows with falling birth rates.
- For all MAR countries, the highest rates of **urbanisation** are seen under this scenario, with 80% of the regional population living in urban areas by 2025. Most development is unplanned, and built on the coast or around the industrial parks.
- Social services are reduced, and **inequity** in resource distribution increases.
- **Emigration** increases, with people from all countries of Central America moving northwards. This is especially relevant for Mexico, which after 2010 sees a lower rate of national population growth within this scenario than in any other. Migration also occurs within the country, with agriculturalists moving from the dry central region to the south, including the Yucatan penisula.

Environmental impacts

- Although sustainable development is much discussed, this scenario sees the greatest rate of **agricultural expansion**. Rates of habitat loss, fragmentation and soil erosion increase. Comparing the MAR countries, the rate of agricultural expansion is greatest in Mexico, Belize and then Guatemala. However, Honduras sees the highest rates of decrease in natural habitats, because the area remaining is already substantially reduced[1].
- Agrochemical **pollution** increases, despite the influence of emissions standards.
- The terrestrial **protected area** network expands slightly by 2025, to encompass 10% of all biomes. For 20% of the new sites, natural ecosystems are successfully protected from change over the scenario period. 60% are partially protected from change, and 20% fail to be protected (see Section 3-4).
- **Water** quality decreases and abstraction for tourism and agriculture increases, as a result of limited interest in promoting good watershed management practices.
- Both agricultural and natural ecosystems are vulnerable to an increasing frequency of **climate** extremes. Fire frequency increases, especially in the dry forests of Honduras and Guatemala.

[1] 56% of Honduras was already dedicated to agriculture by 2000, as opposed to 31% in Guatemala, in 19% in Belize and only 6% in Mexico.

3.1.3 Policy First

3.1.3.1 GEO-3 scenario overview

"*Decisive initiatives are taken by governments in an attempt to reach specific social and environmental goals. A coordinated pro-environment and anti-poverty drive balances the momentum for economic development at any cost. Environmental and social costs and gains are factored into policy measures, regulatory frameworks and planning processes. All these are reinforced by fiscal levers or incentives such as carbon taxes and tax breaks. International 'soft law' treaties and binding instruments affecting environment and development are integrated into unified blueprints and their status in law is upgraded, though fresh provision is made for open consultation processes to allow for regional and local variants.* " (UNEP 2002).

3.1.3.2 MAR region summary (based on GEO-4 draft)

Economy and governance

- Whilst many **policies** are more reactive than strategic, governments take a close interest in social and environmental problems.
- Exports of **primary goods** continue to form a crucial part of the region's economy, and the **tourism** sector grows significantly with public support.
- By 2025, this is the scenario with the highest **GDP** per capita growth rates for Guatemala, Belize and Honduras. For Mexico, Markets First has a slightly higher growth rate, partly as a result of increased remittances from North America.

Population and standard of living

- Equity increases, with progress towards the Millennium Development Goals on **education, income and health**. Emigration decreases as quality of life improves.
- Over the MAR region, **population growth** continues, but the rate of increase slows more rapidly than in Markets First, especially in Honduras and Guatemala.
- **Urbanisation** continues, but is subject to stronger planning constraints.

Environmental impacts

- Land use becomes better regulated, especially around riverine corridors. Implementation is patchy, but the rate of deforestation decreases. Over the MAR region, **deforestation** continues to result in erosion and land degradation, but at a lesser rate than in the Markets First scenario. In Mexico, forest cover decreases only until 2010, when an ambitious national forestry plan reverses the trend. Mexican forest area surpasses 2000 levels by 2025.
- By 2015, cooperation on the management of **transboundary watersheds** develops in the MAR region. Water quality increases as a result.
- Certification schemes for timber, agriculture and fisheries are encouraged.
- The terrestrial **protected area** network expands by 2025 to encompass 10% of all biomes and all single-site endemic species by 2025. For 65% of the new sites, natural ecosystems are completely protected from change over the period. 25% are partially protected from change (allowing sustainable use), and 10% fail to be protected (see Section 3-4). The marine protected area network also grows, with a focus on enhancing resilience to coral bleaching[1].

[1] through reserve network design to optimise larval dispersal opportunities and to include more resilient reef types (Schuttenberg 2001)

- Research is undertaken into **adaptation** measures to cope with the changing climate. By 2025, more diverse agricultural systems are being encouraged with the aim of resilience to climate change impacts.
- Policies are adopted to assign economic values to coastal ecosystems such as **mangroves** that provide protection from sea surges. However, coastal developments continue to expand, and coastal degradation continues.

3.1.4 Sustainability First

3.1.4.1 GEO-3 scenario overview

"*A new environment and development paradigm emerges in response to the challenge of sustainability, supported by new, more equitable values and institutions. A more visionary state of affairs prevails, where radical shifts in the way people interact with one another and with the world around them stimulate and support sustainable policy measures and accountable corporate behaviour. There is much fuller collaboration between governments, citizens and other stakeholder groups in decision-making on issues of close common concern. A consensus is reached on what needs to be done to satisfy basic needs and realize personal goals without beggaring others or spoiling the outlook for posterity.* " (UNEP 2002).

3.1.4.2 MAR region summary (based on GEO-4 draft)

Economy and governance

- **Economic cooperation** between the MAR countries increases.
- Governments make a strong commitment to **sustainable development**. Efficiency in the use of energy, land and material resources is promoted. There are efforts to adopt an ecosystem approach to land use planning, with particular attention to watershed protection. Awareness campaigns are directed both at industry and the general public, and help to change consumption patterns.
- The **tourist industry** continues to grow, but smaller packages become more popular, so that there are fewer large developments.
- For Belize, Guatemala and Honduras, **GDP per capita** growth rates are greater than those for Markets First, but are slightly smaller than for Policy First. Most other quality of life indicators are strongest under this scenario.

Population and standard of living

- Considerable resources are directed to **poverty alleviation** as the scenario progresses. Many of the Millennium Development Goals are achieved by 2015, and further progress is made by 2025.
- For Guatemala and Honduras in particular, this is the scenario with the lowest rate of **population increase**. The rate of population growth in this scenario for Mexico is therefore higher than in Markets First, partly because fewer people feel the need to migrate to find work. Overall, population growth rates decrease.
- There is less growth in **urban area** within this scenario than any other; most urban development is concentrated in medium and small cities.

Environmental impacts

- A shared environmental agenda arises in the region. National regulation and incentives develop further to control pollution and generate local payments for local environmental services such as water.
- At national to local scale, Agenda 21 gains strength, promoting involvement of community and business groups in areas such as integrated land management. The rate of loss and fragmentation of key habitats decreases.
- The move towards organic agriculture and the use of biological controls is unexpectedly assisted by rising oil prices, which increase the cost of agrochemical use. Extension services for these more sustainable practices develop. Food yields improve. The combined impact of increased efficiency of natural resource use and ecosystem restoration means that by 2025, agricultural area begins to decrease slightly in all MAR countries.
- Several large Clean Development Mechanism projects are implemented, with forest landscape restoration initiatives being particularly successful in Honduras.
- The terrestrial protected area system expands to represent all key regional ecosystems and species, including more transboundary reserves. It includes at least 10% of all biomes and all single-site endemic species by 2025. For 30% of the new sites, natural ecosystems are completely protected from change over the period. 65% are partially protected from change (allowing sustainable use), and 5% fail to be protected despite the best intentions (see Section 3-4). The marine protected area network also grows, with no-catch zones being established by local agreement to conserve fisheries.

3.2 Population and land cover change: comparisons between scenarios

This section summarises the population and land cover changes across the scenarios. Land cover change was modelled using a combination of three models (for methods, see next section). Figure 3-1 summarises the questions addressed using the different models. For Mexico, the annual rate of agricultural expansion within Markets First was multiplied by 1.5, to represent internal migration by farmers from the dry central parts of the country.

The rate of land cover change under the different scenarios was estimated for the whole of the four countries based on results from IFs and IMAGE. The changes in land cover were then applied to the watershed area, assuming the rate of land cover change within the MAR model region would match that within the remainder of the countries. CLUE-S was used to allocate land cover within the region.

Differences between the scenarios can more easily be seen by comparing the changes in human population or land cover (Figures 3-2, 3-3, 3-4 and 3-4) than by comparing the total population and area values (Figures 3-2, 3-5 and 3-6). Greater detail for land cover change is available in the Section 3.3.

The population of all four countries continues to grow under all scenarios (Figures 3-2 and 3-3). The population figures shown here represent the whole countries, not just the MAR region. The highest growth rates are consistently found in Guatemala and Honduras, but there is high variation between scenarios. All except Mexico experience the smallest increase under Sustainability First; for Mexico, Markets First is smallest. Variation in growth rate between scenarios from 2005 to 2025 is smaller for Mexico than for other countries, with Markets First at 17% and the other three scenarios from 21 to 22%. For Belize, rates vary from 24% to 39%, for Guatemala from 44% to 68%, and for Honduras from 37% to 58%.

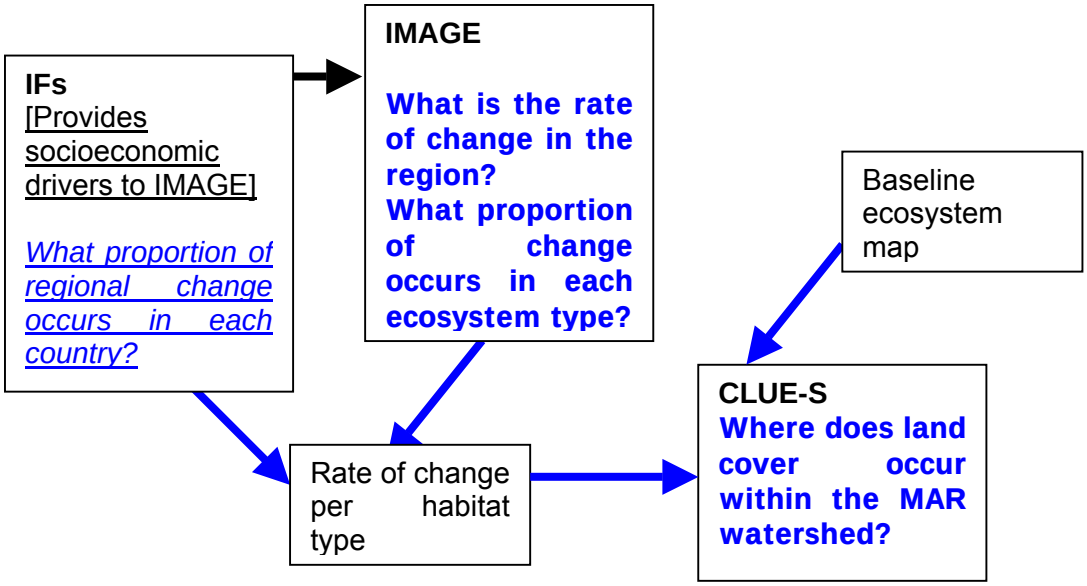


Figure 3-1: Role of three models used to simulate land cover change

The greatest increases in urban and agricultural land are seen under Markets First, followed by Policy First. Where there is an increase in wildland under Sustainability or Policy First, it is usually scrubland, which may regenerate to forest in time. For Mexico, forest area increases under Policy First.

To illustrate the variation between scenarios and countries in detail, change in forest cover can be examined. When considering total change in all forest classes, all countries lose most forest in Markets First (Table 3-1). However, there are differences between the response of the different countries to the different scenarios. Belize, Guatemala and Honduras all lose least forest in Sustainability First (in the case of Honduras, there is an increase in forest area), whilst Mexico still loses a substantial amount of forest to agriculture in that scenario. Whilst there is a gradual decrease in area devoted to agriculture (including pastureland), the major increase by 2025 is in the area of scrubland, rather than of forest (Figure 3-5). This is especially true in Mexico.

Whilst these scenarios provide a range of outcomes, more radical changes are also be possible. For GEO Honduras, the Polestar model was used to quantify the scenarios. It simulated a decrease in forest area of ~20% by 2020 for the Markets-First equivalent, and an increase of 15% under the Sustainability-First equivalent.

Table 3-1: Forest cover change by scenario

Land unit	Percentage change, 2005 to 2025		
	Markets First	Policy First	Sustainability First
IMAGE Central America	-12.5	-5.1	+1.6
Belize	-6.2	-2.2	-0.2
Guatemala	-9.2	-3.9	-1.3
Honduras	-14.1	-7.0	+0.8
Mexico	-3.5	+1.7	-2.1

Within any country, the MAR modelling framework allocates an equal percentage change to broad-leaved forest, pine forest and mangroves between 2005 and 2025. However, the

percentage change in the area of each forest type over the whole of the four countries between 2005 and 2025 differs (Figures 3-9 through 3-12) because there is variation between countries in the baseline forest area belonging to the three categories (Figure 3-8) and in the percentage change allocated to that country.

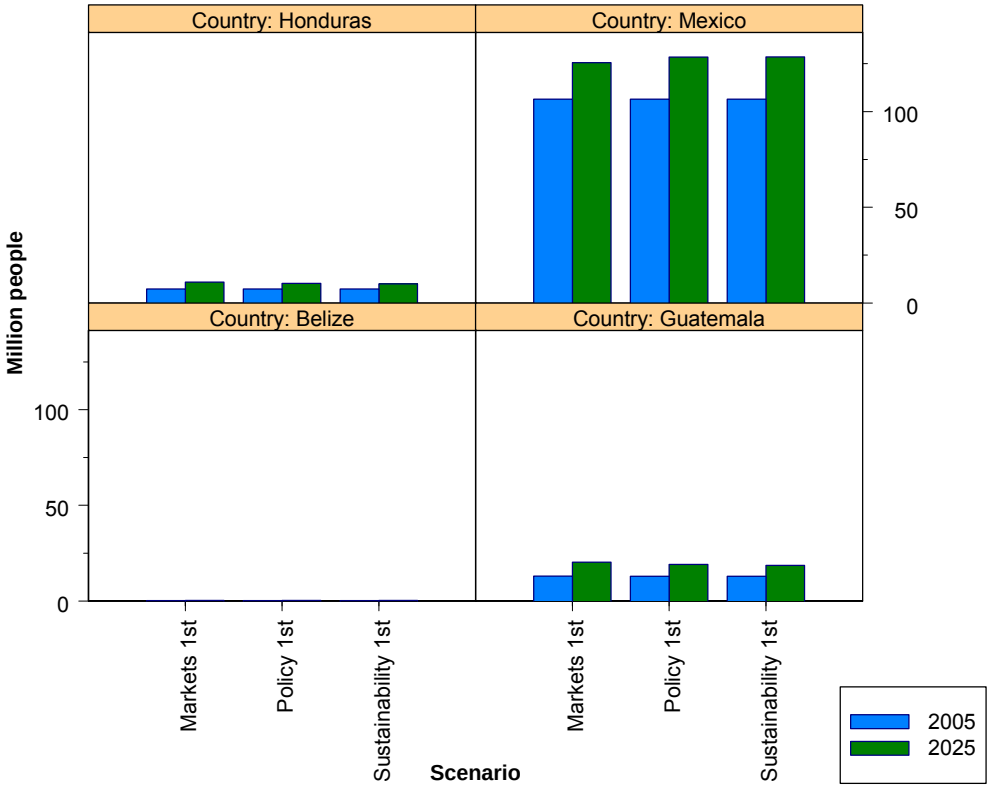


Figure 3-2: National human population at 2005 and 2025 by scenarios (IFs)[1]

[1]Belize population is modelled as 0.26 million at 2005, and at 2025 varies little, from 0.33 million (Policy First, Sustainabilty First) to 0.34 million (Markets First).

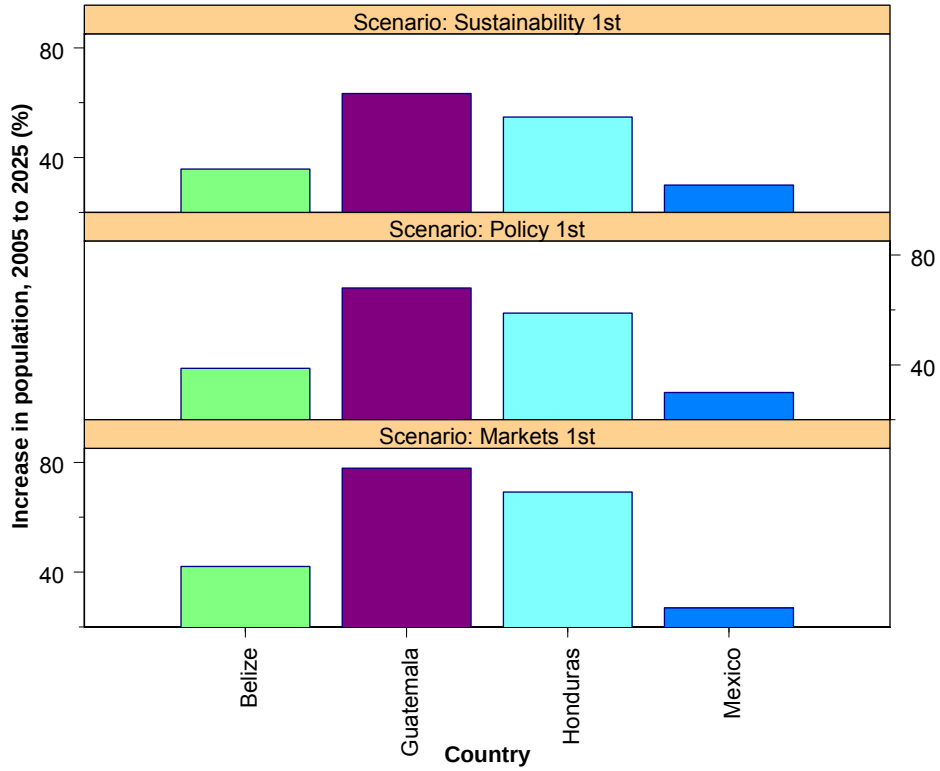


Figure 3-3: Percentage change in national populations, 2000 to 2025, by scenario (IFs)

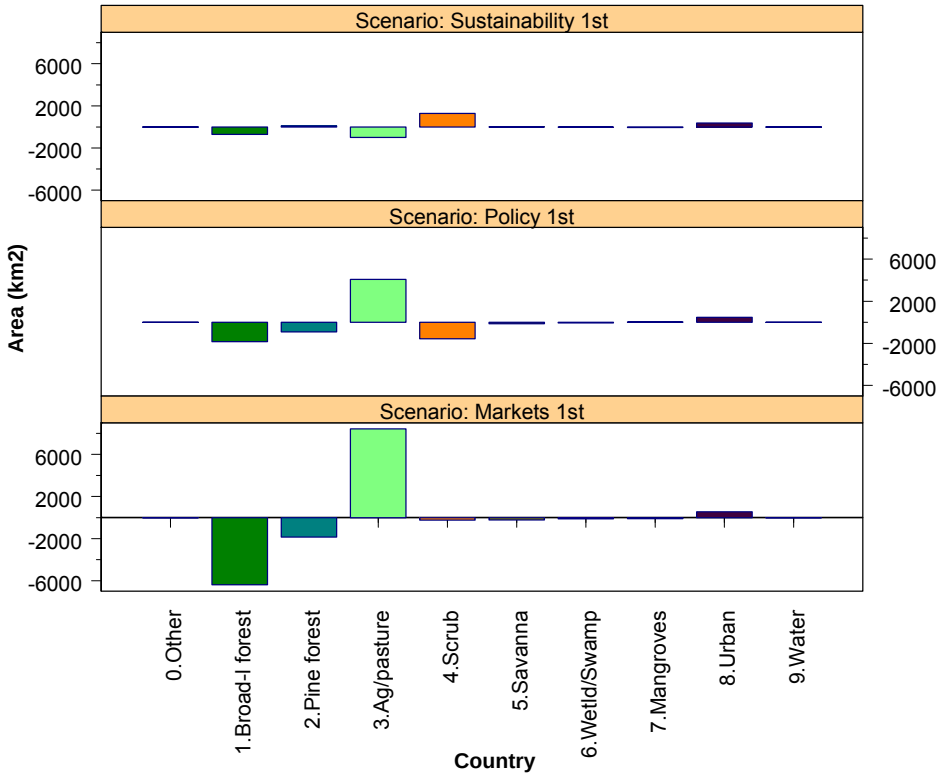


Figure 3-4: Change in land cover, 2005 to 2025, all countries combined

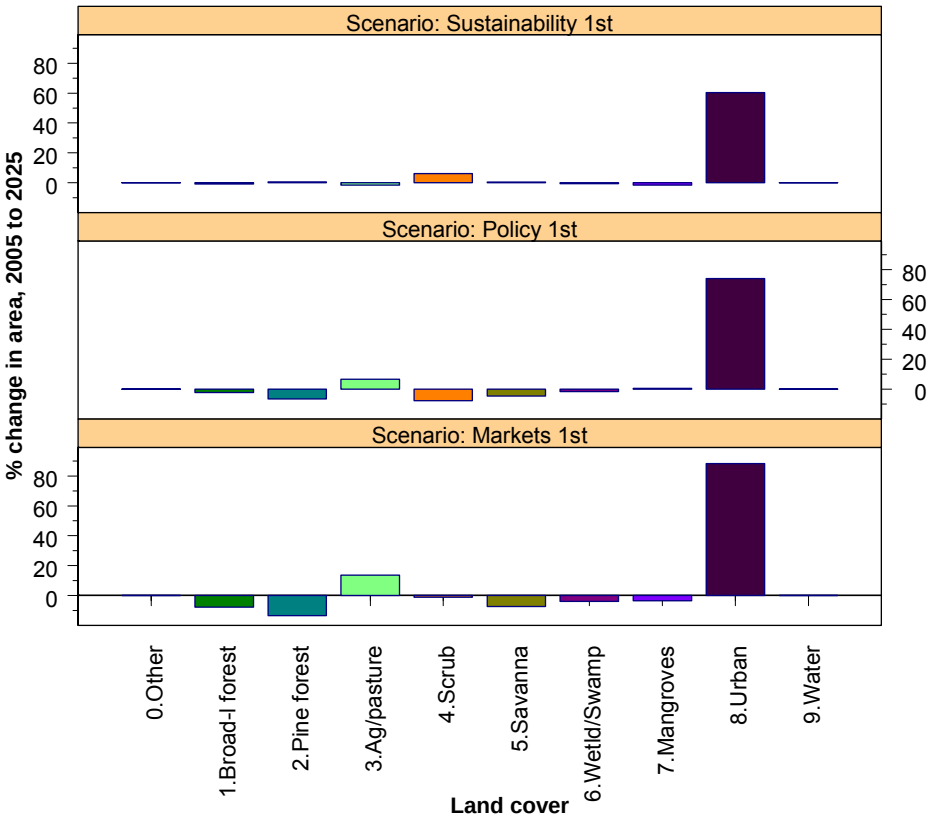


Figure 3-5: Percentage change in land cover, 2005 to 2025, all countries combined

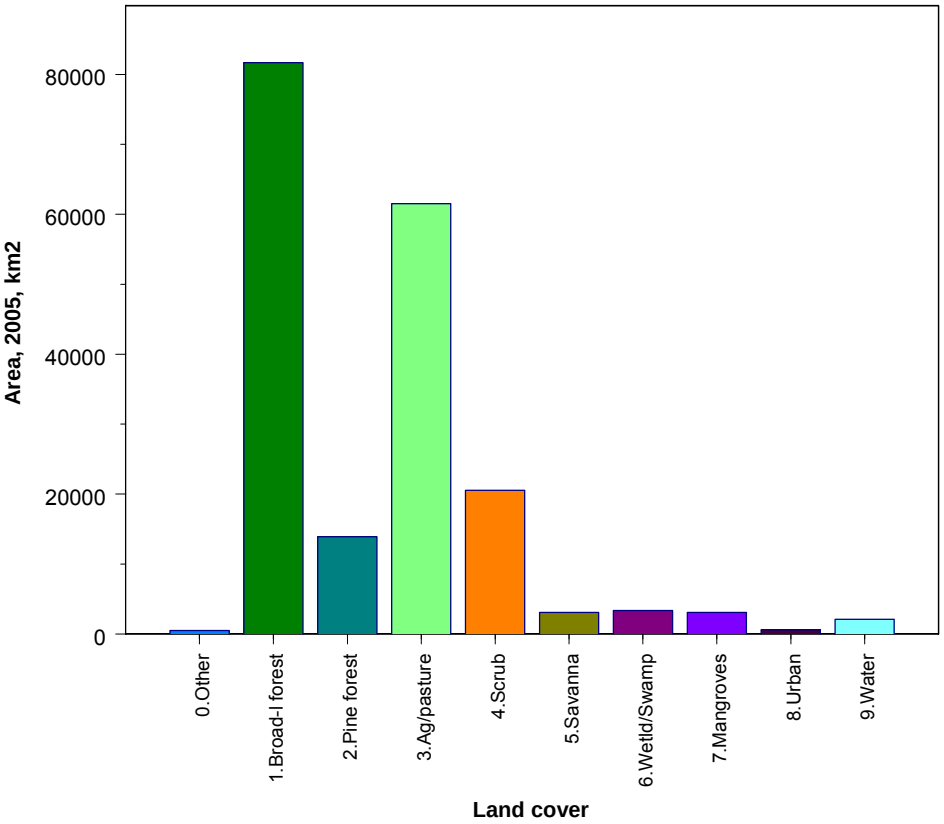


Figure 3-6: Land cover for watershed area at 2005; all countries combined

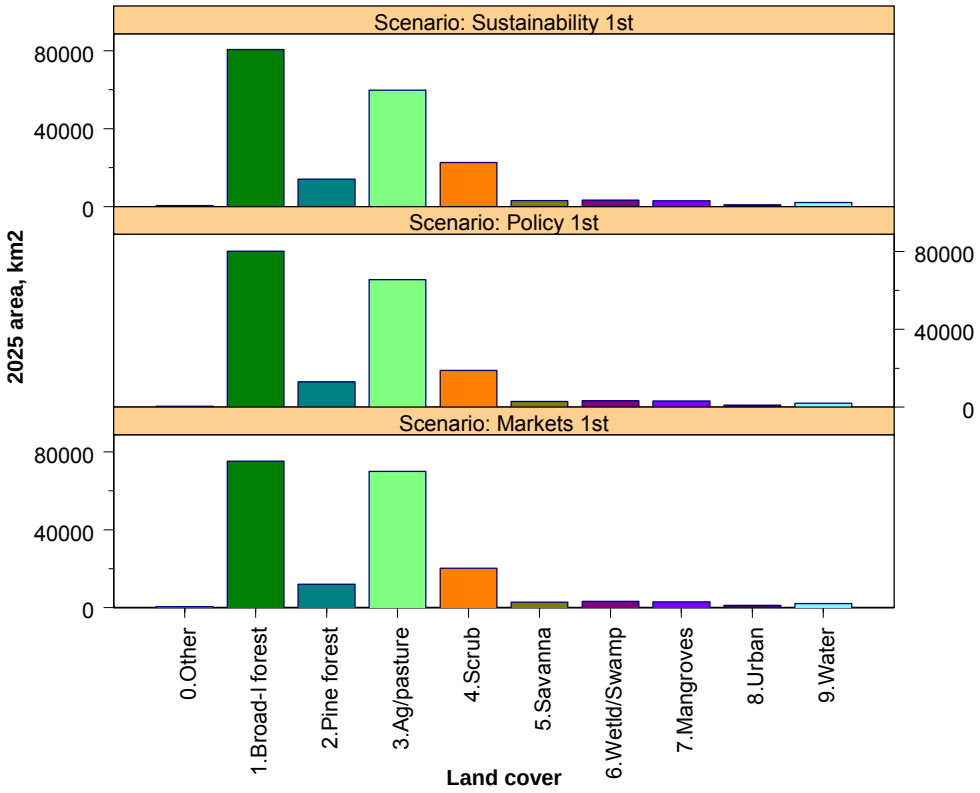


Figure 3-7: Land cover for watershed area at 2025 by scenarios; all countries combined

3.3 Land cover quantification: the IFs and IMAGE models

3.3.1 Model background

Two of the models used in support of GEO are relevant to the MAR project. IMAGE-2[1] is a gridded integrated assessment model, operating at the global scale. It is able to simulate issues like the impact of global climate change on crop production. International Futures (IFs)[2] is a 'macro-agent' based model, also operating at the global scale, but at the resolution of countries rather than on a spatial grid. It represents major agent classes (households, governments, firms), simulating relationships in a variety of global structures (demographic, economic, social, and environmental) (Hughes 2004). It is available online for use in scenario exploration and teaching. IFs provides the driver variables for the GEO-4 scenario. IMAGE projects land use based on these drivers and other interrelated factors, using a half-degree grid, but its outputs are intended to be interpreted on a regional scale.

Within the ICRAN MAR project, the Conversion of Land Use and its Effects (CLUE-S) model has been selected for land cover change modelling on a 250-m grid. The GEO models are used to obtain percentage change in land cover types (rather than area of change) through time, to drive the CLUE-S model.

Each model has been configured independently, so uses its own land cover classification. The land cover classes have been mapped onto one another to give a minimum set as shown in Table 3-2. The major assumptions are that (i) despite inconsistencies between land cover definitions, the ratio of change in land cover between countries and the Meso-America

[1] http://www.mnp.nl/image/

[2] http://ifsmodel.org/; http://www.ifs.du.edu/

region within the IFs model is still a good proxy for the ratio within the IMAGE model; (ii) the relative change between land cover types within the IMAGE model is a reasonable indicator of the change between equivalent types within the CLUE-S model. The 'other' class within CLUE-S and the 'other' class within IFs represent rather different concepts, and do not map onto one another. The 'other' class within CLUE-S represents only 0.25% of the land area for the four countries at the baseline year, and is not allowed to change in area. In IFs, the 'other' class represents 18% and is subject to change. Here, the IFs class is used to assist in calculating change in the scrub, savanna, wetland and swamp categories within CLUE-S.

The baseline year for Belize is 2004; for Mexico, Guatemala and Honduras it is 2000 (Figure 3-8). These are the years for which the latest Ecosystem Map land cover data was available (Meerman & Sabido 2001, Vreugdenhill *et al*. 2002).

IMAGE simulates a historical 8.7% loss over the whole of Central America from 1990 to 2005. Looking into the future, IMAGE simulates a 12.5% loss in forest cover from 2005 to 2025 under Markets First, a 5.1% loss under Policy First and a 1.6% loss under Sustainability First.

In IFs, forest area is initiated using FAO data, with simulated changes being dependent upon the rate of conversion to cropland and grazing area. This rate is driven by agricultural supply and demand, based upon factors such as human population and land development costs. Urban area expands into all other land cover classes equally. The IMAGE model, conversely, uses a terrestrial vegetation model factoring in impacts of climate and soils. As IMAGE does not model urban area changes, IFs values have been used for change to urban land.

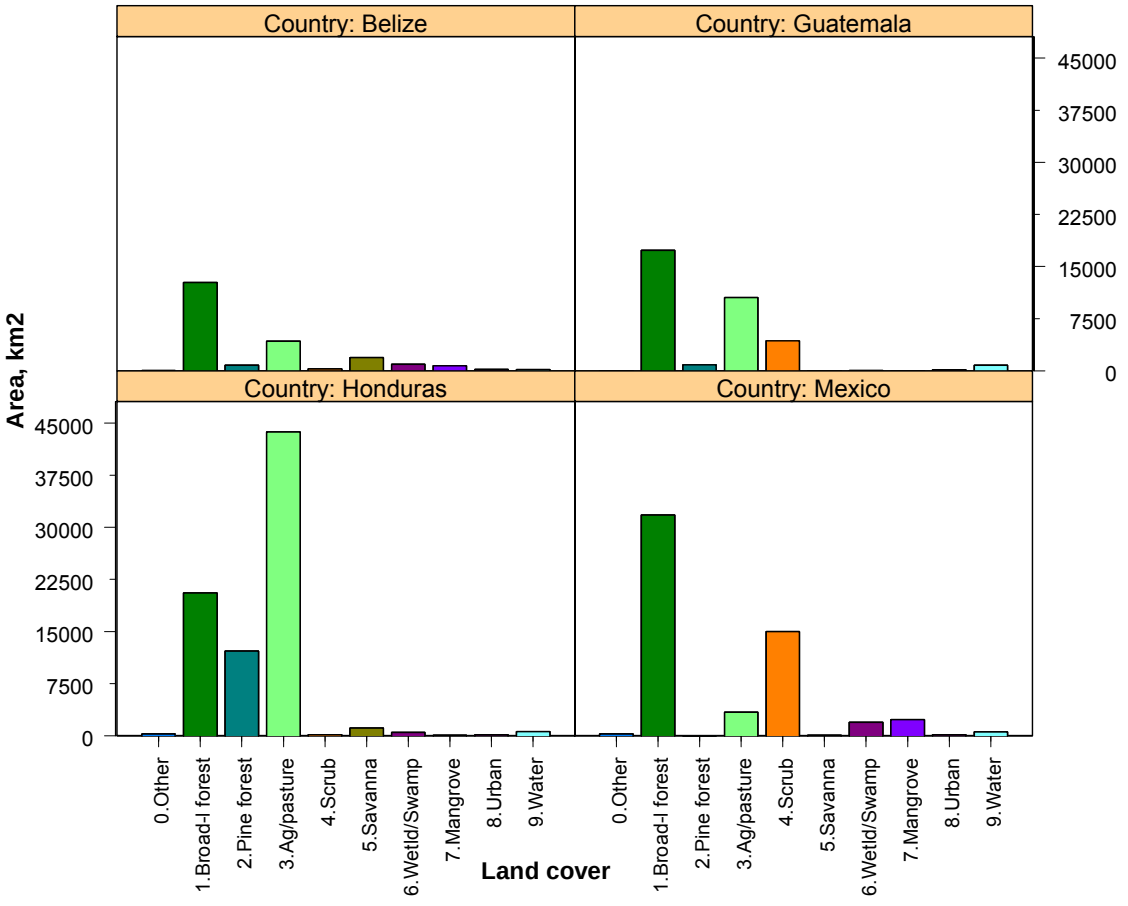


Figure 3-8: Land cover at baseline year (2004 for Belize, 2000 for Guatemala, Honduras and Mexico)

3.3.2 Bringing the models together: methods

The land cover values for the future scenarios as applied to CLUE-S are derived by allocating the percentage change as seen in IMAGE, distributed between countries according to the proportionate national changes in IFs. The land cover types differ between the three models, and are mapped onto one another as shown in Table 3-2. The resulting values are used to drive the CLUE-S land allocation routine as described in detail below.

Table 3-2: Mapping of land cover types between IFs, IMAGE and CLUE-S

Land cover type (CLUE-S[1])	Land cover type (IFs)	Land cover types (IMAGE)	Assumptions for CLUE-S application
0. Other/Unknown (NO CHANGE))	N/a	N/a	CLUE-S requires no change to this class
1. Broad-leaved forest 2. Pine forest 7. Mangroves	Forest	Carbon plantations Regrowth forest (abandoned) Regrowth forest (timber) Warm mixed forest Tropical woodland Tropical forest [On a global scale, this category would include other forest types not present in the Meso-America region]	Equal probability of change of CLUE-S types
3. Agriculture/ pasture	Crop	Food crops Biofuel crops	IFs types are subtypes of CLUE-S type
	Grazing	Grass and fodder	
4. Scrub	Other	Scrubland	
5. Savanna 6. Wetland/swamp	Other	IMAGE savanna, desert, grassland/steppe [on basis that it will include wet grasslands]	Equal probability of change of CLUE-S types
8. Urban	Urban	Excluded from IMAGE by reducing land area per cell accordingly; not modelled in future.	IFs increase in urban area is applied directly, with the expansion reducing the 'other' category.
9. Water (NO CHANGE)	N/a	N/a	CLUE-S requires no change to this class

[1] The 10 land cover classes used by the CLUE-S model are not dictated by CLUE-S. Instead, this is a reduced classification of the land cover classes of the source 'Ecosystem Map' land cover dataset, which was developed and agreed upon by the watershed partners.

For any given year, scenario and IFs land cover type:

f = area for country in IFs (mill ha)
F = area for region in IFs (mill ha) = Σf
m = area for country equivalent to that in IMAGE (mill ha) [derived in this exercise]
M = sum of area for appropriate categories from Table X for region in IMAGE (mill ha) = Σm
c = area for country in CLUE-S (km^2) [derived from map data for year 1, and for later years in this exercise]
C = area of country

i) Estimation of area in IMAGE for country in year n

Foe urban land (see Table 3-2)
$m_{yn\ (urban)} = f_{yn}$

where $f_{yn\ (urban)} = f_{yn-1\ (urban)}$, smoothing was carried out to ensure percentage change in cover was not zero in alternate years (this was an issue for the very small amounts of urban land cover in Belize).

For grazing, forest, crop land categories from IFs

$m_{yn} = M_{yn} (f_{yn}/F_{yn})$

For scrub and savanna / wetland categories from CLUE-S and IMAGE, taking national proportions from the Other category in IFs:

$m_{yn} = M_{yn} (f_{yn}/F_{yn})$

ii) Percentage change assigned to CLUE-S for year n
$= 100 (m_{yn} - m_{yn-1})/ m_{yn-1}$

iii) Land cover assigned to equivalent CLUE-S categories for year n. Area per class is then normalised to country area, based on the fraction represented by that land cover class in that year for that country. The area belonging to 'other' and 'water' CLUE-S categories do not change between years.

$d_{yn} = c_{yn-1} + c_{yn-1} ((m_{yn} - m_{yn-1})/ m_{yn-1})$
$c_{yn} = d_{yn} + ((C - \Sigma d_{yn\ all\ classes}) * d_{yn}) / C)$

Figures 3-9 through 3-12 show the calculated change in land demand for each land use type under all three scenarios. The land demand each year for each land use types is given in Appendix 5.

3.4 Future changes in protected areas

A protected area scenario dataset was created based on the scenario assumptions. These maps represent one hypothetical expansion of the network, rather than a recommended set of designations. No distinction is made between managed and unmanaged forests within CLUE-S, but a distinction can be made between the different protection categories. Existing and new protected areas are allocated to the following categories within the scenarios:

- Sustainable-use (probability of conversion is reduced by designation; driven by the logistic regression)
- No-use (no change after designation to natural ecosystems contained within the area)
- Failed (no protection from land cover change)

The protected areas are implemented within CLUE-S as follows:

1) all no-use areas are designated at the start of the scenario period. No land use change occurs within the natural ecosystem cells inside these areas over the period. This category is applied to IUCN categories I–IV and uncategorised protected areas.

2) New sustainable-use areas may be designated at any time. These areas are applied within the model as a dynamic factor grid, which influences the probability of land cover change, rather than via rule-based restrictions. This is therefore a 'partially protected' rather than a strict 'sustainable use' designation. Applied to categories V-VI.

In summary, areas are assigned to the scenarios as follows:

Markets First – expansion of terrestrial network to 10% of all biomes/countries by 2025; new sites allocated as 20% no-change, 60% sustainable-use, 20% failed

Policy First – expansion of terrestrial network to 10% of all biomes/countries + all single-site endemic species by 2025 and 20% of all biomes/countries by 2050; new sites allocated as 65% no-change, 25% sustainable-use, 10% failed

Sustainability First – expansion of terrestrial network to 10% of all biomes/countries + all single-site endemic species by 2025 and 20% of all biomes/countries by 2050; new sites allocated as 30% no-change, 65% sustainable-use, 5% failed

Failure indicates that there is no barrier to land use change in this protected area.

In Policy First and Sustainability First, the new protected areas are first allocated to priority areas for biodiversity to attain at least 10 percent of each biome/country combination. Additional areas are then allocated to cover single-site endemic species that have not captured, based upon the Alliance for Zero Extinction point dataset. These additional areas are circles of equivalent size to the area required for that species (or for the mean area where this is not specified), thus giving an artificial appearance to the scenario data. The coverage of some biomes is therefore expanded to greater than 10 per cent by 2025 within these two scenarios. A number of protected areas were assigned outside the MAR region of Guatemala, Honduras and Mexico.

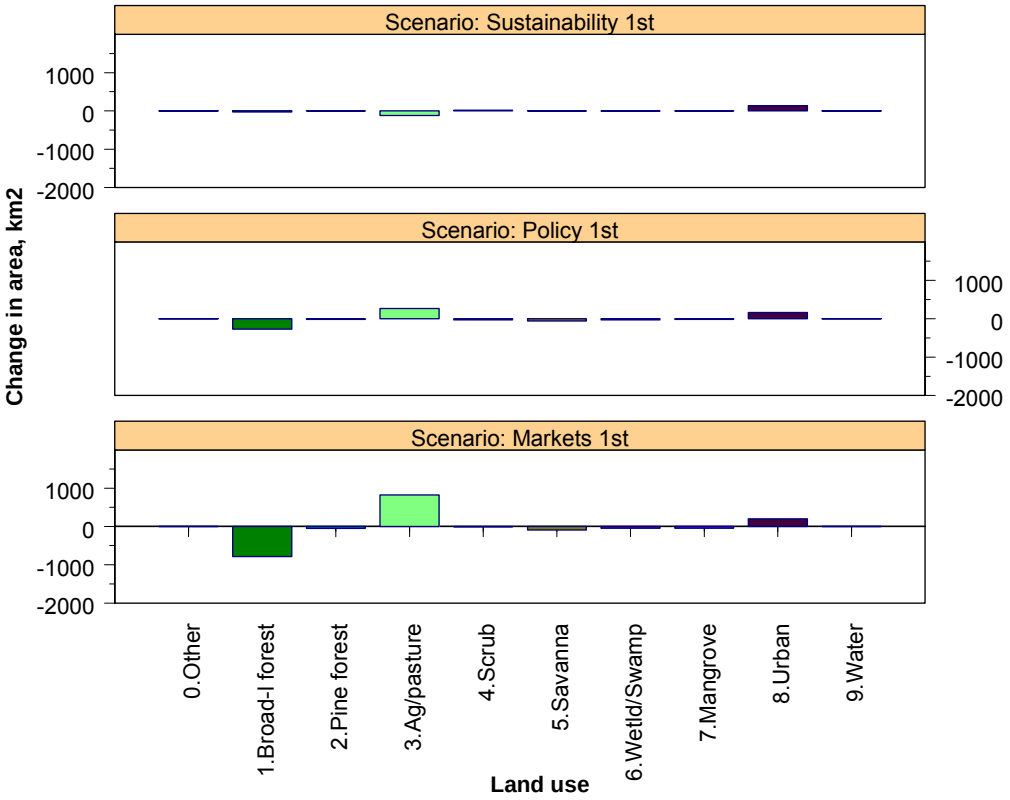


Figure 3-9: Change in land cover for Belize, 2005 to 2025, scenarios

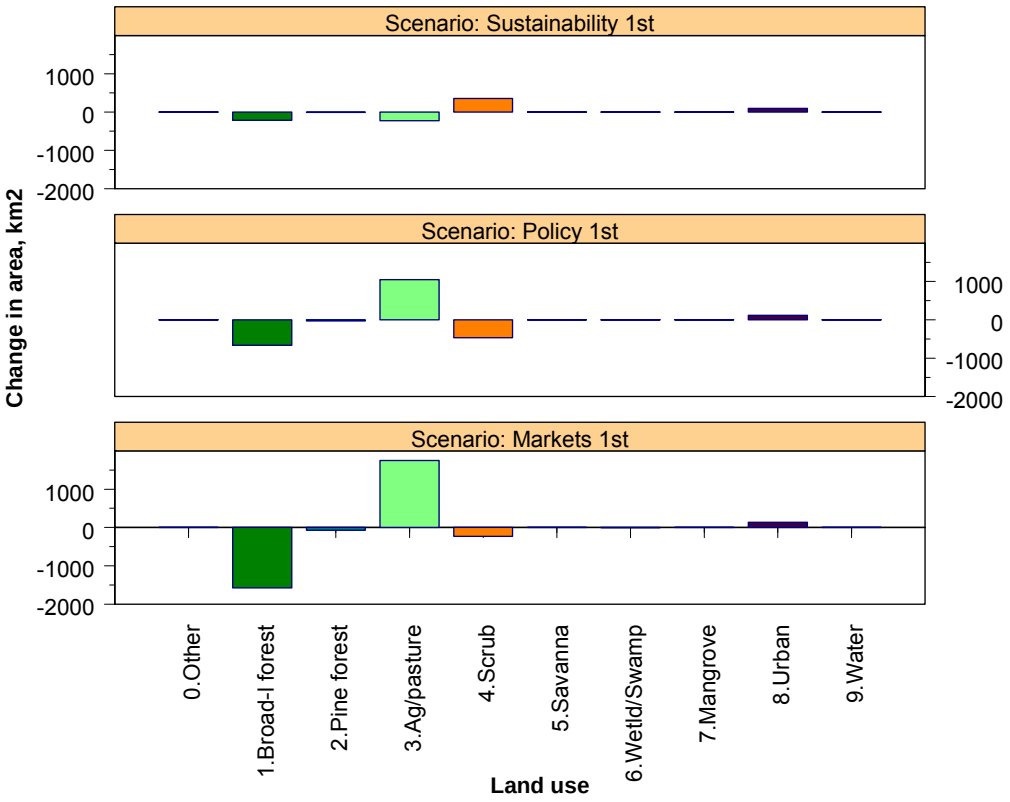


Figure 3-10: Change in land cover for Guatemala, 2005 to 2025, scenarios

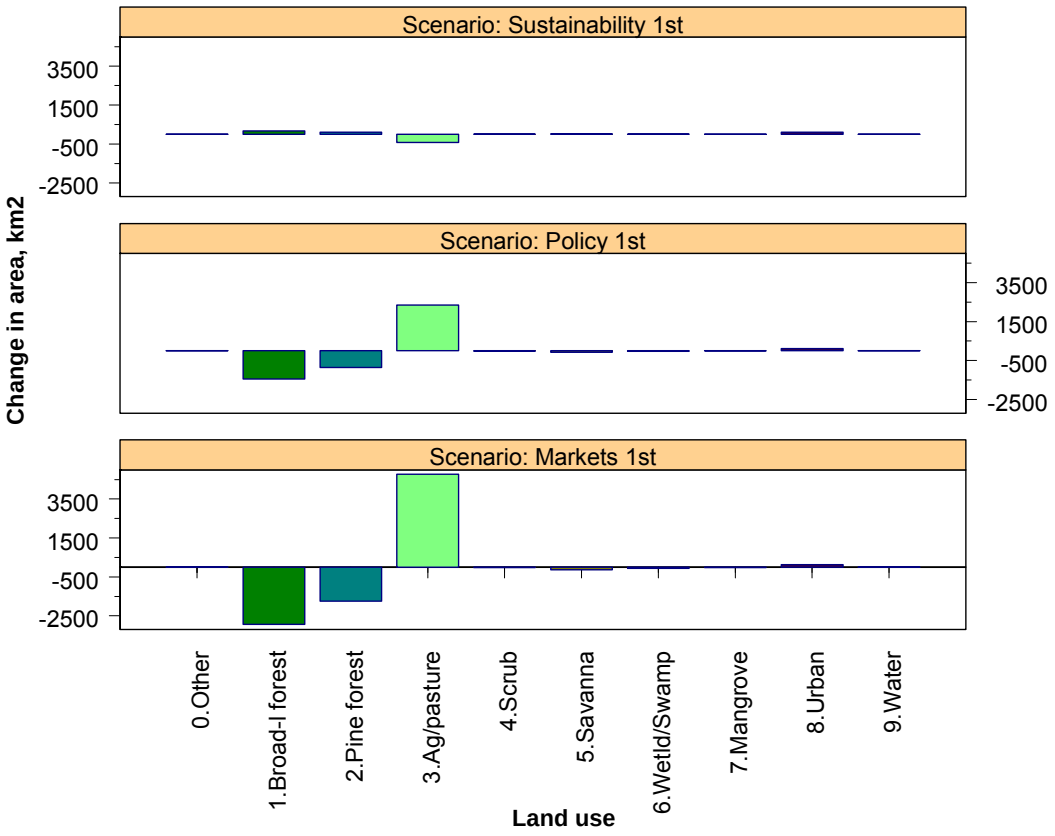


Figure 3-11: Change in land cover for Honduras, 2005 to 2025, scenarios

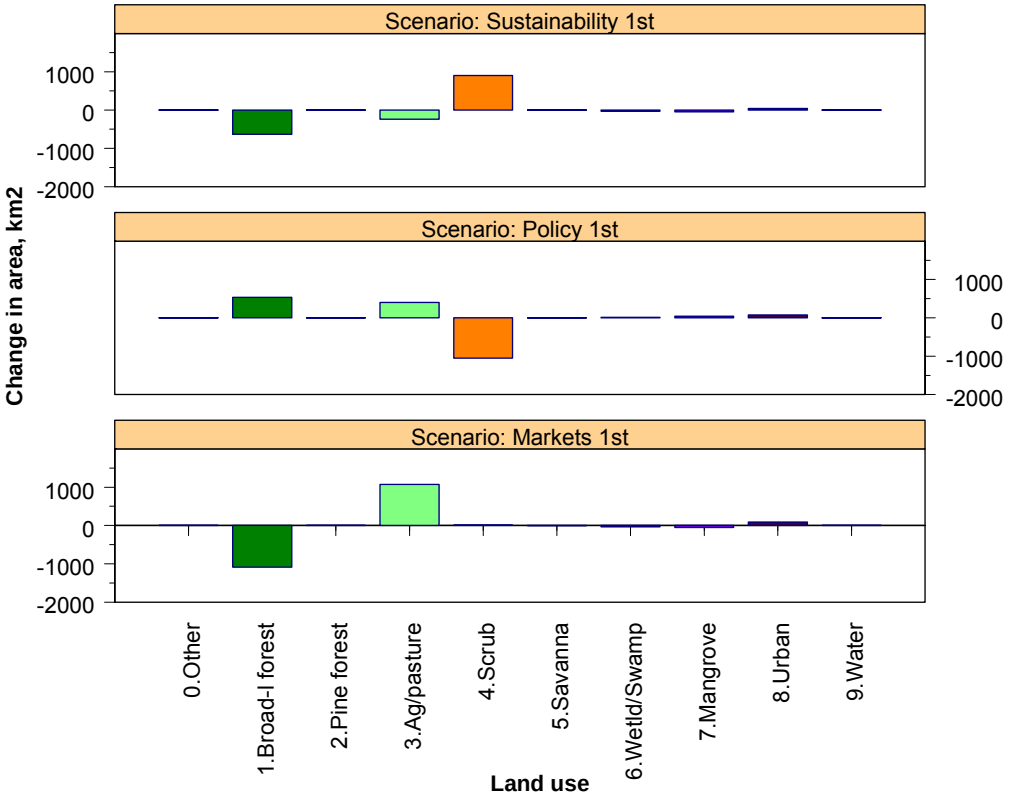


Figure 3-12: Change in land cover for Mexico, 2005 to 2025, scenarios

4 Modelling land use changes for scenarios using CLUE-S

4.1 Important aspects of model development

4.1.1 Land use data

In working with CLUE-S, it became clear that the Ecosystem Map land cover data use were not ideal for use by this model. The model had difficulty with the enormously skewed land use distributions and with the large homogenous areas, particularly in Honduras, which is in part a consequence of the relative large minimum mapping units that were used in the vector Ecosystem Map dataset (10 ha for Belize; 150 ha for the other countries). It is likely that the model would have had less trouble with a remotely sensed classification rather than raster data converted from vector data. It is therefore strongly recommended to use different, more detailed remotely sensed data if the study is to be undertaken or refined in the future.

4.1.2 Probability Surfaces

The single most important aspect of the model development process is to inspect and verify the probability surfaces that CLUE-S uses to allocate land. These surfaces are constructed from the regression parameters and they directly reflect the goodness of fit of the regression equations. They are extremely helpful in assessing whether the way the model is going to allocate land makes sense. If this is not the case, the regression equations should be inspected for any possible typographical errors or, in case they are not statistically significant, replaced by a better equation. Unfortunately, the Relative Operating Statistic (ROC, introduced in Section 2.2.) could be calculated only for Belize, so we do not know the goodness of fit for the equations for the other countries. Therefore, the manual inspection of probability surfaces is essential. Adjustments in the model were made where necessary.

Not surprisingly, the probability surfaces for the Belize looked most plausible, whereas those for Honduras were worst, with Guatemala and Mexico in between. The simulation of Honduras posed a particular problem. The probability surfaces for all but Broadleaved Forest, Pine Forest, and Agriculture\Pasture looked quite unlikely or clearly incorrect. The cause is twofold. First, the three dominant land use types occupy over 95% of the total area, the remaining seven types occupy < 5% of the area. The regression results are not significant for those seven types. As a consequence, the model was not able to reach a solution, i.e., it was unable to properly allocate the demanded land-use based on the probability surfaces.

Two workarounds were applied:

- If the difference in the calculated demand for a land use types hardly changed throughout the simulation period (2000/2004 to 2025), then the land demand was kept constant and the changes that should have occurred were added to another (most comparable) land use type to ensure that the total area remained the same. The regression equations were not changed, because by keeping the land demands equal the equations were essentially bypassed and not relevant.
- The regression equations for urban land in Mexico, Guatemala and Honduras were replaced by equations that made more sense. A generic regression equation based on population density, distance to markets and the presence of tourism hotspots was adopted. This is explained in more detail in Section 4.3.4.

4.1.3 Neighbourhood settings

The user manual and available parameters suggest that CLUE-S can allocate land use in a user-specified (e.g, a 3x3 or 4x4) neighbourhood. Specifying such neighbourhoods (in **NEIGHMAT.TXT**) and giving a weight of 1 to the neighbourhood suggests that the probability surface are constructed in a way that reflects the neighbourhood settings, and that new land use can only be allocated inside the that neighbourhood. This would be useful if you require new grid cells of, for example, forest or urban, to be adjacent to existing cells. However, Peter Verburg confirms that land allocation cannot be influenced in this way.

4.2 Input data preparation

4.2.1 Files used by CLUE-S

Table 4-1: Input files used by CLUE-S. The "created" column indicates which software is used to create the files and the "mandatory" column indicates whether the file is a minimum input data requirement. Files created using CLUE-S are plain text files and may also be edited in a text editor.

Filename	Description	Created	Mandatory
MAIN.1	**Main parameters file**. Listed on exactly 19 lines. Some parameters settings will dictate whether the optional files must be specified or not.	CLUE-S	yes
ALLOC1.REG	**Regression parameters**. Length of file depends on number of land use types and location factors.	CLUE-S	yes
ALLOC2.REG	**Neighbourhood results**. These are additional regression parameters based on the enrichment factor equation. **NOT USED**	CLUE-S	no
ALLOW.TXT	**Change matrix**. The number of rows and columns equal the land cover types, here 10x10.	CLUE-S	yes
NEIGHMAT.TXT	**Neighbourhood settings**. Defines the shape and size (in the form of a small weight matrix) of the analysis neighbourhood for every land use type.	CLUE-S	yes
REGI*.*	**Area restriction file**. A grid that defines where land use changes can and cannot occur. The * is a wildcard here; it does not indicate the simulate year. All active cells must have the value 0, restricted cells a value of –9998, and all others cells –9999 (NoData).	ArcView	no
DEMAND.IN*	**Land use requirements**. Calculated at the aggregate level and organized by rows (simulated years starting at 0) and columns (for every land use types). The * denotes a unique number, not simulated year.	Excel	yes
COV_ALL.0	**Initial land use**. A grid of all land use types at the start (year 0). Grid values must match the land use codes listed in the main parameters file.	ArcView	yes
SC1GR#.FIL	**Static location factor grid**, where # is the number of the location factor; or	ArcView	yes
SC1GR#.FIL (SAME AS ABOVE)	**Land change restrictions grid**. Grid that indicates whether a land use conversion can occur. The # does not denote a location factor. Instead it is a unique values that is also specified in the alloc1.reg.	ArcView	no
SC1GR#.*	**Dynamic location factor grid**, where # is the number of a location factor. The * is the simulated year starting at 0, not a wildcard. Note that also the file src1gr#.fill is	ArcView	no

	needed and it is identical to src1gr#.0.		
LOCSPEC#.FIL	**Location specific preference addition**. Grid used to increase the probability at specific locations. Must be specified for every land use type. **NOT USED.**	ArcView	no

4.2.2 Land use requirements for different scenarios

4.2.2.1 Requirements calculated using IMAGE model

Land use requirements were calculated by Lera Miles using outputs from the International Futures and IMAGE and GEO-4 models, as part of the scenario development process (Section 3.3).[1] Tables 4-2 through 4-5 give the percentage area of each land use type at the present time along with future demands. The precise demand values for every land use type in every simulated year are given in Appendix 5.

*Table 4-2: **Belize**: Distribution of present land use and land demand for the scenarios. Blue coloured land use types were kept fixed at present values and not allowed to change over time.*

	Present	Markets	Policy	Security	Sustain.
0. Other/Unknown	0.06%	0.06%	0.06%	0.06%	0.06%
1. Broad-leaved forest	58.02%	54.33%	56.69%	55.16%	57.78%
2. Pine forest	3.53%	3.31%	3.45%	3.36%	3.52%
3. Agriculture/pasture	19.37%	23.20%	20.64%	22.70%	18.85%
4. Scrub	1.26%	1.23%	1.13%	1.10%	1.37%
5. Savanna	8.63%	8.23%	8.35%	8.11%	8.65%
6. Wetland/Swamp	4.26%	4.07%	4.12%	4.01%	4.27%
7. Mangroves	3.29%	3.08%	3.22%	3.13%	3.28%
8. Urban	0.87%	1.79%	1.64%	1.68%	1.51%
9. Water	0.70%	0.70%	0.70%	0.70%	0.70%

*Table 4-3: **Mexico**: Distribution of present land use and land demand for the scenarios. Blue coloured land use types were kept fixed at present values and not allowed to change over time. Note that there is no pine forest in Mexico; this required some adjustments to the model.*

	Present	Markets	Policy	Security	Sustain.
0. Other/Unknown	0.45%	0.45%	0.45%	0.45%	0.45%
1. Broad-leaved forest	57.33%	54.35%	57.52%	56.78%	54.43%
2. Pine forest	0.00%	0.00%	0.00%	0.00%	0.00%
3. Agriculture/pasture	6.13%	8.00%	6.78%	7.65%	5.39%
4. Scrub	27.06%	28.18%	26.05%	25.96%	30.84%
5. Savanna	0.11%	0.11%	0.11%	0.11%	0.11%
6. Wetland/Swamp	3.47%	3.45%	3.48%	3.48%	3.46%
7. Mangroves	4.18%	4.02%	4.20%	4.14%	3.97%
8. Urban	0.26%	0.43%	0.41%	0.42%	0.34%
9. Water	1.00%	1.00%	1.00%	1.00%	1.00%

[1] CLUE-S does not dictate a particular method for calculating the land use requirements. The use of IMAGE and International Futures was possible only because we had access to these models. Simpler methods are possible and recommended. For example, land use requirements could be calculated using appropriate economic demand models or, very simply, by setting hypothetical land use requirements for the scenarios end year and interpolating the land requirements between start year and end year using a linear or exponential growth model.

*Table 4-4: **Guatemala**: Distribution of present land use and land demand for the scenarios. Blue coloured land use types were kept fixed at present values and not allowed to change over time. The area savanna is very small but not exactly zero (the distinction is significant).*

	Present	Markets	Policy	Security	Sustain.
0. Other/Unknown	0.02%	0.02%	0.02%	0.02%	0.02%
1. Broad-leaved forest	51.11%	45.76%	48.61%	46.63%	49.74%
2. Pine forest	2.48%	2.22%	2.36%	2.26%	2.41%
3. Agriculture/pasture	31.00%	36.27%	34.15%	36.64%	29.81%
4. Scrub	12.66%	12.56%	11.76%	11.31%	14.97%
5. Savanna	0.001%	0.001%	0.001%	0.001%	0.001%
6. Wetland/Swamp	0.04%	0.04%	0.04%	0.04%	0.04%
7. Mangroves	0.00%	0.00%	0.00%	0.00%	0.00%
8. Urban	0.35%	0.79%	0.71%	0.76%	0.66%
9. Water	2.34%	2.34%	2.34%	2.34%	2.34%

*Table 4-5: **Honduras**: Distribution of present land use and land demand for the scenarios. Blue=forced fixed at initial area, not allowed to changed over time.*

	Present	Markets	Policy	Security	Sustain.
0. Other/Unknown	0.29%	0.29%	0.29%	0.29%	0.29%
1. Broad-leaved forest	25.94%	22.47%	24.42%	22.90%	26.64%
2. Pine forest	15.39%	13.34%	14.49%	13.59%	15.81%
3. Agriculture/pasture	55.17%	60.74%	57.59%	60.13%	53.74%
4. Scrub	0.19%	0.18%	0.17%	0.16%	0.23%
5. Savanna	1.41%	1.27%	1.32%	1.24%	1.50%
6. Wetland/Swamp	0.60%	0.54%	0.56%	0.52%	0.63%
7. Mangroves	0.10%	0.09%	0.10%	0.09%	0.11%
8. Urban	0.16%	0.35%	0.32%	0.32%	0.32%
9. Water	0.74%	0.74%	0.74%	0.74%	0.74%

4.2.2.2 Adjustments in land demands for CLUE-S model

The initial plan was to use the calculated demands in Appendix 5 as the land demand files for CLUE-S. From the initial model runs, it became clear that the model could not always reach a solution. This was caused by some land use types that occupy only a small fraction of the total area and hardly change over time. The annual changes may be close to within the convergence criteria of the model. Examples include scrub and mangroves in Honduras (Table 4-5). This adds complexity to the model without yielding any benefits - the input data made it difficult for the model to reach a solution.

Some adjustments were made to the land demands that provided a workaround for this issue. The adjustment was to keep the area of certain land use types constant, and adding the hectares that should have changed to those of the most similar land use type (so that total area remains constant). Note that the demand for *Other* and *Water* is always kept constant. Table 4-6 indicates which land use change demands were kept constant. For example, for Mexico, Savanna was fixed and the change in Savanna that *should have occurred* was allocated to Scrub (that is what the +#5 means). Wetland was also kept constant, with the change that *should have occurred* being added to mangroves.

Table 4-6 shows that generally, along with Water and Other, the land use types that occupy < 0.5% of the total area were kept constant. Wetland in Mexico occupies a larger fraction (3.47%), but was kept constant as it hardly changes across all scenarios (Table 4-3).

Note that Urban land was considered too important to keep constant, even though the area can be quite small. Instead, problems with the allocation of Urban land were tackled by modifying the regression equations.

Table 4-6: Present land use distribution with red coloured values for those types for which the demand was kept constant over time because the demand changes were smaller than the iteration tolerance of CLUE-S, or so small that the model was prevented from reaching a solution. The required change in land was added to another land use type, as indicated within parenthesis.

	Belize	Mexico	Guatemala	Honduras
0. Other/Unknown	*0.06%*	*0.45%*	*0.02%*	*0.29%*
1. Broad-leaved forest	58.02%	57.33%	51.11%	25.94%
2. Pine forest	3.53%	*0.00%*	2.48%	15.39%
3. Agriculture/pasture	19.37%	6.13%	31.00%	(+#6,7) 55.17%
4. Scrub	1.26%	(+#5) 27.06%	(+#5,6,7) 12.66%	*0.19%*
5. Savanna	8.63%	*0.11%*	*0.00%*	(+#4) 1.41%
6. Wetland/Swamp	4.26%	*3.47%*	*0.04%*	*0.60%*
7. Mangroves	3.29%	(+#6) 4.18%	*0.00%*	*0.10%*
8. Urban	0.87%	0.26%	0.35%	0.16%
9. Water	*0.70%*	*1.00%*	*2.34%*	*0.74%*

4.2.3 Main model parameters

The main parameter file has 19 lines with numbers. For further details, please see the User's Manual. Below are the main parameters used for Belize. Only lines 5, 6, 8 and 9 are different for the four countries. These parameters can be read from the header of the ascii grid files.

Table 4-7a: Main model parameters as used for the simulations.

Line	Parameters	Description
1	10	Number of land use types
2	1	Number of regions
3	*country-dependent*	Max number of independent variables in equation
4	12	Total number of driving factors
5	*country-dependent*	Number of rows
6	*country-dependent*	Number of columns
7	6.25	Cell area in ha (250 m grid)
8	*country-dependent*	Xll coordinate of grids
9	*country-dependent*	Yll coordinate of grids
10	0 1 2 3 4 5 6 7 8 9	Number coding land use types
11	1 .8 .8 .1 .4 .4 .8 .8 .9 1	Codes for conversion elasticities
12	*country-dependent*	Iteration variables for land use types
13	2000[1] 2025	Start and end year of simulation
14	1 11	Number and codes of dynamic explanatory factors
15	1	Output file choice
16	0	Region specific regression choice
17	1 15	Initialization of land use history
18	0	Neighbourhood calculation choice
19	0	Location specific preference addition.

[1] The start year for Belize was 2004.

Table 4-7b: Country specific variables

	Belize	Mexico	Guatemala	Honduras
Line 3. nvariables	11	11	10	9
Line 5. nrows	1151	1674	1503	1005
Line 6. ncols	604	1262	1310	2131
Line 8. xllcorner	261500	213250	41250	260250
Line 9. yllcorner	1757500	1971250	1596500	1521000
Line 12. Iteration[1]	0.3 1.5	0.5 3.0	0.5 3.0	0.4 3

Some variables proved more challenging:

- Line 10: Number coding of land use types. In principle very straightforward, but note that the numbering must be without any gaps. Mexico has no pine forest (land use type 2) within the MAR, yet this land use must be included.
- Line 11: Conversion elasticities. Too many values of, or close to, 1 will stabilize the system and may prevent the model from reaching a solution. The elasticities had to be relaxed.
- Line 12: Iteration variables. Settings that are too relaxed could result in land use allocations different from the expected one (as specified in the land use requirements file), whilst settings that are too strict could significantly increase the simulation time -- because more iterations are needed each time set—or cause the model to fail to reach the desired iteration[2]. The default settings (0.3 and 3.0) were a good starting point and only some minor adjustments had to be made.
- Line 18: Neighbourhood function. Was not used because there was insufficient information available about the potential influence within the neighbourhood. See section 4.1.3 for further information about neighbourhood settings.
- Line 19: Location-specific preference addition. A potentially powerful feature, which was not used because insufficient spatial data was available to support it.

4.2.4 Regression parameters

The regression equation parameters (Tables 2-2 through 2-4) were reformatted to **`ALLOC1.REG`** files for each country. Although this is, in principle, a straightforward task, initial model runs indicated that for all countries but Belize, the model was unable to reach a solution. The land use allocation module was not able to significantly change the land allocation even after thousand of iterations.

[1] These iteration variables are the smallest settings with which the model was able to reach a solution. The variables are slightly different among countries, which is a reflection of the different country sizes, land distribution, and in particular smallest and largest (percentage wise) land allocation.

[2] The model execution stops if no solution has been reached after 20 000 iterations for any simulated year.

Numerous tests runs with adjusted model parameters were run to identify the cause[1]. It was concluded that the problems were the combined effect of the following aspects of the model and the MAR data:

- Regression results for land use types with a small percentage of the area, such as Urban, were inaccurate because the sample size that the regression is based on is too small. One solution is to substitute a "common sense" equation.
- The land use distribution of all four countries is extremely skewed, with the most dominant land use type occupying over 50% of the area and the least dominant one less than 1%, and Mexico, Guatemala and Honduras have one or more land use type occupying less than 0.1% of the area (Table 4-6). The results of the regression analysis are naturally insignificant for the least dominant land use types and the probability maps that CLUE-S calculates for those land use types not significant either and in fact very incorrect. They have predominantly zero values.
- The CLUE-S allocation module seems restricted in that it may be unable to make simultaneous adjustments in allocated areas across a wide range[2]. For example, the model had problems making an adjustment of < 10 ha in one land use type and 5 000 ha in another land use type during the same iteration. Consequently, the model is unable to arrive at very small demand figures and the maximum allowed deviation of those land use types is almost always exceeded, causing the model to iterate until the maximum of 20 000 iterations is met.

  The underlying problem may by relatively small iteration variables. These variables (the numbers between the "*" columns in the **LOG.FIL**) have only three decimal places, and if the operating values are only significant at the third decimal, it is very difficult for the model to make small adjustments. For example, if an iteration variable is 0.002 then a change to 0.003 represents a 50% adjustment in the area.

As a workaround the following changes were attempted:

- First, if initial model runs show that iteration variables are significant only at the third decimal place, the relative elasticities are reduced (this will increase the value of the iteration variable because $TPROP_{I,U} = P_{I,U} + ELAS_u + ITER_u$)
- Second, the regression equations for land use types occupying less then 0.5% of the area were deemed inaccurate and insignificant, despite an apparently high ROC value. The regression coefficients were removed from the **ALLOC1.REG** files and replaced by a constant (probability) of 0.5. Whilst not a proper parameter setting, this change is insignificant because few grid cells are affected, and it allows the model to find a solution at last.
- Land use demands that change very little between the initial year and 2025 –for example, the area of Mangroves in Mexico, which are always around 0.09 – 0.11% of the total area (Table 4-6), were adjusted to remain constant (at the initial value), similar to the Water and Other/Unknown categories. The difference in area was allocated to the most similar land use type so that the total area remained the same.

[1] Temporary adjustments in model parameters that were made include: (1) use of much larger iteration variables, in both absolute and relative mode, thus allowing the model to reach a solution quicker and reducing the number of iterations needed; (2) use of a change matrix composed only of 1s, thus providing the greatest flexibility by allowing any land use type; (3) replacement of the least accurate regression equations by a constant equation of 0.5.

[2] This is not documented anywhere based on own experience using the model.

- For all countries, the regression coefficients for Urban were considered inaccurate and were replaced by a subjectively chosen function with a dependency on population density, access to markets, and tourist hotspots ($-1 + 0.0005*LF_0 - 0.2*LF_7 + 0.5*LF_9$). The parameters used in this function were slightly adjusted after inspection of the probability surfaces and test simulation runs.
- For Honduras, the following regression constants were changed:
    - For Savanna, the regression constant was changed from –14.65 to –13.0. This did not expand the area with a non-zero probability, but it did increase the probability of areas that already had a non-zero probability. It was expected that this would made a conversion to Savanna more likely as its probability would now exceed that of (most importantly) Broadleaved Forest, and other types.
    - For Other (#0), Scrub (#4), Wetland/Swamp (#6), Mangroves (#7) and Water (#9), the regression equation was replaced by a constant of 1 (the value is unimportant). These land use types were kept constant during the simulation.
    - A new regression equation for Urban was selected: $0.5 + 0.005*LU_0 - 0.3*LU_7$. This produced a much-improved probability surface that is dependent on population density and accessibility to markets.

The neighbourhood function will ensure that no pixellated areas can exist.

4.2.5 Conversion elasticities

This parameter relates to the reversibility of the land use change. Land use types with a high capital investment (e.g., urban; permanent crops such as banana plantations) will not easily be converted in other uses as long as there is sufficient demand. Other land use types easily shift location when the location becomes more suitable for different land use types. Arable land often makes place for urban development, while expansion of agricultural land occurs at the forest frontier.

For each land use type, a value needs to be specified that represents the relative elasticity to change, ranging from 0 (easy conversion) to 1 (irreversible change).

> 0: Means that all changes for that land use type are allowed, independent from the current land use of a location. This means that a certain land use type can be removed at one place and allocated at another place at the same time: for example, in shifting cultivation.
>
> 1: means that grid cells with one land use type cannot be added and removed at the same time. This is relevant for land use types that are difficult to convert, i.e., urban settlements and primary forests. This stabilizes the system, for example, preventing simultaneous deforestation and reforestation in different areas.
>
> >0…<1: Means that changes are allowed, however, the higher the value the higher the preference that will be given to locations that are already under this land use type.

After initial trial and error runs, it was clear that the key was to use elasticities that are as high as possible, but that do not stabilise the system too much and would prevent the model from reaching a solution. Values of 1 stabilize the system and from the initial model runs it appeared that these values are too stringent, i.e., they can prevent CLUE-S from reaching a solution even after thousands of iterations. Changing a value of 1.0 to 0.95 makes the model significantly more flexible. Likewise, with values of 0 for more flexible land use types such as agriculture, the model changes land use too much throughout the area. Higher values such as 0.2 for agriculture and 0.5 for scrub gave model results that appeared more plausible, i.e.,

a less complete overhaul of the land use pattern. The suggested settings (Table 4-8) are based on expert knowledge of actual past land use patterns and observed model behaviour.

Table 4-8: Default conversion elasticities for the land use types.

Land use type	elasticity
0. Other/Unknown	0.9
1. Broad-leaved forest	0.95
2. Pine forest	0.95
3. Agriculture/pasture	0.0
4. Scrub	0.2
5. Savanna	0.5
6. Wetland/Swamp	0.8
7. Mangroves	0.8
8. Urban	0.9
9. Water	1.0

4.2.6 Conversion matrix

Table 4-9 indicates the default conversion settings, and Tables 4-10 through 4-13 the actual values used for each country. Note that the conversion to and from Other/Unknown (#0) and Water (#9) are not allowed. The 'demand' for these land use types is unlikely to change, and the CLUE-S model operates better if conversions are prohibited. Per-country adjustments were made for those land use types that were artificially kept constant. For example, for Mexico, the rows and columns associated with Pine Forest (non existent) Savanna and Wetland/Swamp were constant 0s as well.

Care had to be taken that there is always at least 1 "from" land use types for every "to" land use type (besides the "to" land use type itself), and vice versa; otherwise the model may be unable to reach a solution because no conversion can be carried out. Most importantly, in **`ALLOW.TXT`** the values in all rows and columns of all land use types kept constant had to be set to 0, except for the value on the same row and column. This adjustment in **`ALLOW.TXT`** is critical to prevent the model from starting calculations with these cells.[1]

Table 4-9: default conversion matrix. Note that some adjustments had to be made for all countries to allow for sufficient change options, as indicated in blue in the next four tables.

Current ↓ Future →	0	1	2	3	4	5	6	7	8	9
0. Other/Unknown	1	0	0	0	0	0	0	0	0	0
1. Broad-leaved forest	0	1	0	1	1	1	0	0	1	0
2. Pine forest	0	0	1	0	1	1	0	0	1	0
3. Agriculture/pasture	0	0	0	1	1	1	1	0	1	0
4. Scrub	0	1	1	1	1	1	0	0	1	0
5. Savanna	0	1	1	1	1	1	0	0	1	0
6. Wetland/Swamp	0	0	0	1	1	0	1	1	1	0
7. Mangroves	0	0	0	0	1	0	1	1	1	0
8. Urban	0	0	0	0	0	0	0	0	1	0
9. Water	0	0	0	0	0	0	0	0	0	1

[1] This was found out by trial and error, and is not a documented model feature.

*Table 4-10: Modified conversion matrix for **Belize** conversion. The medium grey coloured rows and/or columns are associated with land use types that were kept constant and did not change.*

Current ↓ Future →	0	1	2	3	4	5	6	7	8	9
0. Other/Unknown	1	0	0	0	0	0	0	0	0	0
1. Broad-leaved forest	0	1	0	1	1	1	0	0	1	0
2. Pine forest	0	0	1	0	1	0	0	0	0	0
3. Agriculture/pasture	0	0	0	1	1	1	1	0	1	0
4. Scrub	0	1	1	1	1	1	0	0	1	0
5. Savanna	0	1	0	0	1	1	0	0	1	0
6. Wetland/Swamp	0	0	0	1	1	0	1	1	1	0
7. Mangroves	0	0	0	0	1	0	1	1	1	0
8. Urban	0	0	0	0	0	0	0	0	1	0
9. Water	0	0	0	0	0	0	0	0	0	1

*Table 4-11: modified conversion matrix for **Mexico**. The medium grey coloured rows and/or columns are associated with land use types that were kept constant and did not change.*

Current ↓ Future →	0	1	2	3	4	5	6	7	8	9
0. Other/Unknown	1	0	0	0	0	0	0	0	0	0
1. Broad-leaved forest	0	1	0	105	105	0	0	0	105	0
2. Pine forest	0	0	1	0	0	0	0	0	0	0
3. Agriculture/pasture	0	0	0	1	1	0	0	0	1	0
4. Scrub	0	1	0	1	1	0	0	***1***	1	0
5. Savanna	0	0	0	0	0	1	0	0	0	0
6. Wetland/Swamp	0	0	0	0	0	0	1	0	0	0
7. Mangroves	0	0	0	0	1	0	0	1	1	0
8. Urban	0	0	0	0	***1***	0	0	0	1	0
9. Water	0	0	0	0	0	0	0	0	0	1

Table 4-12: modified conversion matrix *for **Honduras**. The medium grey coloured rows and/or columns are associated with land use types that were kept constant and did not change.*

Current ↓ Future →	0	1	2	3	4	5	6	7	8	9
0. Other/Unknown	1	0	0	0	0	0	0	0	0	0
1. Broad-leaved forest	0	1	0	105	0	105	0	0	1	0
2. Pine forest	0	0	1	***105***	0	105	0	0	1	0
3. Agriculture/pasture	0	***1***[1]	***1***	1	0	1	**0**	0	1	0
4. Scrub	0	0	0	0	1	0	0	0	0	0
5. Savanna	0	***0***	***0***	1	0	1	0	0	***0***	0
6. Wetland/Swamp	0	0	0	0	0	0	1	0	*0*	0
7. Mangroves	0	0	0	0	0	0	0	1	0	0
8. Urban	0	0	0	0	0	0	0	0	1	0
9. Water	0	0	0	0	0	0	0	0	0	1

[1] Conversion from agriculture to broad-leaved and pine forest had to be allowed so that the model could reach a solution, whereas conversion from savanna to either forest type was not allowed to prevent large shifts in the location of savanna.

Table 4-13: modified conversion matrix *for **Guatemala**. The medium grey coloured rows and/or columns are associated with land use types that were kept constant and did not change.*

Current ↓ Future →	0	1	2	3	4	5	6	7	8	9
0. Other/Unknown	1	0	0	0	0	0	0	0	0	0
1. Broad-leaved forest	0	1	0	105	105	0	0	0	105	0
2. Pine forest	0	0	1	0	105	0	0	0	***0***[1]	0
3. Agriculture/pasture	0	0	0	1	1	0	0	0	1	0
4. Scrub	0	1	1	1	1	0	0	0	***0***	0
5. Savanna	0	0	0	0	0	1	0	0	0	0
6. Wetland/Swamp	0	0	0	0	0	0	1	0	0	0
7. Mangroves	0	0	0	0	0	0	0	1	0	0
8. Urban	0	0	0	0	***1***	0	0	0	1	0
9. Water	0	0	0	0	0	0	0	0	0	1

4.2.7 Dynamic location factor grids: Protected Areas

From all location factors listed in Table 1-6, only the last two - fully protected areas and partially protected areas - were used as dynamic location factor grids that are different in every simulated year. While population density is often a dynamic location factor in CLUE-S applications, the lack of spatially-explicit population scenarios made this impossible.

Two shapefiles (**`EXISTING_PA.SHP`** and **`SCENARIO124.SHP`**) that were used for creating all necessary dynamic location grids. The fields *USE_CLASS, SC1-USE, SC2-USE, SC3-USE* and *SC4-USE* indicated whether the polygon was fully protected ("NO_USE"), partially protected area ("SUST-USE"), or not designated under that scenario ("EXCLUDED"). For the third scenario about 20% of the areas were identified as "FAILED". There is no difference from the land use model's point of view between an protected area labelled FAILED or EXCLUDED - in both cases the area is not considered protected, because under that future scenario its protection failed, or it was not protected in the first place.

An Avenue script was developed for creating all location factor grids in a fully automatic way and saved in ASCII grid format (Appendix 2). This script uses a specially created shapefile **`SCEN_COMBINED_4RASTER.SHP`** that has 9 additional fields: *YEARINCL, S1PAS1, S1PA2, S2PAS1, S2PA2, S3PAS1, S3PA2, S4PAS1,* and *S4PA2.*

4.2.8 Dealing with absence of pine forest in Mexico

There is no pine forest on the map for the MAR region of Mexico. This is the only total absence of any land use type in the four countries. It required special attention and some adjustments in model parameters to avoid a runtime error (overflow error).

One solution might be to adjust the numbering of the land use types to fill the gap, i.e., numbers 0-1,3-9 (2 is the missing pine forest) would have to be changed to 0-8. As this process is cumbersome and error-prone, the following tweaks were made instead:

- Added dummy regression coefficients for land use type 2 in file **`ALLOC1.REG`** because this file must contain regression coefficients for all land use types. A dummy equation with a constant of 0 and a regression coefficient of 0 for the first factor grid was used.

[1] Conversion from pine forest and scrub to urban was prohibited to force change from broad-leaved forest to urban and generate more plausible urban expansion

- In **COV1.ALL**, changed the value of four grid cells from 1 (broadleaved forest) to 2 (pine forest), thus introducing artificial pine forests. Four cells in the bottom-left corner of the grid were chosen solely because these cells are easy to identify. These cells were returned to broadleaved forest in the simulated land use grid **COV22.ALL**. Note that the change was made for 4 cells instead of 1 cell, so that the corresponding area has no significant decimal value, and CLUE-S will not make a rounding error when the demand figures are read in (the demand values in **LOG.FIL** suggest that they are rounded to 1 decimal place, although that may a formatting matter).
- In the demand file **DEMAND1.FIL**, replaced the 0 hectare value in the third column with 25. That is the area of the additional cell in ha. The values in the second column (broadleaved forest) are reduced by 25 hectares.
- In **ALLOW.TXT**, changed all values in the third row and third column to 0 except the value at position [3,3]. Thus, pine forest cannot change to anything else.

4.3 Simulation results

4.3.1 Simulated changes in land use and in forest cover

Figures 4-1 to 4-5 show the present and simulated land use patterns for 2025. These land cover raster data were shared with WRI on 20th July 2006 for use in the N-SPECT hydrological simulations. Figures 4-6 to 4-8 show the areas of change only, making the new areas of each land use class easier to identify.

A minor anomaly in the simulated land use pattern near San Pedro Sula, Honduras can be seen, with some areas of forest "sandwiched" in between new urban land. The cause of this was identified (probability surfaces and regressions) but could not easily be resolved. It is merely a reflection of the probabilistic nature of the model and that the exact allocation by the model of land use at a local level cannot easily be influenced.

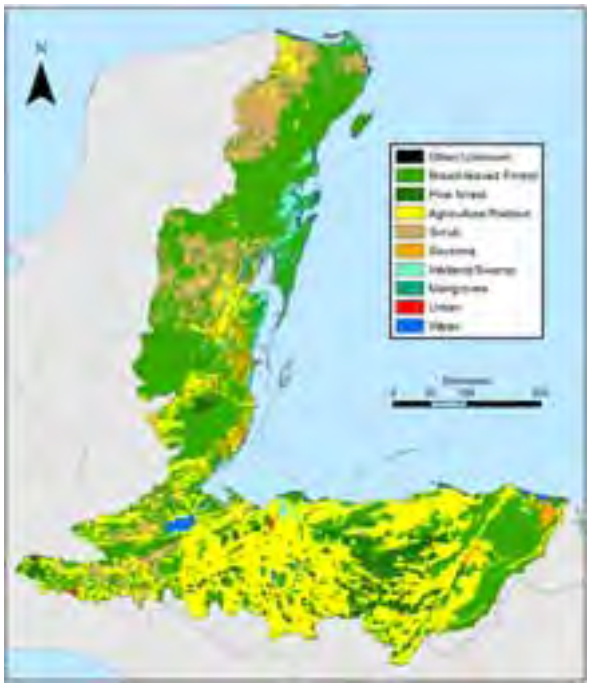
4.3.2 Average and maximum deviation of solution

The iterative allocation module never achieves an allocation that fully matches the demand. This is controlled by the iteration variables on line 12 of the main parameter file. A relative iteration mode with an average deviation of 0.5% and a maximum individual deviation (for any individual land use type) of 3.0% was used. Table 4-15 below gives the actual deviations that were achieved, which are always equal to or lower than the maximum values.

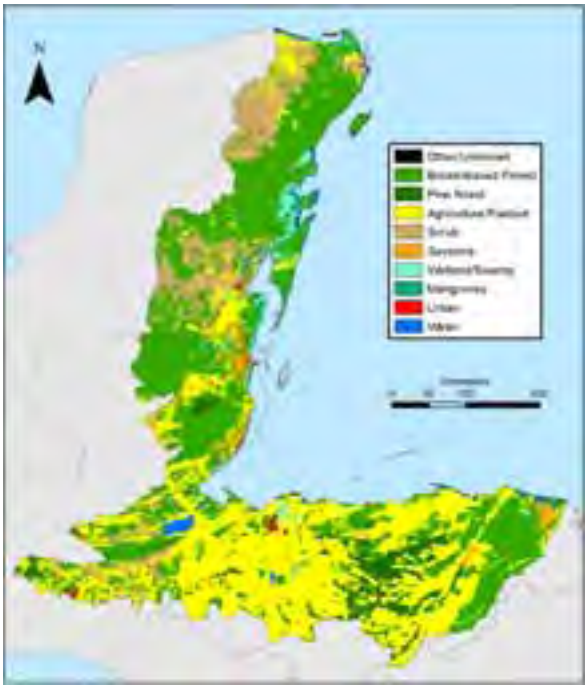
Table 4-15: mean and maximum deviation between demand and allocated land use, in percentage of absolute area, for land use in the final simulated year, 2025). These statistics are calculated for every simulated year but presented here only for the final year). The maximums (2nd and 3rd columns) are specified in the main parameter file and are slight adjustments from the default settings in CLUE-S, respectively, 0.35% and 3.0%. In almost all cases the highest deviation applies to land use that occupies the least area and is not kept constant, which almost always is Urban

	Maximums		1. Market First		2. Policy First		4. Sustain. First	
	Mean	*Max*	Mean	Max	Mean	Max	Mean	Max
Belize	*0.3%*	*1.5%*	0.29%	1.00%	0.30%	1.08%	0.27%	0.80%
Mexico	*0.5%*	*3.0%*	0.31%	2.96%	0.31%	2.99%	0.34%	2.99%
Guatemala	*0.5%*	*3.0%*	0.48%	1.85%	0.47%	1.82%	0.48%	2.27%
Honduras	*0.4%*	*3.0%*	0.39%	1.58%	0.40%	2.03%	0.40%	2.87%

Baseline 2000/2004



Market First 2025



Policy First 2025

Sustainability First 2025

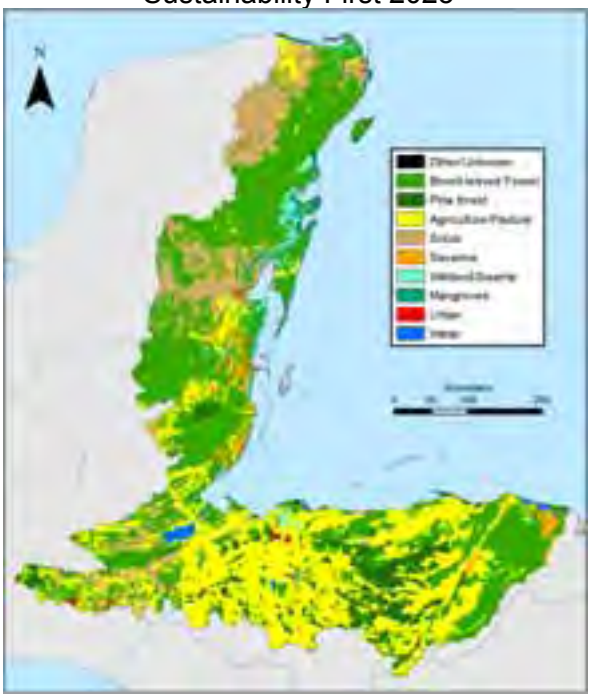


Figure 4-1: Present land cover and simulated land cover for the three scenarios in 2025.

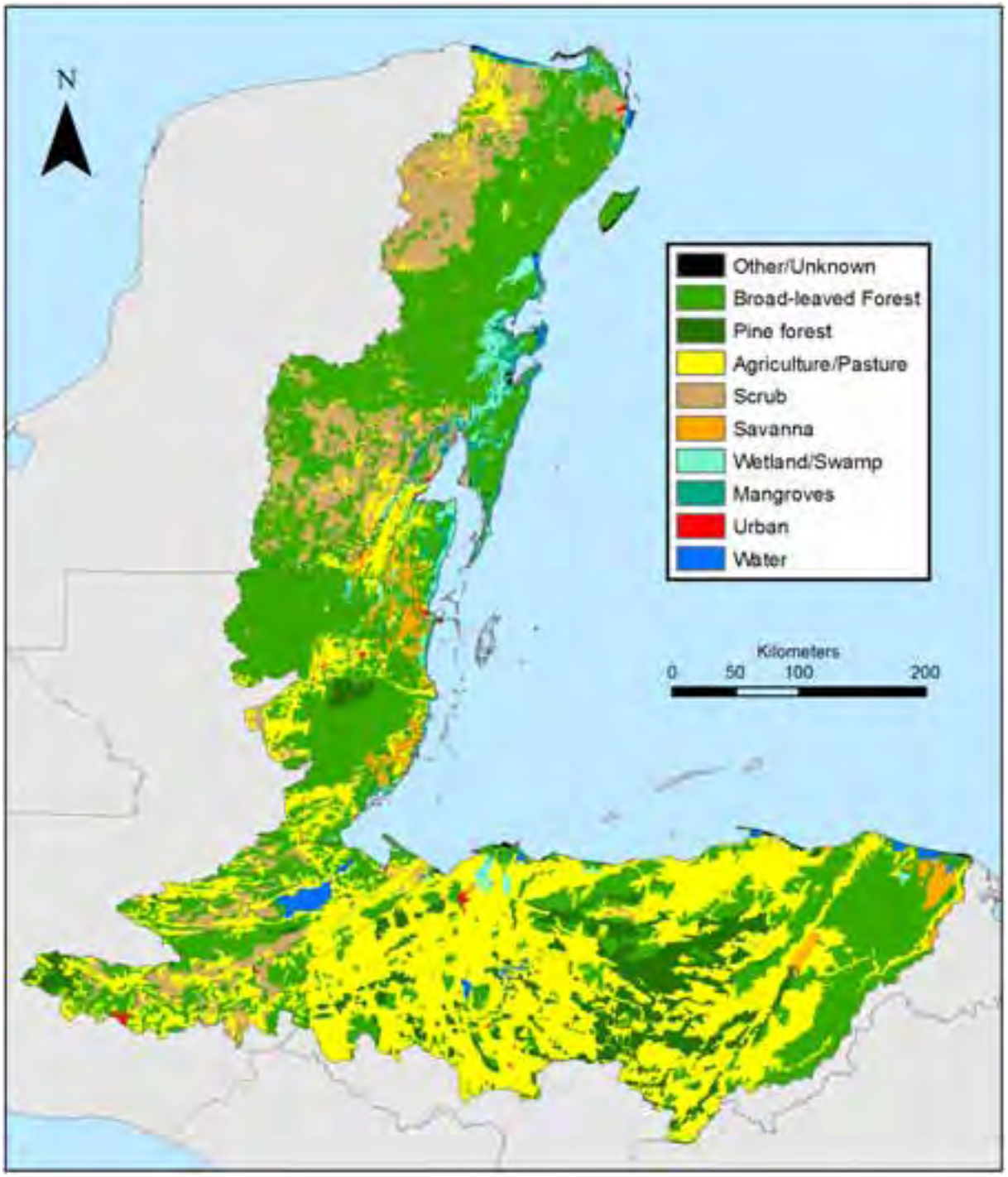


Figure 4-2: Baseline (2000/2004) land use

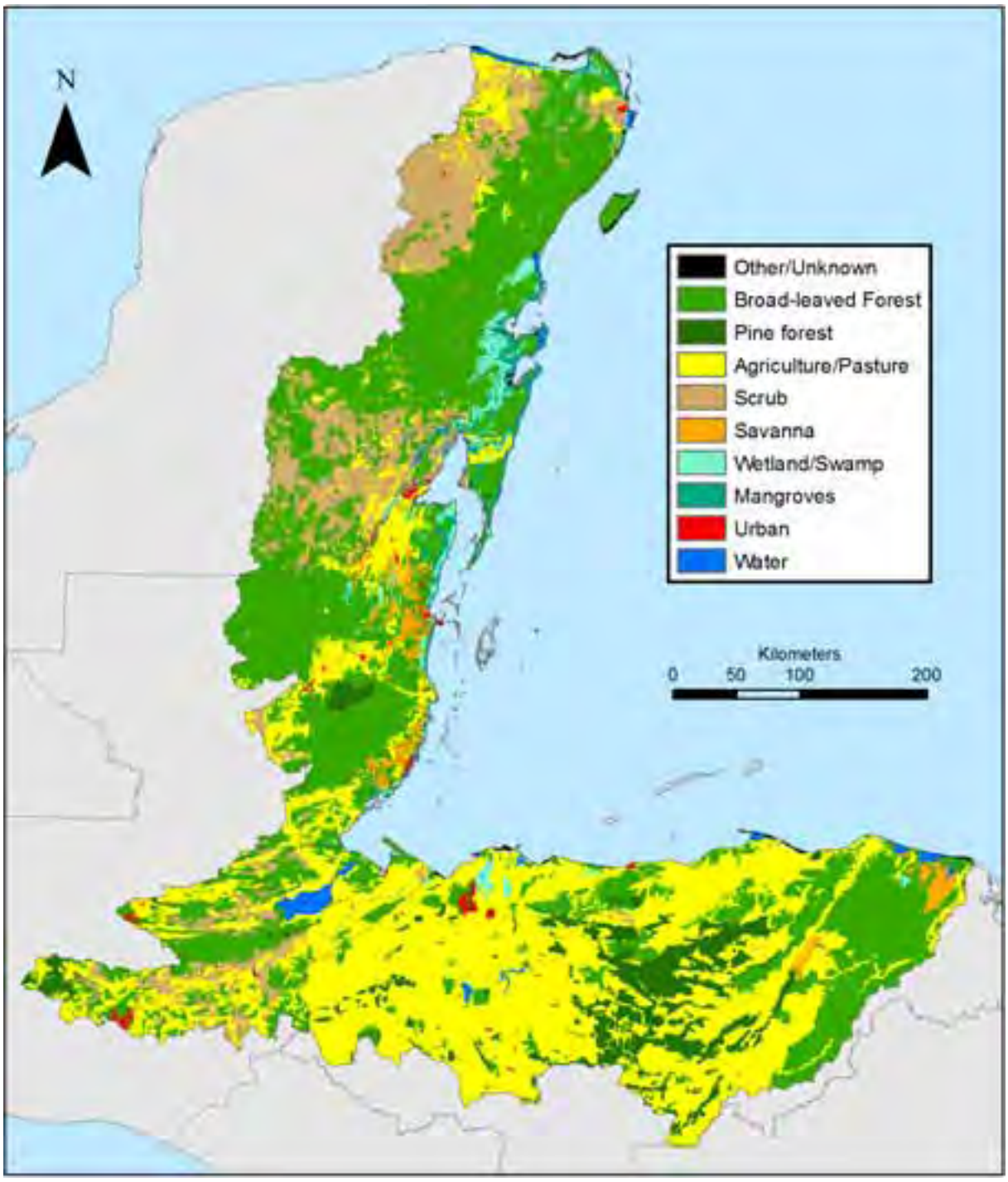


Figure 4-3: Simulated land cover for scenario 1, Markets First, in 2025

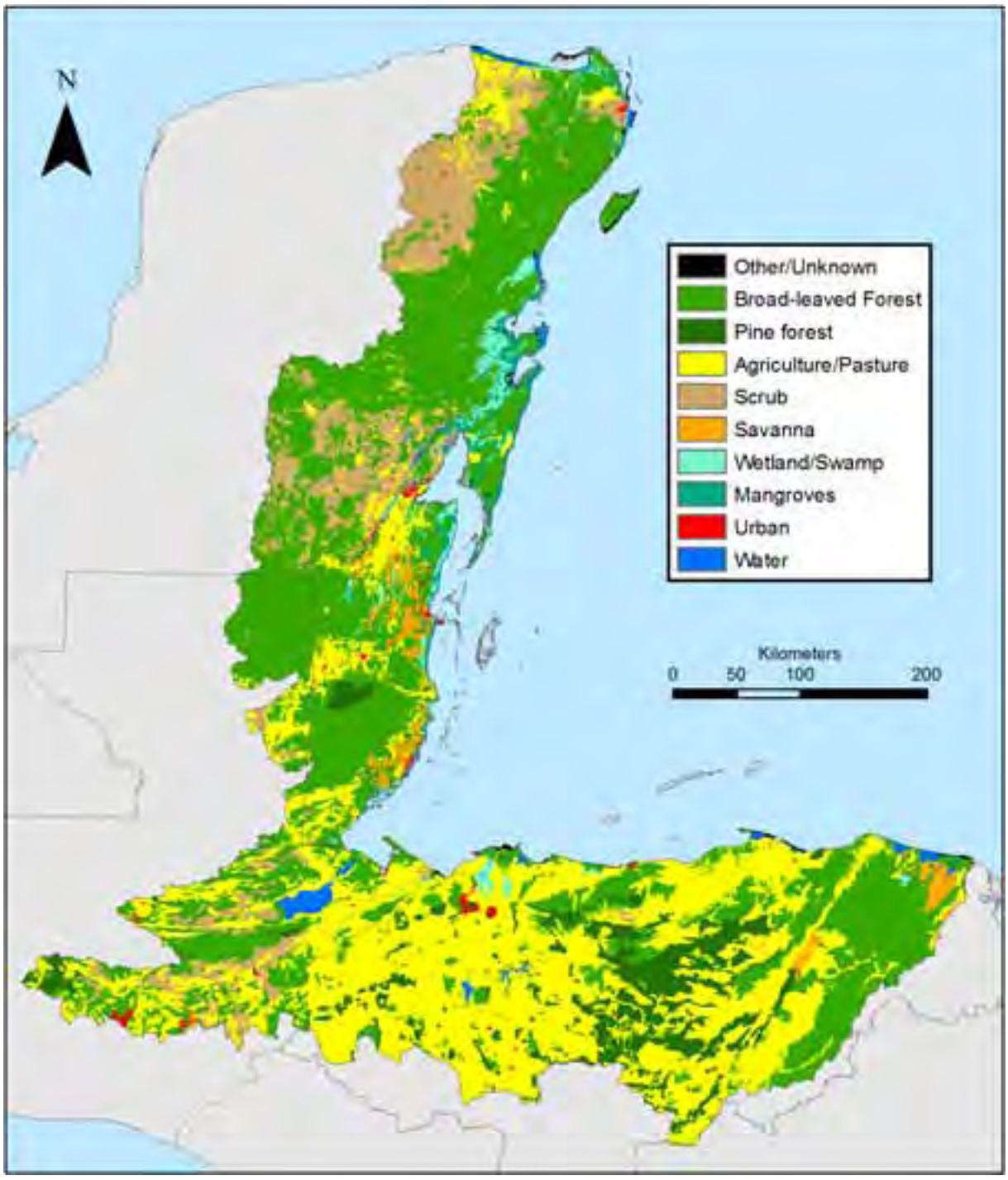


Figure 4-4: Simulated land cover for scenario 2, Policy First, in 2025

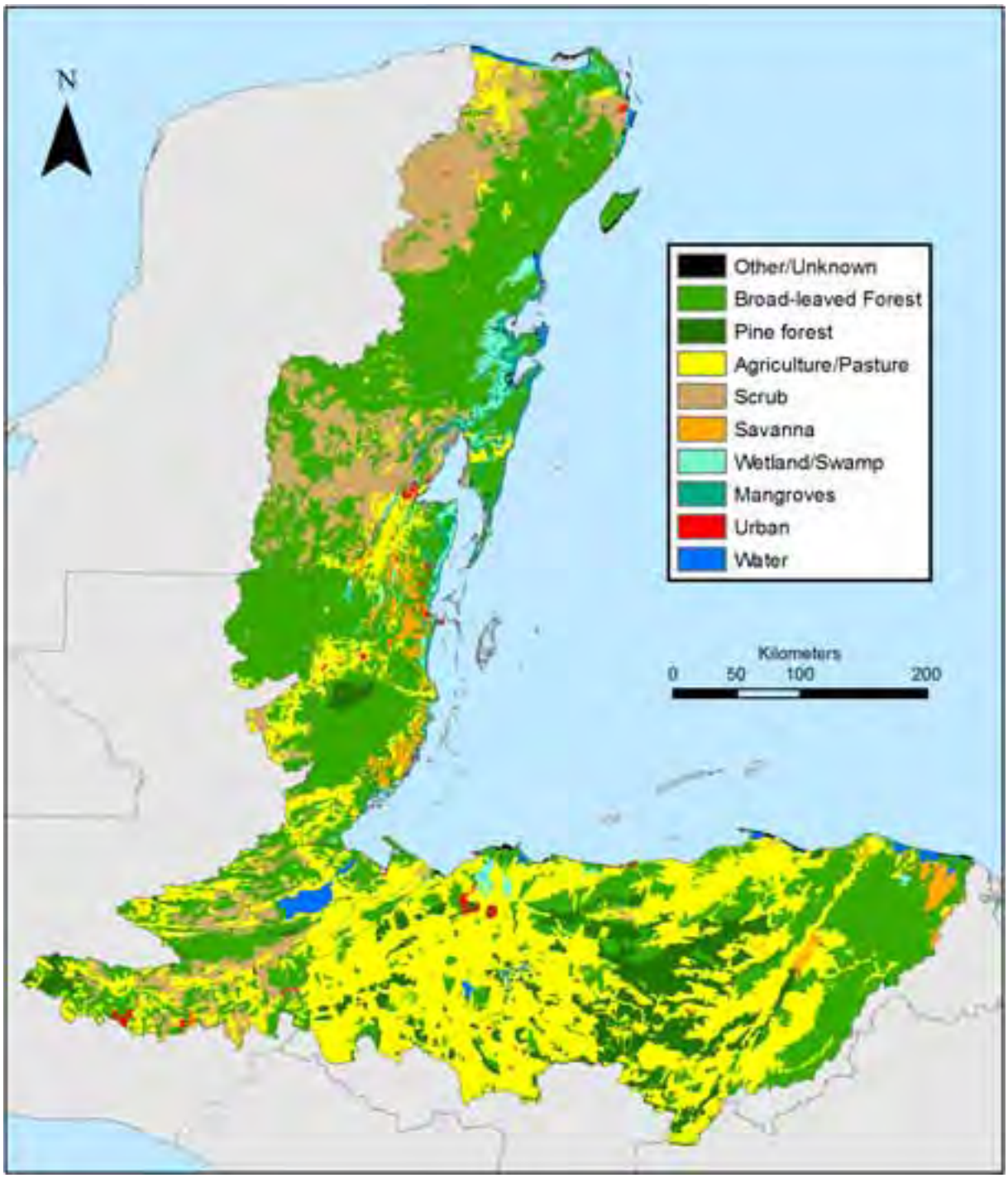


Figure 4-5: Simulated land cover for scenario 4, Sustainability First, in 2025

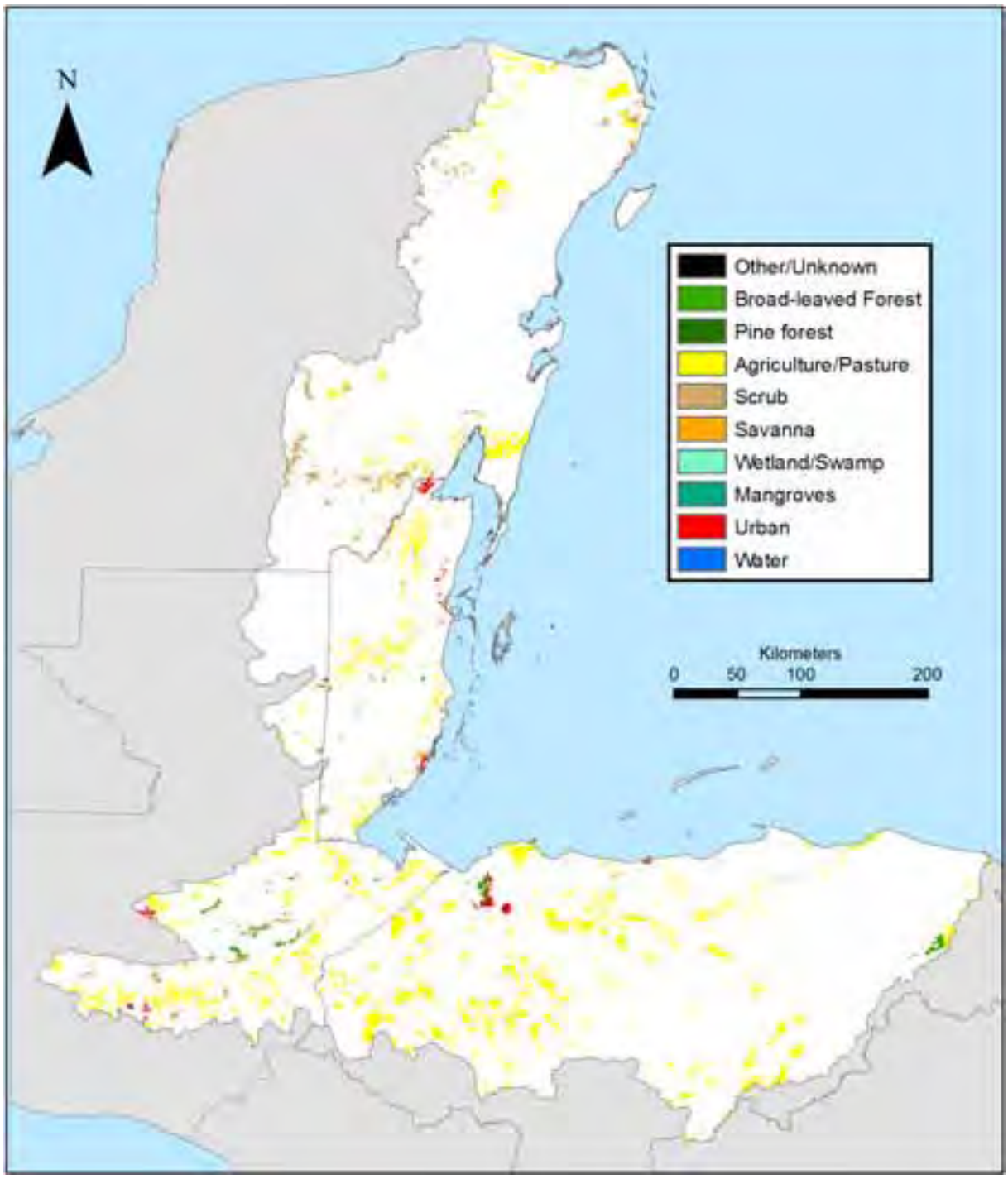


Figure 4-6: Simulated areas of change with 2025 land cover for scenario 1, Markets First

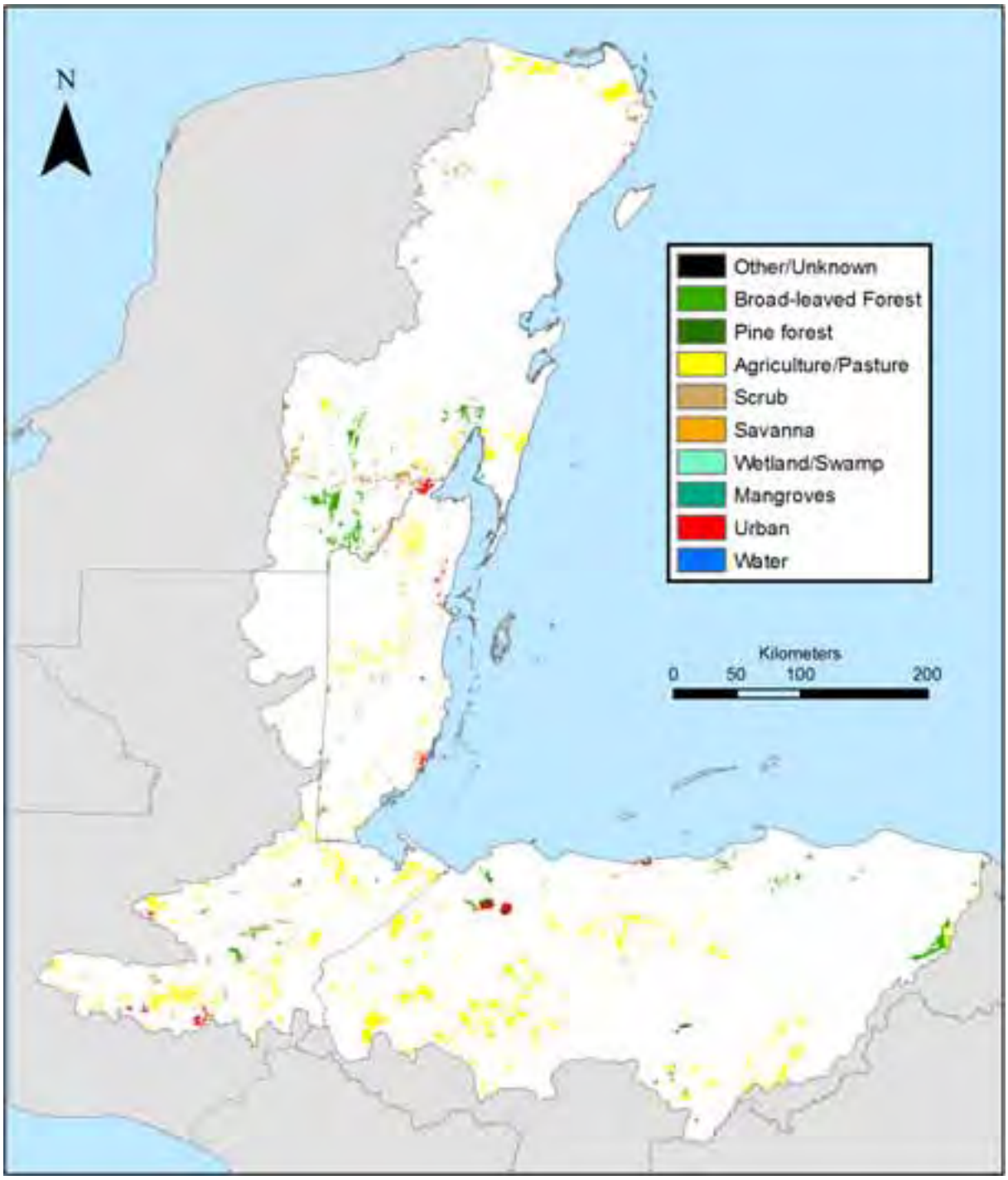


Figure 4-7: Simulated area of change with 2025 land cover for scenario 2, Policy First

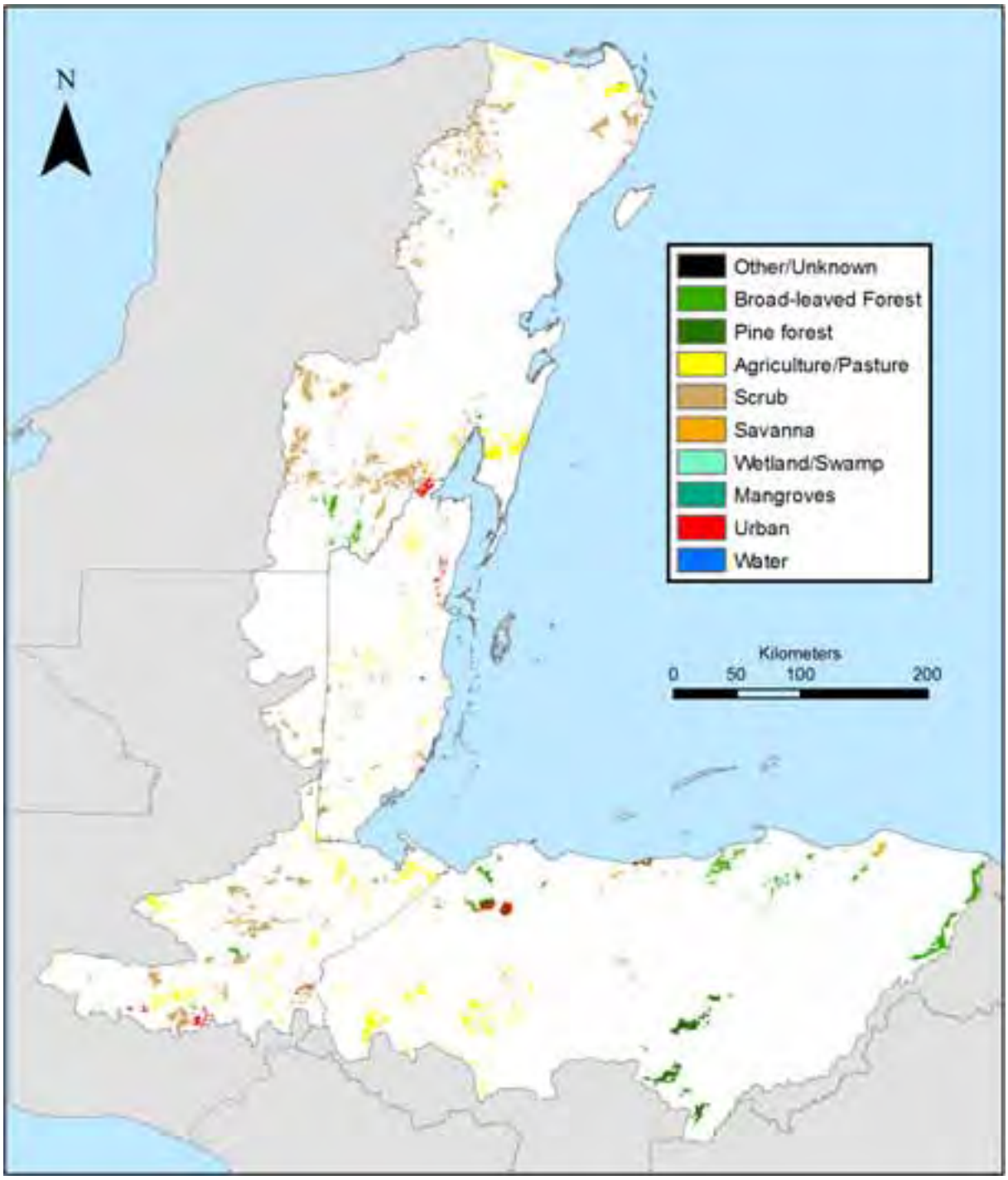


Figure 4-8: Simulated areas of change with 2025 land cover for scenario 4, Sustainability First

5 Workshop, conclusions and recommendations

5.1 Technical Workshop

A *Workshop on Watershed Management, Land Cover Change Analysis, and Modeling of Land-based Sources of Pollution and Sediment Discharge to the MAR* was held 15-18 August 2006 at Galen University, Belize. The workshop consisted of a policy session (1 ½ day) and a technical session (2 ½ days). Two presentations about the scenario development and the land use change modelling were given during the policy session, alongside presentations on the background of the land-use-change threats to the Mesoamerican Reef, and the policy implications of the MAR project.

The last day of the workshop was dedicated to training in land use change modelling using the CLUE-S model. The training programme, exercises and further supporting information --all bundled in a 30 page training package—can be found in Appendix 6.

Proceedings from the workshop have been compiled separately, and summarise feedback received from workshop participants.

5.2 Conclusions and Recommendations

The following conclusions and recommendations are compiled based upon Joep Luijten's experience with the application of CLUE-S to the MAR region, and on feedback received during the workshop.

5.2.1 Application of CLUE-S model to the MAR region

- The CLUE-S methodology has been successfully used to simulated land use changes in the MAR region over the next 25 years. A separate model was developed for each country. This was the correct approach, as it allows more accurate models that better capture the relevant (and different) explanatory factors in each of the countries.
- Simulated land use changes in different directions under the three scenarios, with substantial conversion from forest to agricultural land under the Markets First and Policy First scenarios. Under the Sustainability First scenario, changes towards other land use types could be observed too; most notably changes towards scrub and new forest areas.
- Whilst CLUE-S is a relatively easy model to use, the overall land use change modelling component of the project is quite complex. CLUE-S is not a model that can be quickly applied and run; preparation and implementation requires substantial time (months) and many data conversions. A significant portion of the hours required was spent on data collection and/or creation and quality assurance, data preparation for use in SPSS (regression analysis) and CLUE-S, and the regression analysis. Once the model was properly calibrated, the final simulation runs were a relatively straightforward task.
- CLUE-S does not dictate any particular method for calculating the land use requirements. The use of IMAGE and International Futures was possible only because we had access to these models. Simpler methods are possible and recommended, especially where specific regional policies are to be applied. For example, land use requirements could be calculated using appropriate economic demand models or simply by setting hypothetical land use requirements for the final scenario year and interpolating the land requirements between the start year and end year using a linear or exponential growth model.

- The regression analysis was a somewhat weak part of the study in that many relationships were not very significant and had to be manually tweaked or replaced by either a more logical regression equation (e.g., Urban), as detailed in Section 4.2.4. This is a direct consequence of the characteristics of the land use data that were used. The Ecosystem Map data were relatively coarse and polygon-based. It is believed that the regression analysis and the way CLUE-S allocates land based on the probability surfaces would give better results (and need fewer adjustments in model parameters and/or workarounds for the model not being able to reach a solution) if an original remote sensed raster dataset is used. Workshop participants knew of several recently released new land cover datasets, in particular for Guatemala.
- Another potential approach for improving the regression analysis is to use a "balanced sample" dataset instead of the full dataset for the region. A balanced sample is a dataset for a region that clearly exhibits the relevant relationships between a particular land use type and one or more location factors. Only full datasets were used for the MAR study.
- CLUE-S can be used if land use data from only a single year are available because the model is parameterized: in principle, based on the results of the regression analysis of the present land use pattern and a set of potential explanatory factors. However, it is always better if land use data for two or even three years are available, and these additional data can be used to improve the models. Having data for two years, y_1 and y_2, allows one to parameterize the models based on an regression analysis of the data for y_1, then run the model from y_1 to y_2, compare the simulated land use pattern with the actual land use pattern at y_2, and adjust (calibrate) the improve the model fit. If a third year y_3 is available, then a simulation run from y_2 to y_3 can be undertaken for model verification.

5.2.2 Workshop and training

- This overall work was covered during a 1-hour presentation during the policy part of the workshop and a 1-day training day in CLUE-S. The response to the questionnaires indicated that, in general, the participants found working with CLUE-S very useful.
- The CLUE-S training was quite intense. Any future training should dedicate at least 2 or 3 days to CLUE-S, as that will allow participants to spend more time on three important aspects of the study: (i) in-depth understanding and hands-on working with the actual data for Belize, Mexico, Guatemala and Honduras; (ii) how to use their own datasets; and (iii) the regression analysis of location factors and methods for incorporating additional or different location factors into the model. Any follow-up training should include these aspects, as some attendees requested this in the questionnaires.

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7 Appendices

Appendix 1. Avenue script for NoData filling and filtering

The following Avenue script was created to fill NoData holes and to apply a majority filter to rasters, as mentioned in Section 1.1.1. This script removes any minor imperfections in the raster grids and adds a small buffer of value cells at the edge so that every raster being used for the statistical analysis has exactly the same number of value cells. The script can handle both mean filter and majority filters, and up to 10 iterations at once.

```
' SWBM.Grid.FillNodataGaps

' July 14, 2004. Joep Luijten
' This script was written fill the common Nodata cells in SRTM elevation
' data. The NoData cells are typically areas with steep gradients, river
' valleys, etc. The fill is done iteratively. See ESRI article 22853.
' http://support.esri.com/index.cfm?fa=knowledgebase.techarticles.articleShow&d=22853
' The number of necessary iterations depends on how large the data gaps are.

' 4/1/06. Provide selection menu to choose focalstats type (MEAN ort MAJORITY) and
' output type (floating or integer). This enables to use this script also to fill
' gaps in classified data. The majority filter wasn't as straightforward, though.
'
' The use of the MajorityFilter() does correctly fill any NoData holes inside a grid
' providing that the second argument is set TRUE, however, it does not convert NoData
' cells to value cells at the edge. On the other hand, a FocalStats() of type
' GRID_STATYPE_MAJORITY does create value cells at the edge (1 cell wide per
' iteration). Hence, it was deemed necessary to implement a succession of both
' methods at each iteration step to achieve the desired result.

theView = av.GetActiveDoc
theTheme = theView.GetActiveThemes.Get(0)
rawDem = theTheme.GetGrid
titmsg = "Fill NoData gaps in GRID"

' Check to proceed
if (MsgBox.YesNo("Fill NoData gaps in GRID theme" ++ theTheme.GetName + "?",titmsg, FALSE) =
FALSE) then
 return nil
end

' Method
iMethodList = {"MEAN 3x3 filter, return floating grid",
      "MEAN 3x3 filter, return integer grid",
      "MAJORITY 3x3 filter, return integer grid"}
iMethod = Msgbox.ListAsString (iMethodList, "Select FocalStats method", titmsg)

if (iMethod = nil) then
 return nil
else
 iMethodIndex = iMethodList.FindByValue(iMethod)

 if (iMethodIndex = 0) then
  bMean = true
  bFloat = true
 elseif (iMethodIndex = 1) then
  bMean = true
  bFloat = false
 elseif (iMethodIndex = 2) then
  bMean = false
  bFloat = false
 end
end


' Prompt for number of iterations
errorMsg = "You must enter a number between 1 and 10"
while (true)
 Niter = MsgBox.Input("Number of iterations [1-10]:",titmsg,"3")
 if (nIter = NIL) then return nil end
 if (nIter.IsNumber.Not) then
  MsgBox.Warning(errorMsg,titmsg)
 else
  nIter = nIter.AsNumber
  if ((nIter < 1) or (NIter > 10)) then
   MsgBox.Warning(errorMsg,titmsg)
  else
   break
```

```
  end
 end
end


' Check for any values < 0 or >= 32768 (in SRTM data, 32768 is used for NoData).
gStats = rawDem.GetStatistics

setMin = false
if (gStats.Get(0) < 0) then
 setMin = Msgbox.YesNo("The grid contains negative values (as low as"++
  gStats.Get(0).AsString ++ "). These are unusual --though not impossible-- elevation"++
  "values that you may want to set to zero. Do you want to do this?",titmsg, TRUE)
end

setMax = false
if (gStats.Get(1) >= 32768) then
 setMax = Msgbox.YesNo("The grid contains very high values that are unlikely elevations."++
  "Note that SRTM data often contain values 32768 (NoData) and 95xxx (incorrect)."++
  "You are strongly recommended to set these values to NoData. Okay?",titmsg, TRUE)

 if (setMax) then
  mxMsg = "You must enter a number between 0 and 100000"
  while (true)
   mxCut = MsgBox.Input("Maximum cutoff value (excluded):",titmsg,"32768")
   if (mxCut = NIL) then return nil end
   if (mxCut.IsNumber.Not) then
    MsgBox.Warning(mxMsg,titmsg)
   else
    mxCut = mxCut.AsNumber
    if ((mxCut < 0) or (mxCut > 100000)) then
     MsgBox.Warning(mxMsg,titmsg)
    else
     break 'Value is OK
    end
   end
  end
 end
end

' Apply min and max values
if (setMin and setMax) then
 g0 = ((rawDem < 0.asgrid).Con(0.asgrid,(rawDem >= mxCut.asgrid).SetNull(rawDem)))
elseif (setMin and setMax.Not) then
 g0 = ((rawDem < 0.asgrid).Con(0.asgrid,rawDem))
elseif (setMin.Not and setMax) then
 g0 = ((rawDem >= mxCut.asgrid).SetNull(rawDem))
else
 g0 = rawDem
end

' Perform iterative fill. Two methods in succession for the majority filter.

theNbrHood = NbrHood.Make ' Default 3x3 rectangular neighborhood

if (nIter >= 1) then
 if (bmean = true) then
   g1 = (g0.IsNull).Con((g0.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g0)
 else
   g1tmp = ((g0.IsNull).Con(g0.MajorityFilter(TRUE, TRUE),g0))
   g1 = (g1tmp.IsNull).Con((g1tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g1tmp)
 end
 if (nIter = 1) then
  gFinal = g1
 end
end

if (nIter >= 2) then
 if (bmean = true) then
   g2 = (g1.IsNull).Con((g1.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g1)
 else
   g2tmp = ((g1.IsNull).Con(g1.MajorityFilter(TRUE, TRUE),g1))
   g2 = (g2tmp.IsNull).Con((g2tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g2tmp)
 end
 if (nIter = 2) then
  gFinal = g2
 end
end

if (nIter >= 3) then
 if (bmean = true) then
   g3 = (g2.IsNull).Con((g2.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g2)
 else
   g3tmp = ((g2.IsNull).Con(g2.MajorityFilter(TRUE, TRUE),g2))
   g3 = (g3tmp.IsNull).Con((g3tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g3tmp)
```

```
 end
 if (nIter = 3) then
  gFinal = g3
 end
end

if (nIter >= 4) then
 if (bmean = true) then
   g4 = (g3.IsNull).Con((g3.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g3)
 else
   g4tmp = ((g3.IsNull).Con(g3.MajorityFilter(TRUE, TRUE),g3))
   g4 = (g4tmp.IsNull).Con((g4tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g4tmp)
 end
 if (nIter = 4) then
  gFinal = g4
 end
end

if (nIter >= 5) then
 if (bmean = true) then
   g5 = (g4.IsNull).Con((g4.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g4)
 else
   g5tmp = ((g4.IsNull).Con(g4.MajorityFilter(TRUE, TRUE),g4))
   g5 = (g5tmp.IsNull).Con((g5tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g5tmp)
 end
 if (nIter = 5) then
  gFinal = g5
 end
end

if (nIter >= 6) then
 if (bmean = true) then
   g6 = (g5.IsNull).Con((g5.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g5)
 else
   g6tmp = ((g5.IsNull).Con(g5.MajorityFilter(TRUE, TRUE),g5))
   g6 = (g6tmp.IsNull).Con((g6tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g6tmp)
 end
 if (nIter = 6) then
  gFinal = g6
 end
end

if (nIter >= 7) then
 if (bmean = true) then
   g7 = (g6.IsNull).Con((g6.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g6)
 else
   g7tmp = ((g6.IsNull).Con(g6.MajorityFilter(TRUE, TRUE),g6))
   g7 = (g7tmp.IsNull).Con((g7tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g7tmp)
 end
 if (nIter = 7) then
  gFinal = g7
 end
end

if (nIter >= 8) then
 if (bmean = true) then
   g8 = (g7.IsNull).Con((g7.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g7)
 else
   g8tmp = ((g7.IsNull).Con(g7.MajorityFilter(TRUE, TRUE),g7))
   g8 = (g8tmp.IsNull).Con((g8tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g8tmp)
 end
 if (nIter = 8) then
  gFinal = g8
 end
end

if (nIter >= 9) then
 if (bmean = true) then
   g9 = (g8.IsNull).Con((g8.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g8)
 else
   g9tmp = ((g8.IsNull).Con(g8.MajorityFilter(TRUE, TRUE),g8))
   g9 = (g9tmp.IsNull).Con((g9tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g9tmp)
 end
 if (nIter = 9) then
  gFinal = g9
 end
end

if (nIter >= 10) then
 if (bmean = true) then
   g10 = (g9.IsNull).Con((g9.FocalStats(#GRID_STATYPE_MEAN,theNbrHood,FALSE)),g9)
 else
   g10tmp = ((g9.IsNull).Con(g9.MajorityFilter(TRUE, TRUE),g9))
   g10                                                                                    =
(g10tmp.IsNull).Con((g10tmp.FocalStats(#GRID_STATYPE_MAJORITY,theNbrHood,FALSE)),g10tmp)
```

```
 end
 if (nIter = 10) then
  gFinal = g10
 end
end

' Make final grid
if (bFloat = true) then
 gFinal2 = gFinal.Float
 sOper = "("+nIter.asstring++"pass)"
else
 gFinal2 = gFinal.Int
end

' Construct new title name
if (bMean = true) then
 sname = theTheme.GetName++"("+nIter.asstring++"pass MEAN filter)"
else
 sname = theTheme.GetName++"("+nIter.asstring++"pass MAJORITY filter)"
end

' Add filled grid theme to view
newGTheme = GTheme.Make(gFinal2)
newGTheme.SetName(sname)
theView.AddTheme(newGTheme)
theView.Invalidate
```

Appendix 2. Avenue script for creating dynamic protected areas grids

The script below was used to create dynamic location grids for the protected area scenarios. The script requires a view that contains five themes: the protected areas shapefile (**SCEN_COMBINED_4RASTER.SHP**) and the four mask grids for the countries (**MASK_BZ_250, MASK_GT_250, MASK_MX_250, MASK_HN_250**). The protected areas shapefile must have eight additional fields *S1PA1, S2PA2, A1PA1, .., S4PA2*, each with 0 and 1 values, indicating whether the polygon is a full or partially protected area. The scripts generates the grid **SRC1G11.FIL** (static fully protected areas), **REGION_NO_USE_S1MKT.FIL** (also static fully protected areas a value of –9998 for those areas) and **SRC1G12.0, SRC1G12.1**, …, through to **SRC1G12.25** (dynamic partially protected areas).

```
' Create.Dynamic.ProtectedAreas.Grids

' Location factor numbers (as in CLUE-S regression files)
locFacNum_fullProt = 11
locFacNum_partProt = 12
baseOutFolder = "D:\Work_WCMC\CLUES\dyndata\"

' Get active view
theView = av.FindDoc("protected areas")
thePrj = TheView.Getprojection
if (theView.Is(View).Not) then
 msgbox.Info ("Active document must be a view","")
 return nil
end

' Select country to process
country = MsgBox.ListAsString({"BZ","MX","GT","HN"}, "Select country","")
if (country = NIL) then
 return nil
end

' select scenario to process
scenario = MsgBox.ListAsString(
 {"1 Market First","2 Policy First","3 Security First","4 Sustainability First"},
 "Select scenario","")
if (scenario = NIL) then
 return nil
else
 scenNo = scenario.Left(1).AsNumber
end

' Select protected areas shapefile (modified to with special fields added)
thmList = theView.GetThemes
if (thmList.Count > 0) then
  wdpaThm = MsgBox.ListAsString(thmList, "Select the Protected Areas shapefile." +
   "The attribute table must include fields S"+scenNo.asstring+
    "PA1 and S"+scenNo.AsString+"PA2.","")
  if (wdpaThm = NIL) then
   return nil
  else
   theFTab = wdpaThm.GetFTab
   fldList = theFtab.GetFields
  end
else
 return nil
end

' Output directory
outDir = Msgbox.Input("Output folder","",baseOutFolder + country)
if (outDir = NIL) then return NIL end
if (scenNo = 1) then
 subdir = "s1mkt"
elseif (scenNo = 2) then
 subdir = "s2pol"
elseif (scenNo = 3) then
 subdir = "s3sec"
elseif (scenNo = 4) then
 subdir = "s4sus"
end
outDir = outDir + "\" + subdir

' Get mask grid. If the hardcoded name not found the selection menu will be shown.
maskName = "mask_" + country + "_250"
maskThm= theView.FindTheme(maskName)
```

```
if (maskThm <> NIL) then
 maskGrid = maskThm.Getgrid
else
 if (thmList.Count > 0) then
  maskThm = MsgBox.ListAsString(thmList,
   "Select the mask grid for " + country,"")
  if (maskThm = NIL) then
   return nil
  else
   maskGrid = maskThm.Getgrid
  end
 else
  return nil
 end
end

' Set analysis extent same to mask grid
aRect = maskgrid.getExtent
aCell = maskgrid.getCellSize
Grid.SetAnalysisExtent (#GRID_ENVTYPE_VALUE, aRect)
Grid.SetAnalysisCellsize(#GRID_ENVTYPE_VALUE, aCell)

' Create grid with only zeros for country extent
zeroGrid = ((maskGrid.IsNull).setnull(0.asgrid))


' **** STATIC LOCATION FACTOR FOR FULLY PROTECTED AREAS ****

' Filename for static location factor grid
cluename = "Src1gr" + locFacNum_fullProt.asstring + ".fil"

' Query to select all WDPA to include
fld1 = "S" +scenNo.asString + "pa1"

expr = "(["+fld1+"] = 1)"
theBitmap = theFTab.GetSelection
theFtab.Query(expr, theBitmap, #VTAB_SELTYPE_NEW)
theFTab.UpdateSelection

' Convert shape to grid.
tmp1Grid = Grid.MakeFromFTab(theFTab,thePrj,nil,nil)
tmp2Grid = (tmp1Grid.IsNull).Con(0.AsGrid,tmp1Grid) 'Grid with 0s and 1s
finGrid = ((maskGrid.IsNull).setnull(tmp2grid)) 'Clip grid

' Save grid in ascii format
theFn = (outdir + "\" + cluename).AsFileName
if (File.Exists(theFn)) then File.Delete(theFn) end
fingrid.SaveAsAscii(theFn)

' Also make a correspnding area restriction file. Active cells must have value
' of 0, restricted cells -9998, all other cells (NoData) -9999.
resGrid = (finGrid = 1.asgrid).Con(-9998.asgrid,finGrid)
theFn = (outdir + "\region_no_use_" + subdir + ".fil").AsFileName
if (File.Exists(theFn)) then File.Delete(theFn) end
resGrid.SaveAsAscii(theFn)

resGrid = nil
fingrid = nil
tmp2grid = nil
tmp1grid = nil

' **** DYNAMIC LOCATION GRIDS FOR PARTIALLY PROTECTED AREAS ****

' Number of years for which to save dynamic grids
 if (country = "BZ") then
  nYears = 21 '2004 to 2025
 else
  nYears = 25 '2000 to 2025
 end

' Save 2 WDPA location factor grid for each year
for each i in 0..nYears

  ' New grid name
  cluename = "Src1gr" + locFacNum_partProt.asstring + "." + i.asstring

  ' Actual simulated year. First year will be 0 for grid naming convention.
  if (country = "bz") then
   year = 2004 + i
  else
   year = 2000 + i
  end

  ' Select field name
  fld1 = "S" +scenNo.asString + "pa2"
```

```
  fld2 = "Yearincl"

  ' Query to select all WDPA to include
  expr = "(["+fld1+"] = 1) and (["+fld2+"] <= "+year.asstring + ")"
  theBitmap = theFTab.GetSelection
  theFtab.Query(expr, theBitmap, #VTAB_SELTYPE_NEW)
  theFTab.UpdateSelection

  ' Convert shape to grid.
  tmp1Grid = Grid.MakeFromFTab(theFTab,thePrj,nil,nil)
  tmp2Grid = (tmp1Grid.IsNull).Con(0.AsGrid,tmp1Grid) 'Grid with 0s and 1s
  finGrid = ((maskGrid.IsNull).setnull(tmp2grid)) 'Clip grid

  ' Save grid in ascii format
  theFn = (outdir + "\" + cluename).AsFileName
  if (File.Exists(theFn)) then File.Delete(theFn) end
  fingrid.SaveAsAscii(theFn)

  fingrid = nil
  tmp2grid = nil
  tmp1grid = nil

  ' Add theme to view
  'grdThm = GTheme.Make(finGrid)
  'grdThm.SetName(cluename)
  'theView.addTheme(grdThm)

end

zerogrid = nil
```

Appendix 3: Complete list of available spatial data

Below is a complete list of all land cover/land use datasets and other spatial data that were identified during the data collection phase. Many of these data have also been downloaded. The yellow shaded rows indicate the datasets selected for this project. Informal notes on data availability and access have been left in the table in case of relevance to readers.

LAND USE / LAND COVER DATASETS

Dataset Name / Theme	Extent / Country	Years	Resolution	Classes	Got data?	Status / Comments / Constraints
GLOBAL/ REGIONAL						
GLC2000	Global	2000 (Nov 1999 to Dec 2000)	1 km	22	Joep has 2000	Based on SPOT VEGETATION data. Good regional accuracy as local experts involved. May lack global consistency of Modis, less important for this project.
MODIS Land Cover	Global	Oct 2000 to Oct 2001	1 km			Globally consistent automated classification. No training sites in project region. Will be updated every six months and or a land cover change product provided. Gill contacted Boston University and EROS Data Center re next update/ release schedule.
FRA 2000	Global	2000 – based on 1992- 1996 images	1 km			Only forest / open forest / non-forest in legend.
FRA control site data	Global network of 117 Landsat scenes	1980s, 1990s and around 2000	30 m (Landsat)			Used for calibration of the lower resolution data above. Three control sites are totally within the project area, three more are partially of interest. *Dataset release is being investigated.*
GeoCover	Global (split into regions)	1990 (1989, 90 & 94) and 2000 (2000 & 2002)	30 m	13		Estimated costs are $650 per date layer. WRI experience suggests **agricultural land under classified**. Richard Borda (rborda@earthsat.com) emailed Gill on 7/5/05 that 2000 data for Central America are now available. http://www.geocover.com/gc_lc/data_products/ Composites (band 742) from http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp show substantial patchy cloud coverage (and cloud shadows) throughout the region, particularly in eastern Belize and Guatemala. Therefore, this data is unlikely be very useful. **Suggest not to use these data.**

NASA SERVIR	Regional	2000, 2003, 2004 and 2005	30 m (Landsat)			Could use 2000 Landsat and STRM data as a baseline? Technical problems with Landsat mean data for 2004/5 is not available – recent MODIS data substituted. Other regional data layers available through MesoStor at http://servir.nsstc.nasa.gov. *Contacts* = daniel.irwin@nasa.gov and jtullis@cast.uark.edu It seems that land cover data cannot be downloaded through MesoStor
Ecosystems map (CCAD) **2003 revision**	Regional (Central America **excluding Mexico**)	Varies by country, 1993-99, both pre- and post-Mitch	Polygons, based on LandSat 5 data, 1:250 000	Modified UNESCO classification, 22 classes with Spanish legend	Joep has a copy	Detailed ecosystem legend (a modified UNESCO classification) contains one class for Agricultural Systems, one for Plantations and one for Urban Areas. This is the 2003 revision (the first version was released in 2001), which is still based on the same 1993-99 Landsat TM imagery, however the revised version corrects known errors on the map, includes a completely revised version of Costa Rica, and includes some changes to the classification system that resulted from agreements between the countries at a workshop in Guatemala in late 2002.
MANGROVES						
UNEP-WCMC Mangroves	Pan Tropical but not MEXICO	Continuing Updates	Various		Yes	Only shows Mangroves, but is supposedly (!!) frequently improved and updated. Comparison with the Ecomap showed that the data is the same for Honduras (2003 version) but very different for Belize (2004 version). Lack of confidence in accuracy of WCMC data so suggest to not use them
Ecomap 2003 Mangroves					Yes	Full coverage. Best option to use as source, except for Belize, for which more recent and more accurate data is available.
BZ Ecomap 2004 mangroves	Belize only	see below			Yes	Relatively minor updates compared to the 2003 Ecomap. Assumed better. Best option for Belize.
CZMAI / Emil Mangroves	Belize only	Emil says latest			Yes	File: bz_mainland_mangrove_2004_c92_2. The data is generally more detailed and contains lots of small polygons. Also, the data appears to be converted from a raster but the source raster is unknown. Very different from the Mangroves in the 2004 Ecomap. The latter contain numerous areas classified as mangroves that are not included in this (Emil's) dataset so we cannot just complement both data.
BELIZE						
Fairweather & Gray (1994)	Belize	1989-90-92	SPOT XS 30 m, 1:76k	54		Detailed methodology available – see Land Use of Belize 1989-92.pdf

Iremonger & Brokaw (1995)	Belize	1993	Landsat 1:250 000	52		Results of NARMAP project. Methodology available – provided to mabr@unep-wcmc.org in late June 2005.
Meerman & Sabido (2001)	Belize	1993-96-98	LandSat 1:250 000	83		Initial (2001) version of Ecosystem map. Now obsolete. Meerman & Sabido 2001 - Vol 1.pdf
2004 Ecosystem Map of Belize	Belize	Landsat TM 98-99-04 + many other sources	Landsat ETM 1:110 000	Total of 96. Default legend has 18 classes. Multiple agric.	Joep has a copy	Originally from 1998-99 TM imagery, but improved upon through fieldwork, additional TM imagery (Jan 04), etc. Also includes the reefs and islands. See NPAPSP Gap Analysis (public).pdf and ecosys_bze_2004.pdf http://biological-diversity.info/Ecosystems.htm
HONDURAS						
CIAT Hurricane Mitch Atlas; CIAT indicators CD	Honduras (not full country coverage)	1986 and 1994	30 m, TM based		Joep has 1986 and 1994	http://gisweb.ciat.cgiar.org/cross_scale/atlas-mitch.htm Contains recommended land use, capacity and forestry. CIAT does not have more recent data.
Iremonger Vegetation data	Honduras					Emil emailed Susan Iremonger for further information on data on 7th August 2005. I think this data is the Honduran part of the initial 2001 Ecosystem map.
2003 Ecosystem map		2 x 2/93, 2x 3/94, 1x12.98 (west) images + aerialphotos				SEE "GLOBAL/REGIONAL" SECTION FOR DETAILS. Note that base TM imagery is the oldest used for the ecosystem map, though completed with aerial photos/verification./
MEXICO						
INEGI "Serie II" National Forest Inventory	Mexico	1993	125k / 30 m			http://www.selvamaya.org Mexican forest inventory of 1994. An update of mexico's 1968-1986 land cover classification using 1993 Landsat TM images. Data made public in 2000 and re-processed by TNC for inclusion in Selva Maya CD
National Forest Inventory 2000	Mexico	2000				**http://indy2.igeograf.unam.mx/ua_morelia/_private/2002/mapping_of_Mexico.PDF.**

2003 Ecomap (not quite true)		1999, 2000	250 km	18	Joep has a copy	UNAM / INEGI / SEMARNAT. Conducted a complete land cover classification for Mexico Aerial photos also used, assessment of accuracy provided, covers whole country. Data set made available by CCAD as part of the 2003 revision of the Central American Ecosystem map. Note, however, that the original 2001 Ecomap didn't include Mexico. Mas *et al*. (2004)
Clark / Harvard / ECOSUR	Mexico, S. Yucatan, Campeche State					Modelling program already undertaken in area adjoining Petén in Guatemala. http://www.clarku.edu/departments/geography/research/sypr.shtml http://earth.clarku.edu/lcluc/
GUATEMALA						
Maya Vegetation Map (CI)	Northern part GT, BZ, and some MX	1997-98 Landsat TM	30 m	12 classes, 1 of which agric.	Joep has a copy	Created by Conservation International from 1997-98 imagery, published in 2000. Daniel Juhn shared this data with Joep in 2001
Forest and Forest changes 1986-2002	Petén only	up to 2002		Forest, agric, water + forest changes every two years	Joep has a copy	A continuation of the work undertaken by the Univ of Maine in 1996-97, this datasets was created by CEMEC-CONAP and WCS, Flores, Guatemala, using SPOT and LANDSAT ET+ data from March 2002. **Very detailed and considered accurate** but covers only Petén. Victor Hugo Ramos shared this data to Joep in April 2003, when the data was just completed.
MAGA	Guatemala	Complete 2001. Source image years unknown	250 km	24		Acquired by MBRS intern, cannot be shared at present. Metadata in **BASE250.PRF** suggest that this is the same as the ecosystem map, although an overlay of the polygons shows that it is not.

OTHER DATASETS

Dataset	Extent	Resolution / Source year	Received / Requested	Comments
ROADS				
CCAD Roads	Regional – in separate file for each country		Joep has a copy	Roads stop at edge of cities – not good for network analysis. Also seems to haver an offset of about 100-200 m (all CCAD data suffer from this). http://www.ccad.ws/documentos/mapas.html
Selva Maya roads	Regional			**VISA_COMUNICACION.SHP** (from Selva Maya CD) and **BZ-GT-MX_ROADS_SELVA_YR-UNKNOWN.SHP** (from Emil). Same data, but with a bad offset of > 1 km, so it was decided not to use these data.
MesoStor	Regional	1990s ?	Joep has a copy	**(RED_VIAL_LINE)** In principle the same as the CCAD data but doesn't have a datum offset. Data have been reclassified in 5 classes: Highway-paved, Highway-unpaved (all year), Highway-unpaved (dry season only), Other road, and paths/tracks. Best available data, however, it remains a fairly low scale dataset. There are obvious discrepancies and missing roads when comparing with imagery (from Google Earth)
J. Meerman, E. Cherrington	Belize only	2000-03	Joep has a copy	**(BZ_ROADS_BTFS_2000-03)** Received from Emil; according to the Belize Spatial Data Inventory (Dec 05) this is an updated of the Land Information Centre's (LIC) roads dataset, using 2000-03 Landsat Imagery, by Meerman. A major visible change with the MesoStor/CCAD dataset is the inclusion of the major road from Belize City in northwest direction (as opposed to the one going in more northern direction from B.C.)
CZMAI	Southern Belize	2005	Joep has a copy	**(BZ_SOUTH-ROADS_CZMAI_2005)**. Revised roads created by Emil Cherrington.
CIAT roads	Honduras		Joep has a copy	From topographic maps.
CCAD Airports	Regional		Joep has a copy	
CCAD Ports	Regional		Joep has a copy	
POPULATION / URBAN EXTENT				
CCAD Population Centres	Regional – in separate file for each country		Joep has a copy	Contains data on district and town name, but no population data attached.
Latin America and Caribbean Pop. Database CIAT	Regional (LAC)	1960 – 2000; 1 km grid	Joep has a copy.	From CIAT web site, http://gisweb.ciat.cgiar.org/population/. Contains vector population maps (pop. per admin unit) and raster surfaces created with an accessibility model. When compared to GPW v3 and overlaying on a Landsat image it becomes clear that this dataset is visibly less accurate than GPW.
GPW v3	Global and by country	1990 – 2015, in steps of 5 years. 1 km grid	Joep has a copy.	Latest version 3 and final GRUMP data available in Dec 05. Actual population density for 1990, 1995 and 2000, and estimated for 2005, 2010 and 2015, and pop density grid appears more accurate than CIAT's LAC. For the actual population, the "ag" grids were selected: adjusted population density to match UN totals. Datasets seem generally better

				than the LAC dataset, except for Belize.
Landscan 2004	Global			Access requested but not yet received
GRUMP urban extent & settlements	Global	Around 2000	Joep has a copy.	Not very accurate. It may be better to digitize the polygons again from Landsat imagery. The settlements points from El Salvador were used to compile a MAR settlements dataset as no alternative data available for that country.
IGN/CCAD settlements	Honduras	unknown	Joep has a copy	(**HN_SETTLEMENTS_IGN-CCAD.SHP**). The most detailed population point data for Honduras. Other dataset from INEGI and CCAD did not included population size. Received from Emil Cherrington
BTFS settlements	Belize	unknown	Joep has a copy	(**BZ_SETTLEMENTS_BTFS.SHP**). Settlements + population size from Belize Tropical Forest Studies, received from Emil.
Selva Maya settlements	MX, BZ and part of GT	Around 2000	Joep has a copy	(**BZ-GT-MX_SETTLEMENTS_SELVA_C2000.SHP**) Settlements and population size from Selva Maya CD.
ELEVATION / SLOPE				
STRM DEM for elevation and slope. (CIAT)	Regional	Orginal 30 deg-sec (90 m), resampled to50 m.		Created by Joep from CIAT's filled SRTM 90 data. Accurately projected to UTM 16/NAD 1927 using Joep's customized Raster Project tool. (downloaded from http://srtm.csi.cgiar.org/)
CLIMATE				
FAO Clim	Global	Some data from 1960 onwards	No	Data from a global network of climatic stations (2 in Belize, ~ 100 in Honduras) available on CD-ROM *(Copy was requested).* http://www.fao.org/sd/2002/EN1203_en.htm
CIAT Worldclim		1km	Joep has a copy	http://biogeo.berkeley.edu/worldclim/worldclim.htm. Considered the best data to use. Has monthly mean temperatures and precipitation in several resolutions (30 sec, 2.5, 5 and 10 min). 1 km resolution is more than sufficient for land use modelling.
SOILS				
SOTER LAC (Latin America and the Caribbean) with parameter estimates	Latin America	1:5 million	Joep has a copy	Can purchase from FAO ($44) but downloaded for free on 13/8/05 from ISRIC http://lime.isric.nl/index.cfm?contentid=162 A secondary dataset of soil parameters estimates was also obtained http://lime.isric.nl/index.cfm?contentid=%20452 These data can be linked to the SOTER GIS data
ISRIC WISEv3	Global	December 2005; 0.5 degree grid		http://www.isric.org/UK/About+Soils/Soil+data/Thematic+data/Soil+Geographic+Data/. WISE dataset contains grid of man of the sae soil properties as the SOTERLAC but also has grid of soil depth

IIASA GAEZ 2000	Global	10 km grid	No	Global Agro-Ecological Zoning 2000. Website states that better databases may be available elsewhere (i.e., SOTERLAC) (http://www.iiasa.ac.at/Research/LUC/gaez.html)
INEGI	Mexico	1:250 k – 1M ??		Included on their map server http://galileo.inegi.gob.mx/website/mexico/viewer.htm, http://mapserver.inegi.gob.mx/map/datos_basicos/uso_suelo/. See metadata http://mapserver.inegi.gob.mx/dsist/Internet%202003/pagina1m.html
Selva Maya	MX, BT, GT, but not Honduras	1: 250 k	Yes	Much more spatial detailed than the FAO SOTER. Emil thinks the classification were originally different in each country but were harmonized to FAO classification as part of the Selva Maya work (http://www.selvamaya.org). **Lacks soil properties data so limited use.**
CONAP / FAO (faosoil.shp)		200-250 k?		From the Grunberg CD. Metadata indicate that FAO was the data source but they say that they do not have such a detailed regional map on record. The data appears to be in at a scale of 200-250 km because it has comparable detail to the Selva Maya data. However, they are absolutely different from the Maya soil data and the soil classes at various picked locations are also different from the SOTERLAC. Rejected for this reason.
ACCESSIBILITY				
Accessibility to markets, roads			Joep created	Created using CIAT's Accessibility Wizard, using roads, cities data.
Accessibility to ports				
RIVERS				
MesoStor / CCAD	Regional, split by country.	1:250 000	Joep has them	http://servir.nsstc.nasa.gov/MesoStor/index.html . Same data on CCAD website as on MesoStor. Contains rivers names. Mostly digitized from 1:50 k-100 k topographic maps. Brief comparison with DCW (1:1m scale) shows that CCAD data are more detailed, but many small 1st order streams included in DCW are missing from the CCAD dataset. For Honduras doesn't include as many secondary streams as CIAT"s "*rios oficiales*" data. Also, unlikely high stream density in central Belize—these are probably very small streams that we may not want to include.
WRI	Regional			More accurate datasets delineated from 90 m SRTM DEM. Locally burned in rivers will be identical to those from other (CCAD) datasets, though overall the DEM_delineated rivers should be more accurate than the older vector data.
CIAT	Honduras	1:50 k	Joep has them	Official rivers (grouped by primary and secondary rivers) digitzed from 1:50 k topographic maps. Includes more secondary rivers than the CCAD data.
CZMAI	Belize		Joep has them	Major rivers in Belize. Includes significantly fewers rivers than in the CCAD rivers data, though this seems more plausible and fits better with the rivers data for the other countries.

PROTECTED AREAS				
Mesostor / CCAD protected areas	Regional	May 2003	Joep has a copy	*Mapa de Areas Naturales Protegidas de la región Mesoamericana*. The data download from the CCAD website (http://www.ccad.ws/documentos/mapas.html) are the same as those from MesoStor. For Honduras also the same as CIAT's data.
WDPA (UNEP-WCMC)	Global, but only updated for MX, GT, HN and BZ	Updated Jan 2006	Joep has a copy	The 18-05-2005 dataset showed significant differences compared to the CCAD dataset and well as CIAT's dataset for Honduras. Major omissions and inaccurate boundaries in Honduras. Dataset updated by WCMC in January 2006 and this version appears to be complete and match the CCAD/MeSostor data. ICUN categories used.
CIAT	Honduras	2000 - 2001	Joep has a copy	On Honduras / Mitch data CD that Joep received from Andy Nelson in 2001. Data could be older than 2001, however, polygon boundaries are the same as those of Mesostor / CCAD dataset. Lacks attribute data and names of area so not very useful.
TOURISM HOTSPOTS				
Selva Maya	MX, BZ and Peten area of GT	2001	Joep has a copy.	Tourism cost layer. It's composed of hexagon-shaped polygons of 100 ha each and an attribute "Qualification" (*Calificacia*) that indicates what part of these 100 ha is under threat. Nearly all of the areas under threat are predominantly mangroves.

Appendix 4: Ecosystem Map land cover classification

The table below shows the classifications for the original 2003 Ecosystem Map for Central America (22 classes), the 2004 Ecosystem Map for Belize (18 classes) and the reclassified and reduced classification that was adopted for the MAR land use change simulations.

2003 Ecosystem map Central America	2004 Ecosystem map Belize	Reclassified / Reduced Classification
☑ 2003 Ecosystem Map	☑ Ecosystem Belize 2004	☑ Reclassified / Reduced Ecosystem Map
Bosques siempreverdes de coníferas	Lowland broad-leaved dry forest	Other/Unknown
Bosques siempreverdes y semisiempreverdes de latifoliadas	Lowland broad-leaved moist forest	Broad-leaved Forest
Bosques siempreverdes y semisiempreverdes mixtos	Lowland broad-leaved wet forest	Pine forest
Bosques semidecíduos de latifoliadas	Lowland pine forest	Agriculture/Pasture
Bosques semidecíduos mixtos	Submontane pine forest	Scrub
Bosques decíduos de latifoliadas	Submontane broad-leaved moist forest	Savanna
Bosques manglares	Submontane broad-leaved wet forest	Wetland/Swamp
Arbustales de coníferas	Lowland savanna	Mangroves
Arbustales de latifoliadas	Mangrove and littoral forest	Urban
Arbustales mixtos	Shrubland	Water
Arbustales xeromórficos subdesérticos	Wetland	
Sabanas	Open sea	
Pastizales naturales	Coral reef	
Páramos	Seagrass	
Pantanos y humedales	Sparse Algae	
Sistemas agropecuarios	Agricultural uses	
Plantaciones forestales	Water	
Arrecifes coralinos	Urban	
Cuerpos de agua		
Sistemas productivos acuáticos (camaroneras, salineras)		
Urbano		
Areas con escasa vegetación		
Sin datos		

Appendix 5. Land use requirements for future scenarios

The 16 tables below give the land use requirements, in ha, for all combinations of four scenarios and the four countries (the third scenario, Security First was not simulated but was calculated for assessment purposes). These land requirements were calculated using outputs from the International Futures and IMAGE models. Bear in mind that the reported areas apply to the parts of the countries that fall within the MAR region, not the whole countries (although for Belize that almost the same). Data are rounded to integer values so that they fit these tables better, however, in the source spreadsheet and CLUE-S input files the numbers have four decimals and the row totals are precisely identical each year.

Belize – Markets First (1)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2001	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2002	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2003	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2004	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2005	1350	1266094	77034	424658	27701	189098	93403	71868	19489	15319
2006	1350	1264534	76939	426287	27622	188862	93286	71779	20036	15319
2007	1350	1262814	76834	427859	27539	188601	93157	71682	20858	15319
2008	1350	1261095	76729	429430	27456	188341	93029	71584	21679	15319
2009	1350	1259541	76635	431054	27377	188105	92912	71496	22224	15319
2010	1350	1257987	76540	432676	27298	187870	92796	71408	22769	15319
2011	1350	1254227	76312	437724	27166	186599	92168	71194	23954	15319
2012	1350	1250765	76101	442918	27039	185368	91560	70998	24595	15319
2013	1350	1247279	75889	448148	26912	184128	90948	70800	25240	15319
2014	1350	1243608	75665	453355	26781	182856	90319	70592	26168	15319
2015	1350	1239913	75441	458596	26648	181576	89687	70382	27101	15319
2016	1350	1234418	75106	463740	26539	181659	89728	70070	28084	15319
2017	1350	1228869	74769	468934	26429	181743	89770	69755	29076	15319
2018	1350	1222781	74398	473991	26307	181756	89776	69409	30926	15319
2019	1350	1217122	74054	479284	26195	181841	89818	69088	31942	15319
2020	1350	1211407	73706	484630	26082	181927	89860	68764	32968	15319
2021	1350	1206852	73429	489062	26230	181567	89683	68505	34016	15319
2022	1350	1202247	73149	493541	26380	181203	89503	68244	35076	15319
2023	1350	1197593	72866	498069	26532	180836	89321	67980	36148	15319
2024	1350	1192887	72579	502646	26686	180464	89138	67713	37231	15319
2025	1350	1187643	72260	507064	26830	180015	88916	67415	39201	15319

Belize – Policy First (2)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2001	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2002	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2003	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2004	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2005	1350	1266863	77080	424586	27660	188608	93160	71912	19475	15319
2006	1350	1266174	77038	425261	27666	188298	93007	71873	20027	15319
2007	1350	1265486	76997	425936	27671	187988	92854	71833	20578	15319
2008	1350	1264797	76955	426611	27677	187679	92702	71794	21129	15319
2009	1350	1264109	76913	427285	27683	187370	92549	71755	21680	15319
2010	1350	1263260	76861	427905	27685	187037	92384	71707	22505	15319
2011	1350	1261364	76746	430321	27292	186154	91948	71600	23919	15319
2012	1350	1259950	76660	432909	26909	185340	91546	71519	24509	15319
2013	1350	1258532	76573	435505	26525	184525	91143	71439	25102	15319
2014	1350	1257110	76487	438107	26140	183706	90739	71358	25696	15319
2015	1350	1255684	76400	440717	25754	182886	90334	71277	26291	15319
2016	1350	1254525	76330	441286	25579	183098	90439	71211	26876	15319
2017	1350	1253202	76249	441798	25400	183287	90532	71136	27739	15319
2018	1350	1251877	76169	442311	25221	183476	90625	71061	28604	15319
2019	1350	1249742	76039	442539	25025	183546	90660	70940	30853	15319
2020	1350	1248574	75968	443110	24849	183760	90766	70874	31444	15319
2021	1350	1246838	75862	444761	24844	183533	90654	70775	32077	15319
2022	1350	1244933	75746	446362	24835	183282	90530	70667	32990	15319
2023	1350	1243020	75630	447969	24826	183029	90405	70558	33907	15319
2024	1350	1241098	75513	449582	24817	182776	90280	70449	34828	15319
2025	1350	1239169	75395	451203	24808	182521	90154	70340	35753	15319

Belize – Security First (3)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2001	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2002	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2003	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2004	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2005	1350	1264703	76949	427174	27637	188452	93083	71789	19558	15319
2006	1350	1261107	76730	430766	27645	188321	93019	71585	20171	15319
2007	1350	1257329	76500	434322	27650	188166	92942	71370	21066	15319
2008	1350	1253531	76269	437896	27654	188009	92865	71155	21965	15319
2009	1350	1249876	76047	441546	27663	187876	92799	70947	22589	15319
2010	1350	1246201	75823	445216	27671	187743	92733	70739	23217	15319
2011	1350	1245291	75768	447368	27195	186551	92144	70687	24340	15319
2012	1350	1244706	75732	449635	26726	185408	91580	70654	24903	15319
2013	1350	1244121	75697	451901	26257	184265	91015	70621	25466	15319
2014	1350	1243536	75661	454167	25788	183123	90451	70588	26029	15319
2015	1350	1242952	75626	456433	25319	181981	89887	70554	26591	15319
2016	1350	1239775	75432	459462	25142	182032	89913	70374	27214	15319
2017	1350	1236422	75228	462443	24960	182060	89926	70184	28120	15319
2018	1350	1233057	75023	465435	24778	182088	89940	69993	29029	15319
2019	1350	1228870	74769	468132	24579	181996	89895	69755	31347	15319
2020	1350	1225640	74572	471208	24399	182048	89920	69572	31984	15319
2021	1350	1221861	74342	476170	24339	181130	89467	69357	32677	15319
2022	1350	1217893	74101	481105	24275	180181	88998	69132	33659	15319
2023	1350	1213895	73858	486076	24211	179226	88526	68905	34647	15319
2024	1350	1209868	73613	491083	24147	178263	88051	68676	35643	15319
2025	1350	1205812	73366	496127	24082	177293	87572	68446	36646	15319

Belize – Sustainability First (4)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2001	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2002	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2003	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2004	1350	1268419	77175	423513	27481	188638	93175	72000	18944	15319
2005	1350	1265979	77027	423865	27964	189559	93630	71861	19460	15319
2006	1350	1265681	77008	423094	28313	189728	93714	71845	19961	15319
2007	1350	1265386	76990	422328	28661	189896	93797	71828	20458	15319
2008	1350	1265092	76973	421565	29007	190063	93879	71811	20954	15319
2009	1350	1264799	76955	420807	29351	190229	93961	71795	21446	15319
2010	1350	1264349	76927	420000	29689	190371	94031	71769	22207	15319
2011	1350	1263655	76885	420523	29394	189923	93810	71730	23424	15319
2012	1350	1263439	76872	421204	29110	189548	93625	71717	23827	15319
2013	1350	1263224	76859	421885	28827	189173	93440	71705	24230	15319
2014	1350	1263010	76846	422565	28544	188799	93255	71693	24633	15319
2015	1350	1262556	76818	423165	28255	188389	93052	71667	25441	15319
2016	1350	1263376	76868	421240	28605	188323	93020	71714	26198	15319
2017	1350	1264192	76918	419324	28954	188258	92988	71760	26951	15319
2018	1350	1265004	76967	417417	29300	188193	92956	71806	27700	15319
2019	1350	1265812	77016	415519	29645	188129	92924	71852	28446	15319
2020	1350	1266617	77065	413631	29989	188065	92892	71898	29188	15319
2021	1350	1265925	77023	413303	29968	188292	93004	71858	29970	15319
2022	1350	1265234	76981	412975	29947	188519	93117	71819	30751	15319
2023	1350	1264545	76939	412649	29926	188746	93229	71780	31530	15319
2024	1350	1263858	76897	412322	29905	188972	93340	71741	32307	15319
2025	1350	1263171	76856	411997	29884	189198	93452	71702	33083	15319

Mexico – Markets First (1)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	25170	3176090	0	339800	1499060	6230	192100	231680	14540	55540
2001	25170	3164869	0	339063	1511370	6245	192561	230861	14531	55540
2002	25170	3153630	0	338325	1523649	6260	193019	230042	14576	55540
2003	25170	3142325	0	337578	1535875	6274	193471	229217	14759	55540
2004	25170	3131021	0	336831	1548078	6289	193923	228392	14966	55540
2005	25170	3119670	0	336078	1560235	6304	194370	227564	15279	55540
2006	25170	3119057	0	337553	1558890	6308	194515	227556	15621	55540
2007	25170	3118443	0	339036	1557542	6313	194662	227547	15957	55540
2008	25170	3117821	0	340525	1556187	6318	194809	227538	16302	55540
2009	25170	3117190	0	342021	1554826	6323	194956	227529	16656	55540
2010	25170	3116554	0	343524	1553460	6327	195103	227519	17012	55540
2011	25170	3112825	0	350335	1550771	6304	194392	227415	17458	55540
2012	25170	3109001	0	357280	1548046	6281	193671	227310	17910	55540
2013	25170	3105082	0	364362	1545286	6257	192941	227203	18369	55540
2014	25170	3101063	0	371585	1542490	6233	192201	227095	18833	55540
2015	25170	3096943	0	378952	1539656	6209	191452	226985	19304	55540
2016	25170	3091923	0	385853	1536920	6226	191984	226800	19794	55540
2017	25170	3086790	0	392901	1534145	6244	192524	226612	20284	55540
2018	25170	3081537	0	400097	1531329	6262	193073	226422	20781	55540
2019	25170	3076173	0	407450	1528477	6280	193630	226229	21261	55540
2020	25170	3070681	0	414961	1525581	6298	194197	226034	21749	55540
2021	25170	3059017	0	420449	1532633	6279	193606	225334	22181	55540
2022	25170	3047250	0	426018	1539762	6260	193013	224631	22567	55540
2023	25170	3035316	0	431653	1546938	6240	192411	223918	23024	55540
2024	25170	3023252	0	437366	1554181	6220	191804	223199	23477	55540
2025	25170	3011053	0	443157	1561490	6201	191192	222474	23934	55540

Mexico – Policy First (2)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	25170	3176090	0	339800	1499060	6230	192100	231680	14540	55540
2001	25170	3167551	0	338953	1509124	6229	192064	231057	14522	55540
2002	25170	3159003	0	338104	1519148	6228	192026	230434	14558	55540
2003	25170	3150392	0	337248	1529106	6226	191983	229805	14739	55540
2004	25170	3141793	0	336394	1539035	6225	191940	229178	14935	55540
2005	25170	3133155	0	335535	1548908	6223	191893	228548	15238	55540
2006	25170	3131327	0	336049	1550242	6217	191703	228415	15547	55540
2007	25170	3129491	0	336563	1551576	6211	191514	228281	15864	55540
2008	25170	3127658	0	337078	1552914	6205	191324	228147	16174	55540
2009	25170	3125819	0	337593	1554252	6199	191134	228013	16491	55540
2010	25170	3123972	0	338108	1555589	6192	190943	227878	16817	55540
2011	25170	3133761	0	341959	1540817	6192	190943	228592	17235	55540
2012	25170	3143673	0	345856	1525869	6192	190943	229315	17650	55540
2013	25170	3153700	0	349800	1510738	6192	190943	230047	18078	55540
2014	25170	3163855	0	353793	1495425	6192	190943	230787	18504	55540
2015	25170	3174133	0	357835	1479924	6192	190944	231537	18934	55540
2016	25170	3178436	0	359441	1472715	6212	191535	231851	19311	55540
2017	25170	3182770	0	361058	1465463	6231	192130	232167	19681	55540
2018	25170	3187131	0	362684	1458167	6250	192728	232485	20054	55540
2019	25170	3191528	0	364322	1450830	6270	193332	232806	20413	55540
2020	25170	3195952	0	365970	1443447	6290	193938	233129	20774	55540
2021	25170	3194102	0	367852	1443411	6283	193737	232994	21120	55540
2022	25170	3192243	0	369744	1443375	6277	193536	232858	21467	55540
2023	25170	3190378	0	371646	1443341	6270	193333	232722	21809	55540
2024	25170	3188499	0	373558	1443305	6263	193129	232585	22160	55540
2025	25170	3186614	0	375481	1443271	6257	192924	232448	22505	55540

Mexico – Security First (3)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	25170	3176090	0	339800	1499060	6230	192100	231680	14540	55540
2001	25170	3164761	0	342164	1508816	6229	192081	230854	14596	55540
2002	25170	3153312	0	344543	1518632	6229	192059	230018	14707	55540
2003	25170	3141689	0	346930	1528483	6228	192032	229171	14967	55540
2004	25170	3129968	0	349336	1538405	6227	192005	228316	15244	55540
2005	25170	3118097	0	351753	1548376	6226	191973	227450	15625	55540
2006	25170	3111864	0	354597	1551612	6233	192184	226995	16015	55540
2007	25170	3105581	0	357470	1554884	6240	192397	226537	16393	55540
2008	25170	3099238	0	360370	1558187	6247	192611	226074	16774	55540
2009	25170	3092834	0	363297	1561521	6254	192828	225607	17159	55540
2010	25170	3086373	0	366253	1564890	6261	193048	225136	17540	55540
2011	25170	3098032	0	370351	1547864	6261	193057	225986	17949	55540
2012	25170	3109842	0	374500	1530628	6261	193067	226848	18355	55540
2013	25170	3121800	0	378701	1513175	6262	193077	227720	18766	55540
2014	25170	3133909	0	382956	1495501	6262	193087	228603	19182	55540
2015	25170	3146173	0	387265	1477601	6262	193097	229498	19604	55540
2016	25170	3148485	0	390238	1471169	6281	193668	229666	19993	55540
2017	25170	3150829	0	393242	1464678	6300	194245	229837	20369	55540
2018	25170	3153197	0	396276	1458121	6318	194827	230010	20749	55540
2019	25170	3155594	0	399342	1451501	6338	195416	230185	21125	55540
2020	25170	3158020	0	402438	1444817	6357	196011	230362	21496	55540
2021	25170	3155586	0	406655	1443540	6335	195330	230184	21871	55540
2022	25170	3153125	0	410919	1442248	6312	194641	230005	22250	55540
2023	25170	3150642	0	415230	1440944	6290	193945	229824	22624	55540
2024	25170	3148132	0	419590	1439626	6267	193241	229641	23003	55540
2025	25170	3145598	0	423999	1438296	6244	192530	229456	23378	55540

Mexico – Sustainability First (4)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	25170	3176090	0	339800	1499060	6230	192100	231680	14540	55540
2001	25170	3156301	0	336268	1523463	6244	192518	230237	14469	55540
2002	25170	3136665	0	332766	1547610	6257	192930	228804	14468	55540
2003	25170	3117149	0	329291	1571489	6270	193333	227381	14588	55540
2004	25170	3097804	0	325847	1595128	6283	193732	225969	14737	55540
2005	25170	3078590	0	322431	1618511	6296	194123	224568	14982	55540
2006	25170	3067062	0	319307	1634197	6284	193758	223727	15164	55540
2007	25170	3055652	0	316217	1649715	6272	193397	222895	15353	55540
2008	25170	3044366	0	313159	1665072	6260	193040	222071	15532	55540
2009	25170	3033193	0	310132	1680267	6249	192687	221256	15716	55540
2010	25170	3022137	0	307138	1695303	6238	192337	220450	15898	55540
2011	25170	3030211	0	308811	1684418	6245	192565	221039	16211	55540
2012	25170	3038337	0	310496	1673469	6253	192795	221632	16518	55540
2013	25170	3046513	0	312191	1662453	6260	193027	222228	16828	55540
2014	25170	3054743	0	313896	1651373	6268	193260	222828	17131	55540
2015	25170	3063023	0	315612	1640226	6275	193495	223432	17437	55540
2016	25170	3053430	0	312442	1654360	6250	192709	222733	17577	55540
2017	25170	3043955	0	309310	1668329	6225	191932	222041	17708	55540
2018	25170	3034595	0	306216	1682135	6200	191165	221359	17830	55540
2019	25170	3025346	0	303158	1695779	6175	190407	220684	17951	55540
2020	25170	3016213	0	300136	1709268	6151	189658	220018	18056	55540
2021	25170	3016022	0	299869	1709171	6162	190010	220004	18262	55540
2022	25170	3015836	0	299603	1709076	6174	190361	219990	18460	55540
2023	25170	3015654	0	299337	1708983	6185	190713	219977	18652	55540
2024	25170	3015475	0	299071	1708893	6196	191065	219964	18836	55540
2025	25170	3015301	0	298806	1708804	6208	191416	219951	19013	55540

Guatemala – Markets First (1)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	825	1732256	84038	1050588	429225	31	1344	75	11831	79219
2001	825	1727615	83812	1051491	433175	31	1348	75	11840	79219
2002	825	1722851	83581	1052325	437101	31	1353	75	12070	79219
2003	825	1718051	83348	1053143	441025	32	1357	74	12356	79219
2004	825	1713246	83115	1053962	444954	32	1362	74	12642	79219
2005	825	1708377	82879	1054746	448873	32	1366	74	13040	79219
2006	825	1705308	82730	1058393	447985	32	1366	74	13500	79219
2007	825	1702261	82582	1062066	447103	32	1365	74	13906	79219
2008	825	1699178	82433	1065728	446210	32	1365	74	14368	79219
2009	825	1696061	82282	1069381	445309	32	1364	73	14886	79219
2010	825	1692936	82130	1073041	444406	32	1364	73	15406	79219
2011	825	1683917	81692	1084489	441814	31	1353	73	16018	79219
2012	825	1674867	81253	1096030	439213	31	1342	73	16578	79219
2013	825	1665701	80809	1107609	436581	31	1332	72	17254	79219
2014	825	1656504	80363	1119282	433938	31	1321	72	17877	79219
2015	825	1647219	79912	1131012	431271	30	1310	71	18562	79219
2016	825	1638214	79475	1141983	429025	30	1309	71	19281	79219
2017	825	1629121	79034	1153060	426757	30	1308	71	20006	79219
2018	825	1619912	78587	1164224	424459	30	1307	70	20797	79219
2019	825	1610614	78136	1175497	422139	30	1306	70	21594	79219
2020	825	1601224	77681	1186881	419797	30	1305	69	22400	79219
2021	825	1591320	77200	1195258	420970	30	1299	69	23241	79219
2022	825	1581344	76716	1203695	422152	30	1293	68	24089	79219
2023	825	1571269	76227	1212171	423335	30	1286	68	25000	79219
2024	825	1561149	75737	1220731	424534	30	1280	68	25860	79219
2025	825	1550927	75241	1229330	425734	30	1273	67	26785	79219

Guatemala – Policy First (2)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	825	1732256	84038	1050588	429225	31	1344	75	11831	79219
2001	825	1728690	83864	1051060	432491	31	1345	75	11831	79219
2002	825	1725007	83686	1051462	435728	31	1346	75	12052	79219
2003	825	1721296	83506	1051847	438958	31	1346	75	12329	79219
2004	825	1717586	83326	1052231	442186	31	1347	74	12605	79219
2005	825	1713848	83144	1052597	445407	31	1348	74	12937	79219
2006	825	1710972	83005	1055067	445505	31	1346	74	13387	79219
2007	825	1708094	82865	1057538	445604	31	1344	74	13838	79219
2008	825	1705213	82726	1060012	445703	31	1342	74	14288	79219
2009	825	1702329	82586	1062487	445801	31	1339	74	14740	79219
2010	825	1699443	82446	1064965	445900	31	1337	74	15191	79219
2011	825	1696717	82313	1073311	439878	31	1332	73	15732	79219
2012	825	1694006	82182	1081718	433831	31	1326	73	16219	79219
2013	825	1691253	82048	1090149	427747	31	1321	73	16765	79219
2014	825	1688485	81914	1098624	421632	31	1315	73	17314	79219
2015	825	1685675	81778	1107122	415478	30	1310	73	17922	79219
2016	825	1683253	81660	1111849	412744	30	1311	73	18467	79219
2017	825	1680793	81541	1116575	409992	31	1313	73	19070	79219
2018	825	1678323	81421	1121320	407230	31	1315	73	19676	79219
2019	825	1675842	81301	1126085	404455	31	1317	73	20284	79219
2020	825	1673323	81178	1130850	401663	31	1318	72	20952	79219
2021	825	1668245	80932	1136153	401073	31	1315	72	21566	79219
2022	825	1663146	80685	1141478	400481	31	1312	72	22183	79219
2023	825	1657998	80435	1146806	399879	30	1309	72	22859	79219
2024	825	1652827	80184	1152156	399275	30	1305	72	23538	79219
2025	825	1647635	79932	1157528	398668	30	1302	71	24220	79219

Guatemala – Security First (3)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	825	1732256	84038	1050588	429225	31	1344	75	11831	79219
2001	825	1723440	83610	1057614	431413	31	1342	75	11864	79219
2002	825	1714458	83174	1064607	433583	31	1340	74	12120	79219
2003	825	1705399	82735	1071621	435758	31	1337	74	12433	79219
2004	825	1696290	82293	1078673	437945	31	1335	73	12748	79219
2005	825	1687074	81846	1085726	440129	31	1333	73	13176	79219
2006	825	1679359	81471	1093292	440161	31	1332	73	13669	79219
2007	825	1671596	81095	1100905	440193	31	1331	72	14165	79219
2008	825	1663813	80717	1108584	440233	31	1329	72	14608	79219
2009	825	1655923	80334	1116275	440258	31	1328	72	15167	79219
2010	825	1648012	79951	1124033	440291	31	1327	71	15673	79219
2011	825	1646196	79862	1132191	433491	31	1321	71	16224	79219
2012	825	1644373	79774	1140387	426660	31	1315	71	16778	79219
2013	825	1642541	79685	1148619	419799	30	1309	71	17334	79219
2014	825	1640701	79596	1156889	412906	30	1302	71	17892	79219
2015	825	1638824	79505	1165175	405976	30	1296	71	18511	79219
2016	825	1634743	79307	1171696	403096	30	1296	71	19148	79219
2017	825	1630637	79108	1178257	400199	30	1297	71	19790	79219
2018	825	1626505	78907	1184858	397284	30	1297	70	20435	79219
2019	825	1622319	78704	1191480	394344	30	1297	70	21143	79219
2020	825	1618107	78500	1198143	391385	30	1297	70	21855	79219
2021	825	1610703	78141	1206793	389790	30	1289	70	22573	79219
2022	825	1603222	77778	1215477	388177	30	1280	69	23355	79219
2023	825	1595693	77412	1224216	386554	30	1271	69	24142	79219
2024	825	1588116	77045	1233012	384921	29	1262	69	24933	79219
2025	825	1580490	76675	1241865	383277	29	1253	68	25730	79219

Guatamala – Sustainability First (4)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	825	1732256	84038	1050588	429225	31	1344	75	11831	79219
2001	825	1727351	83800	1047148	437810	31	1352	75	11821	79219
2002	825	1722339	83556	1043644	446351	32	1359	75	12032	79219
2003	825	1717308	83312	1040129	454868	32	1367	74	12297	79219
2004	825	1712286	83069	1036621	463369	32	1375	74	12562	79219
2005	825	1707245	82824	1033102	471846	32	1383	74	12882	79219
2006	825	1705087	82719	1028997	477795	32	1384	74	13298	79219
2007	825	1702967	82617	1024926	483729	32	1385	74	13658	79219
2008	825	1700826	82513	1020853	489633	32	1387	74	14071	79219
2009	825	1698693	82409	1016796	495513	32	1388	74	14482	79219
2010	825	1696569	82306	1012755	501370	32	1390	73	14892	79219
2011	825	1696163	82286	1017167	496929	32	1388	73	15349	79219
2012	825	1695755	82267	1021590	492477	32	1386	73	15807	79219
2013	825	1695318	82245	1026007	488006	32	1384	73	16321	79219
2014	825	1694908	82226	1030452	483532	32	1382	73	16782	79219
2015	825	1694468	82204	1034891	479039	32	1381	73	17298	79219
2016	825	1693259	82146	1030031	484714	32	1379	73	17754	79219
2017	825	1692082	82089	1025210	490371	32	1378	73	18153	79219
2018	825	1690883	82030	1020393	495994	32	1377	73	18604	79219
2019	825	1689661	81971	1015582	501584	32	1376	73	19108	79219
2020	825	1688473	81913	1010809	507157	32	1375	73	19555	79219
2021	825	1687962	81889	1010764	507229	32	1378	73	20061	79219
2022	825	1687422	81862	1010703	507292	32	1380	73	20622	79219
2023	825	1686910	81838	1010658	507364	32	1383	73	21129	79219
2024	825	1686396	81813	1010613	507436	32	1386	73	21638	79219
2025	825	1685854	81786	1010552	507500	32	1389	73	22201	79219

Honduras – Markets First (1)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	23288	2055531	1219894	4372044	15156	111469	47213	8269	13050	58481
2001	23288	2059250	1222101	4365121	15320	112025	47448	8284	13076	58481
2002	23288	2062933	1224286	4358064	15484	112581	47684	8299	13295	58481
2003	23288	2066580	1226451	4350871	15649	113136	47919	8313	13707	58481
2004	23288	2070241	1228623	4343650	15814	113693	48155	8328	14120	58481
2005	23287	2073916	1230805	4336401	15980	114253	48392	8343	14536	58481
2006	23288	2072257	1229820	4338736	15933	114102	48328	8336	15113	58481
2007	23288	2070651	1228867	4341178	15887	113953	48265	8330	15496	58481
2008	23287	2068994	1227883	4343510	15840	113802	48201	8323	16072	58481
2009	23288	2067338	1226900	4345841	15793	113651	48137	8316	16648	58481
2010	23287	2065683	1225918	4348171	15746	113500	48073	8310	17224	58481
2011	23288	2048100	1215484	4377905	15595	112195	47520	8239	17586	58481
2012	23288	2030467	1205019	4407339	15444	110888	46967	8168	18333	58481
2013	23287	2012934	1194614	4436798	15293	109588	46416	8097	18885	58481
2014	23287	1995450	1184238	4466174	15143	108291	45867	8027	19436	58481
2015	23287	1978016	1173891	4495466	14993	106998	45319	7957	19985	58481
2016	23287	1957775	1161878	4527918	14852	106477	45098	7876	20751	58481
2017	23287	1937585	1149896	4560475	14712	105958	44879	7794	21326	58481
2018	23288	1917352	1137889	4592913	14571	105437	44658	7713	22092	58481
2019	23288	1897169	1125911	4625458	14431	104919	44438	7632	22667	58481
2020	23288	1876944	1113908	4657884	14290	104399	44218	7550	23433	58481
2021	23288	1857687	1102480	4689035	14288	103589	43875	7473	24199	58481
2022	23287	1838434	1091053	4720180	14286	102779	43532	7395	24965	58481
2023	23288	1819184	1079629	4751319	14284	101970	43189	7318	25731	58481
2024	23287	1799938	1068207	4782453	14282	101161	42847	7241	26496	58481
2025	23287	1780651	1056761	4813464	14280	100349	42503	7163	27453	58481

Honduras – Policy First (2)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	23288	2055531	1219894	4372044	15156	111469	47213	8269	13050	58481
2001	23287	2060471	1222825	4363631	15296	111725	47321	8289	13066	58481
2002	23287	2065373	1225734	4355090	15436	111980	47429	8308	13275	58481
2003	23288	2070235	1228620	4346421	15575	112232	47536	8328	13677	58481
2004	23288	2075110	1231513	4337731	15715	112485	47643	8348	14079	58481
2005	23288	2079997	1234413	4329020	15856	112739	47751	8367	14482	58481
2006	23288	2079798	1234295	4329061	15855	112528	47661	8366	15058	58481
2007	23288	2079651	1234208	4329209	15855	112320	47573	8366	15442	58481
2008	23287	2079453	1234090	4329251	15855	112110	47484	8365	16017	58481
2009	23287	2079305	1234003	4329399	15855	111902	47396	8364	16400	58481
2010	23288	2079107	1233885	4329440	15855	111692	47307	8364	16975	58481
2011	23288	2069837	1228384	4345162	15586	110852	46951	8326	17527	58481
2012	23288	2060596	1222900	4360835	15318	110014	46596	8289	18076	58481
2013	23287	2051434	1217462	4376567	15052	109181	46244	8252	18433	58481
2014	23287	2042249	1212011	4392144	14785	108349	45891	8215	18980	58481
2015	23288	2033093	1206578	4407673	14520	107518	45539	8178	19525	58481
2016	23288	2025100	1201834	4420186	14389	107402	45490	8146	20078	58481
2017	23288	2017124	1197100	4432672	14258	107285	45441	8114	20631	58481
2018	23288	2009115	1192347	4445025	14128	107166	45390	8082	21372	58481
2019	23287	2001171	1187633	4457460	13997	107050	45341	8050	21922	58481
2020	23288	1993244	1182928	4469870	13868	106934	45292	8018	22471	58481
2021	23288	1981527	1175974	4488621	13816	106427	45077	7971	23212	58481
2022	23288	1969879	1169062	4507447	13764	105923	44864	7924	23761	58481
2023	23288	1958252	1162162	4526240	13713	105420	44651	7877	24310	58481
2024	23287	1946599	1155246	4544890	13661	104915	44437	7831	25047	58481
2025	23287	1935013	1148370	4563615	13610	104414	44225	7784	25594	58481

Honduras – Security First (3)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	23288	2055531	1219894	4372044	15156	111469	47213	8269	13050	58481
2001	23288	2050113	1216678	4380899	15228	111259	47124	8247	13077	58481
2002	23288	2044621	1213419	4389684	15299	111046	47034	8225	13297	58481
2003	23288	2039057	1210117	4398397	15371	110830	46942	8202	13711	58481
2004	23288	2033469	1206801	4407145	15442	110612	46850	8180	14126	58481
2005	23288	2027859	1203471	4415930	15514	110394	46757	8157	14543	58481
2006	23288	2019251	1198363	4429521	15489	110104	46635	8123	15140	58481
2007	23288	2010676	1193273	4443249	15464	109817	46513	8088	15544	58481
2008	23288	2002033	1188144	4456896	15438	109526	46390	8054	16144	58481
2009	23287	1993422	1183034	4470681	15413	109238	46268	8019	16550	58481
2010	23287	1984744	1177884	4484384	15388	108946	46144	7984	17151	58481
2011	23288	1977435	1173546	4497318	15091	108024	45754	7955	17502	58481
2012	23288	1970111	1169200	4510082	14795	107105	45364	7925	18044	58481
2013	23287	1962868	1164901	4522899	14501	106192	44977	7896	18391	58481
2014	23288	1955610	1160593	4535548	14208	105280	44591	7867	18929	58481
2015	23288	1948384	1156305	4548139	13916	104372	44207	7838	19464	58481
2016	23288	1937390	1149781	4565638	13780	104112	44097	7794	20033	58481
2017	23288	1926453	1143290	4583234	13645	103855	43988	7750	20411	58481
2018	23287	1915478	1136776	4600703	13509	103596	43878	7705	20979	58481
2019	23288	1904512	1130268	4618158	13374	103336	43768	7661	21548	58481
2020	23288	1893509	1123738	4635484	13238	103075	43657	7617	22307	58481
2021	23288	1877794	1114412	4661557	13143	102066	43230	7554	22869	58481
2022	23287	1862101	1105099	4687596	13047	101058	42803	7491	23429	58481
2023	23288	1846383	1095771	4713485	12952	100050	42376	7427	24181	58481
2024	23288	1830732	1086482	4739454	12857	99045	41950	7364	24740	58481
2025	23287	1815058	1077180	4765271	12761	98039	41524	7301	25489	58481

Honduras – Sustainability First (4)

LUC	0 Unknown	1 B.L. forest	2 Pine for.	3 Agr/Past	4 Scrub	5 Savanna	6 Wetland	7 Mangroves	8 Urban	9 Water
YEAR										
2000	23288	2055531	1219894	4372044	15156	111469	47213	8269	13050	58481
2001	23288	2063188	1224438	4357898	15517	112537	47665	8300	13083	58481
2002	23288	2070832	1228974	4343575	15879	113608	48118	8330	13308	58481
2003	23287	2078463	1233503	4329074	16242	114681	48573	8361	13728	58481
2004	23288	2086132	1238055	4314501	16607	115759	49030	8392	14149	58481
2005	23288	2093839	1242628	4299855	16974	116843	49489	8423	14573	58481
2006	23288	2100999	1246877	4286923	17237	117294	49680	8452	15163	58481
2007	23287	2108217	1251161	4274086	17501	117749	49872	8481	15559	58481
2008	23288	2115389	1255417	4261130	17764	118201	50064	8510	16150	58481
2009	23288	2122620	1259709	4248268	18029	118656	50257	8539	16547	58481
2010	23288	2129806	1263973	4235289	18293	119109	50449	8568	17138	58481
2011	23287	2126064	1261753	4241690	18091	118699	50275	8552	17501	58481
2012	23287	2122281	1259507	4247966	17890	118287	50100	8537	18056	58481
2013	23288	2118562	1257300	4254328	17690	117880	49928	8522	18416	58481
2014	23288	2114802	1255069	4260564	17490	117470	49754	8507	18968	58481
2015	23287	2111054	1252845	4266782	17290	117062	49582	8492	19518	58481
2016	23288	2114174	1254696	4260809	17530	117192	49637	8505	20083	58481
2017	23288	2117290	1256545	4254844	17769	117321	49691	8517	20647	58481
2018	23288	2120453	1258423	4248992	18008	117453	49747	8530	21019	58481
2019	23288	2123560	1260266	4243045	18246	117582	49802	8542	21582	58481
2020	23288	2126662	1262107	4237106	18484	117711	49856	8555	22144	58481
2021	23287	2123524	1260245	4241333	18474	117872	49925	8542	22709	58481
2022	23288	2120390	1258385	4245555	18464	118034	49993	8530	23274	58481
2023	23288	2117259	1256527	4249773	18455	118195	50061	8517	23838	58481
2024	23288	2114132	1254671	4253986	18445	118356	50129	8504	24402	58481
2025	23288	2111007	1252817	4258194	18435	118517	50198	8492	24965	58481

Appendix 6. CLUE-S Training Package (Exercises)

ICRAN-MAR Watershed Management Workshop

Training Course
"Land cover change modelling using the CLUE-S model"

Friday 18 August

Dr. Joep Luijten

Consultant to the UNEP World Conservation Monitoring Centre

Land cover change modeling using the CLUE-S model

Friday 18 August
Training schedule (revised)

09:00 Introduction to land use change modelling and the CLUE-S model

- Different types of land use change models
- History and applications of CLUE-S in the world
- CLUE-S model structure and key input files
- Separate regression analysis of driving factors in SPSS

10:00 Introduction to case study area (Sibuyan island, Philippines)

10:15 Break

10:30 Practical CLUE-S

- System requirements and installation. Demo *vs* full version
- Exercise 1: Learning to know the user-interface and displaying results.
- Overview of input data files and model parameters files
- Exercise 2: Parameter files and simulating alternative scenarios

12:00 Lunch

13:00 Practical CLUE-S (continued)

- Regression equation parameters files and probability surfaces
- Land use conversion matrix and conversion sequences
- Creating land use requirement (demand) files
- Spatial policies and area restriction files
- Conversion elasticities and crop rotations
- Exercise 3: Creating new area restriction and land requirement files

14:30 Background on the MAR land use change scenario simulations, and CLUE-S data sets for Belize, Guatemala, Mexico and Honduras

- Separate data and simulation per country
- Calculation of the land demand for different scenarios
- Dynamic and static driving factors; protected areas data

14:45 Break

15:00 MAR simulations, continued

- Regression equations and probability surfaces
- Exercise 4: Working with actual scenario data for Belize

16:30 End

More information about CLUE-S model

http://www.cluemodel.nl/

Software used

For the training we will use the latest version of CLUE-S, also named Dyna-CLUE. This version was released in February 2006 is a further development of v2.4
For visualization we use ArcGIS 9.1 with Spatial Analyst extension (ArcView 3 with the Spatial Analyst extension can also be used in combination with CLUE-S).

Further reading

Below is a list of selected further reading related to the land use change modeling, technical documentation of CLUE-S and its applications, and the development and application of scenarios. All papers are included in PDF format on the data CD. The technical report that describes the MAR scenarios and land use modeling in detail is:

> **Luijten, J., L. Miles and E. Cherrington, 2006. Land use change modeling for scenarios for the MAR region. Technical report. ICRAN-MAR Project, UNEP-WCMC.**

Land use change modelling (in general)

- Verburg, P.H., P.P. Schot, M.J. Dijst and A. Veldkamp, 2004. Land use change modelling: current practice and research priorities. GeoJournal 61: 309-324.
- Parker, D.C., S.M. Manson, M.A. Jansen, M.J. Hoffman and P. Deadman, 2003. Multi-agent systems for the simulation of land-use and land-cover change: A review. Annuals of the Association of American Geographers 93(2): 413-337.
- Verburg, P.H. and A. Veldkamp, 2005. Introduction to the Special Issue on spatial modelling to explore land use dynamics. Intl. J. of Geog. Info. Science 19(2) 99-102.
- Briassoulis, H, 2004. Analysis of Land Use Change: Theoretical and Modeling Approaches. In: The Web Book of regional Science.

Land use change modelling in Central America

- Farrow, A., M. Winograd, 2001. Land use modelling at the regional scale: an input to rural sustainability indicators for Central America. *Agric. Ecosyst. & Environ.* 85: 249-268.
- Kok, K., M. Winograd, 2002. Modelling land-use change for Central America, with special reference to the impact of Hurricane Mitch. *Ecological Modelling 149*: 53-69.
- Kok, K., A. Veldkamp, 2001. Evaluating impact of spatial scales on land use pattern analysis in Central America. *Agric. Ecosyst. & Environ. 85:* 205-221.
- Kok, K., 2004. The role of population in understanding Honduran land use patterns. *J. of Environmental Management 72*: 73-89.
- Wassenaar, T., P. Gerber, M. Rosales, M. Ibrahim, P.H. Verburg, H. Steinfield, 1996. Projecting land use changes in the Neotropics: the geography of pasture expansion into forest. Global Environmental Change (in press)

CLUE-S and its applications

- Verburg, 2004. Manual for the CLUE-S model. Wageningen University, the Netherlands.
- Verburg, P.H., W. Soepboer, R.L.V. Espaldon, 2002. Modeling the spatial dynamics of regional land use: The CLUE-S model. *Environmental Management 30*(3): 391-405.
- Verburg, P.H., C.J.E. Schulp, N. Witte, A. Veldkamp, 2005. Downscaling of land use scenarios to assess the dynamics of European landscapes. In: Special issue: Future land use in Europe: Scenario based studies on land use and environmental impact.
- Verburg, P.H., K.P. Overmars, M.G.A. Huigen, W.T. de Groot, and A. Veldkamp, 2006. Analysis of the effects of land use change on protected areas in the Phillippines. Applied Geog. 26: 153-173.
- Verburg, P.H., A. Veldkamp, 2004. Projecting land use transitions at forest fringes in the Philippines at two spatial scales. *Landscape Ecology 19* (1): 77-98 (2004).

Statistical analysis of land use change and explanatory factors

- Koning, G.H.J., A. veldkamp, L.O. Fresco, 1998. Land use in Ecuador: a statistical analysis at different aggregation levels. *Agric. Ecosyst. & Environ. 70:* 231-247.
- Verburg, P.H., 2004. CLUE exercise - How to do the statistical analysis. September 2004. Downloaded from http://www.cluemodel.nl/
- Lessschen, J.P., P.H. Verburg and S.J. Stall, 2005. Statistical methods for analysing the spatial dimension of changes in land use and farming systems. LUCC report series No. 7. ILRI and Wageningen University, Nairobi and Wageningen.
- SPSS 2004. SPSS Regression models 13.0.

Developing future scenarios and empowering stakeholders

- Miles, L., 2006. GEO-4 scenarios and the ICRAN MAR project. UNEP World Conservation Monitoring Centre. Project report. 14 August 2006.
- Verburg, P.H., C.J.E. Schulp, N. Witte, A. Veldkamp, 2006. Downscaling of land use change scenarios to assess the dynamics of European landscapes. Agriculture, Ecosystems and Environment 114: 39-56.
- Rounsevell, M.D.A. et al, 2006. A coherent set of future land use change scenarios for Europe. Agriculture, Ecosystems and Environment 114: 57-68.
- Potting, J. and J. Bakkes, J. (eds), 2004. The GEO-3 scenarios 2002-2032: Quantification and analysis of environmental impacts. UNEP-DEWA/RS.03-4 and RIVM 402001022.

Selected data for Central America

- Balk, D., M. Brickman, B. Anderson, F. Pozzi and G. Yetman, 2005. A global distribution of future population: Estimates to 2015. (GPW v3). CIESEN, Columbia University.
- Balk, D. and G. Yetman, 2004. The global distribution of population: Evaluating the gains in resolution refinement. (GPW v3). CIESEN, Columbia University.
- CIAT, 2005. Latin America and the Carribean (LAC) population database. International Center for Tropical Agriculture, Colombia.
- Vreugdenhill, D., J. Meerman, A. Meyrat, L.D. Gomez and D.J. Graham, 2002. Map of the ecosystems of Central America. Final report. World Bank, Washington, D.C.
- Meerman, J. and W. Sabido. 2001. Central American Ecosystems: Belize. Programme for Belize, Belize City. 2 volumes 50 + 88 pp. http://biological-diversity.info/Ecosystems.htm
- Batjes, N.H., 2005. SOTER-based soil parameter estimates for Latin America and the Caribbean (version 1.0). ISRIC – World Soil Information, Wageningen, the Netherlands.

PDF files for all readings ca be found in ..\ *Training\Documentation*\

What is included on the CLUE-S training CD?

Everyone who participates in the training on Friday will receive a data CD that includes the following files organized in several folders:

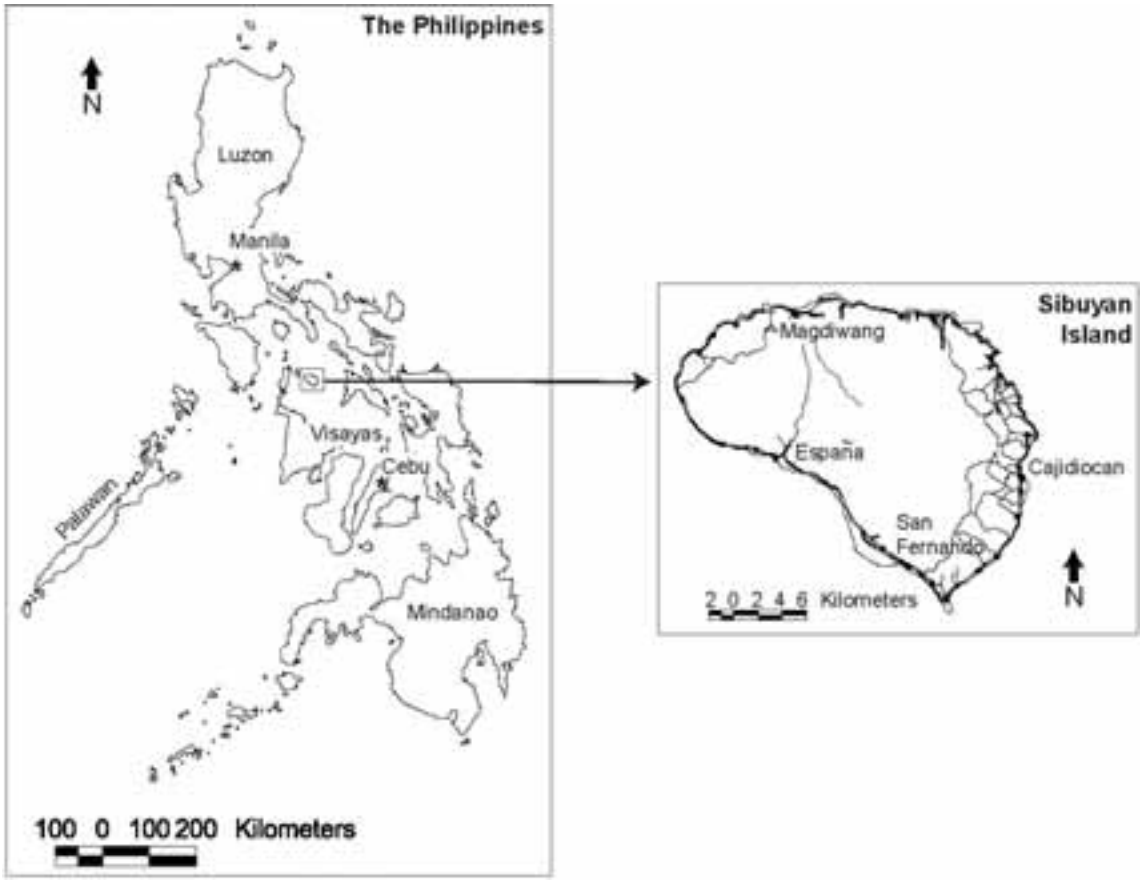
Directory on CD	Description
Software	
..\CLUE-S\Dyna_CLUE_full\	Installation package of the full Dyna-CLUE model (latest version of CLUE-S released in January 2006). It includes the sample data for Sibuyan Island.
..\CLUE-S\MAR_executable\	A specially compiled version of the Dyna-CLUE main executable for use in the ICRAN-MAR project. It has been optimized for memory usage and execution speed.
..\Other\	Installers for supporting software that we will used during the training: TextPad 4.7, WinZip 9, and Adobe Reader.
CLUES_BZ	Complete Dyna-CLUE model (program files and all data files) for Belize, which will be used during the training. **Please note: If you copy this folder from CD, all files will be read-only. You must right-click the folder, select Properties, uncheck "read-only", and apply it to all subfolders and files.**
Documentation	
..\MAR_Modeling\	Full technical report of the land use modeling for the MAR region, along with the CLUE-S user manual.
..\Readings\	Scientific publications and documents related to some source data that serve as (optional) further reading.
Scenario_results	Land cover grid for the base year and for the three simulated scenarios in 2025. There are also three grids that show the areas of change in land cover.
Data	
..\CLUE-S *&* ..\CLUE-S\MAR\	Location factor grids, dynamic factor grids, and land use grids for the entire MAR (in the subfolder), as separate files for Belize, Mexico, Honduras and Guatemala. These files are the actual input files for CLUE-S. Files have been compressed in *.zip files. Please note, metadata have been included with the combined MAR data, not the individual country datasets.
..\Clipmask\	Raster datasets of the precise spatial extent and resolution for the MAR and the four countries, as they were used to prepare (clip) all CLUE-S input data.
..\Basedata\	Vector and raster datasets that were used for creating the location factor grid for the MAR. These include original, third party data dataset and derived datasets. All data have been loaded in ***MAR Data Master.MXD***
.\Avenue Scripts\	ArcView Avenue scripts for (i) creating dynamic factor grids for protected areas, (ii) calculating the length of the dry season, and (iii) for filling *NoData* gaps in grids.
Maps	PDF files of two large format (A0) maps.

Background of the demonstration case study area, Sibuyan Island, the Philippines

For the first two exercises the case study of Sibuyan Island is used. This is the same case study area for which data are included with the demo version of CLUE-S. The datasets are relatively small and simulations execute quickly, so it is ideal to start with.

Sibuyan Island is located in the Romblon Province in the Philippines. The island measures 28 km east to west at its widest point and 24 km north to south, with a land area of approximately 456 km^2 surrounded by deep water. Steep mountain slopes covered with forest canopy characterize the island. The land surrounding the high mountains slopes gently to the sea and is mainly used for agricultural, mining and residential activities.

The island was selected as a case study because of its very rich biodiversity. About 700 vascular plant species live on Sibuyan Island including 54 endemic to the island and 180 endemic to the Philippine archipelago. Fauna diversity is low, but endemism is high. This makes the island a 'hot spot' for nature conservation and relevant for a detailed study of land use change. For this application a spatial resolution of 250 × 250 meter is used.



Location of Sibuyan Island

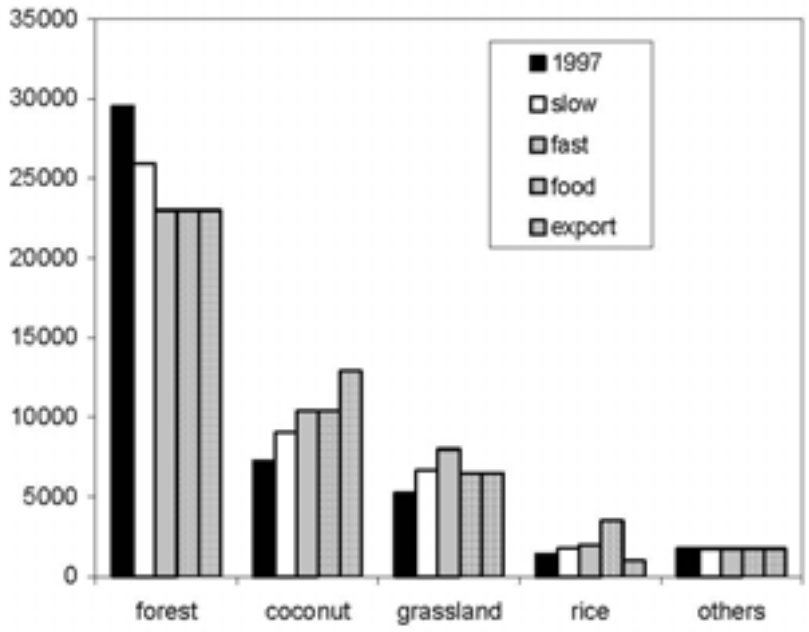
Five different land use types are distinguished for the simulation (see table below). **Important: for CLUE-S the land use numbering must start at 0, not 1.**

Land use types on Sibuyan Island.

Land use code	Land use type
0	Forest
1	Coconut plantations
2	Grassland
3	Rice fields
4	Others (mangrove/beach/villages/etc)

Four different files with land requirements (demand) scenarios have been created for the period from 1997 to 2011. The land requirements are not very realistic for this short time period, but allow us to clearly analyze the differences between the scenarios. Figure 2 summarizes the land requirements defined in the four scenarios:

1. **Slow growth scenario**, in this scenario a continuation of the land transformation rates of the past ten years is assumed, meaning deforestation and an increase in the area of coconut plantations, grassland and rice-area.
2. **Fast growth scenario**, in this scenario a higher rate of land transformation is assumed, leading to rapid conversions of forest to coconut, grassland and rice fields.
3. **Food-focus scenario**, a high rate of land transformation is foreseen, however, compared to the 'fast growth scenario' relatively more land is dedicated to rice cultivation in order to supply food for the population of the island.
4. **Export oriented scenario**, the same high land conversion rate applies. However, it is assumed that high copra prices make it profitable to dedicate most land to coconut plantations and less land to food crops.



Demands for each land use type, for the base year (1997) and four scenarios. The combined demand of all land use types is the same each year (45162.5 ha).

Exercise 1: Learning the CLUE-S user-interface and displaying results in ArcGIS

Objective: This exercise makes you familiar with the user-interface of CLUE-S and how you can display the simulation results in ArcGIS/ArcMap. The precise definition of the different parameters and input files is discussed Exercise 2 and in the user manual.

1.0 INSTALLING CLUE-S

CLUE-S (Dyna-CLUE) has been pre-installed on all computers in the training lab and the data on the training CD have been copied to the folder **C:\Training**.
If you are using your own laptop, or if want to install CLUE-S and the training data later in your office, then you can install them as follows:

- Open Windows Explorer and browse to the training CD.
- Double-click *Clues_Training.exe* and extract all files to a location on the hard disk. The default location is "C:" but you may specify another one.
- Double-click ***setup.exe*** from the *Training\Software\CLUE-S\Dyna_CLUE_Full* to install CLUE-S. Keep the default destination directory of "C:\CLUES".
- [MAR simulations only]. A 'tailored' main executable was compiled for use in this project. Copy *Training\Software\CLUE-S\MAR_executable**clues.exe*** to the installation directory and overwrite the existing file.

1.1 START CLUE-S

CLUE-S can be started in two different ways:
1. Click Start | Programs | CLUE-S tools | CLUE-S
2. Open the directory where CLUE-S is installed with explorer and double-click '*clues.exe*'

The user-interface should appear on the screen (Figure 1-1).
The "Neighborhood Result" and "Neighborhood setting" buttons only appear after checking the "Neighborhood variables" checkbox. These functions are not used in the exercises. A description of the functions can be found in the CLUE-S manual.

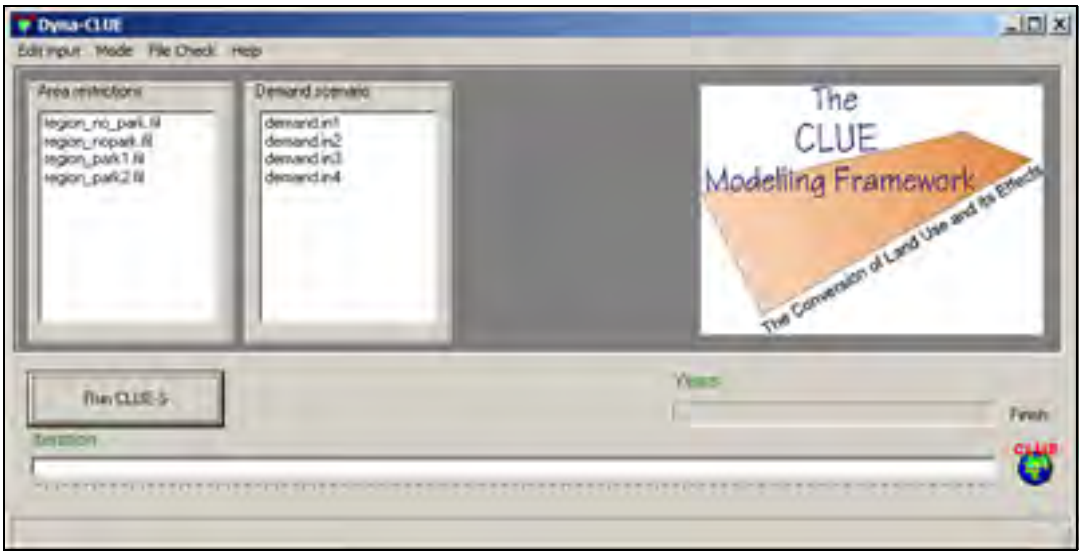


Figure 1-1. *Interface of the CLUE-S v2.4 (Dyna-CLUE) model*

1.2 MAIN FUNCTIONS

The user interface makes it possible to edit the main input files through a built-in text editor and allows the user to choose the scenario conditions. When all parameters are set the simulation can start by clicking the 'Run CLUE-S' button. Simulation results will be saved to output files that can be imported by a GIS for display and analysis (CLUE-S does not have any built-in graphical capabilities).

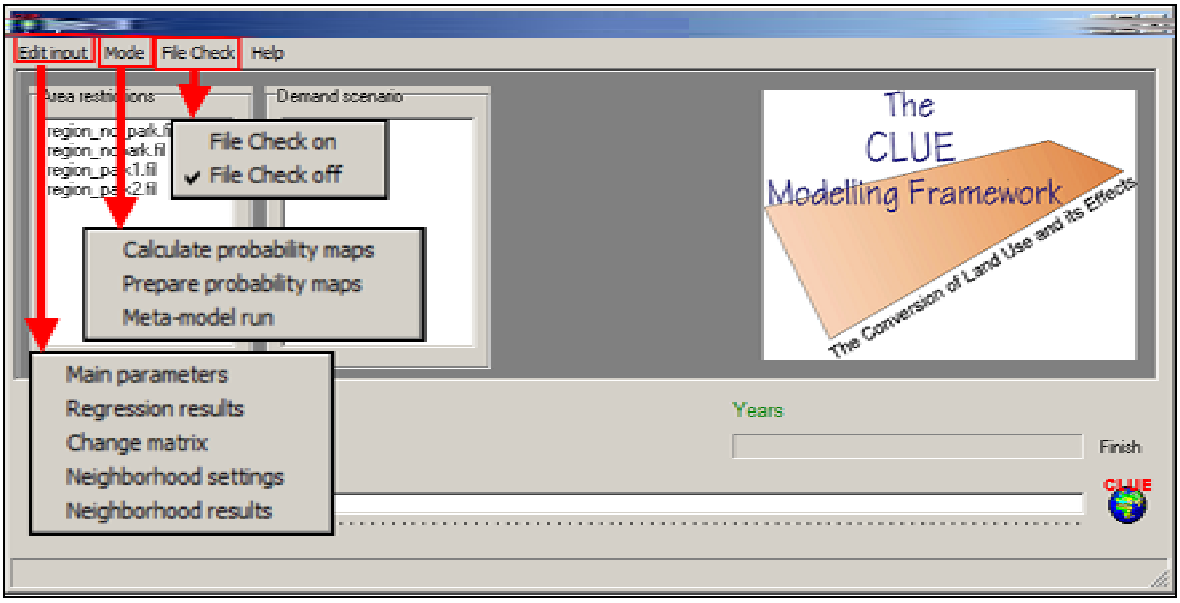


Figure 1-2. *Explanation of the menu options of the CLUE-S interface*

Most commonly used menu options are

Main parameters: Edit the main settings of the model (file: *main.1*)
Regression results: Edit the regression equations (*alloc1.reg*)
Change matrix: Edit the land use conversion matrix (*allow.txt*)
Calculate probability maps: Create probability maps for every land use types
Neighborhood settings: Edit the neighborhood settings (*neighmat.txt*)
Neighborhood results: Edit the neighborhood results (*alloc2.reg*)

1.3 START THE SIMULATION

- Make sure that all input files are correctly defined (correct input files for Sibuyan Island are supplied with both the demo version full version of CLUE-S)

- Select an '**area restriction'** input file

  The 'area restriction' file indicates which cells of a rectangular grid are part of the case-study area and can also contain information on the locations that belong to an area with restrictions to land use conversion, e.g. a natural park. You must always create and select an area restriction file, even if there are no actual restrictions. In exercise 2 you will learn more about this file.

- Select a '**land requirements'** (demand) input file

  The 'land requirements' file contains for each year that is simulated the required area of the different land use types. These claims can be calculated in other models or can be based on trend extrapolation and demographic projections. Different land requirements are possible for different scenarios. The demand values must always be expressed in hectares.

- Click 'Run CLUE-S'.

The simulations will now start and the status bars show the progress (Fig. 1-3).

NOTE: The status-bar for the iterative procedure shows the average difference between the allocated area of the different land use types and the required allocation of the different land use types. The simulation of one year is finished if the allocated area deviates less than the specified maximum allowed deviation. Only when one of the land use types exceeds the specified maximum deviation between allocation and requirements for one of the land use types the iterations will continue and a special indicator will appear on the screen.

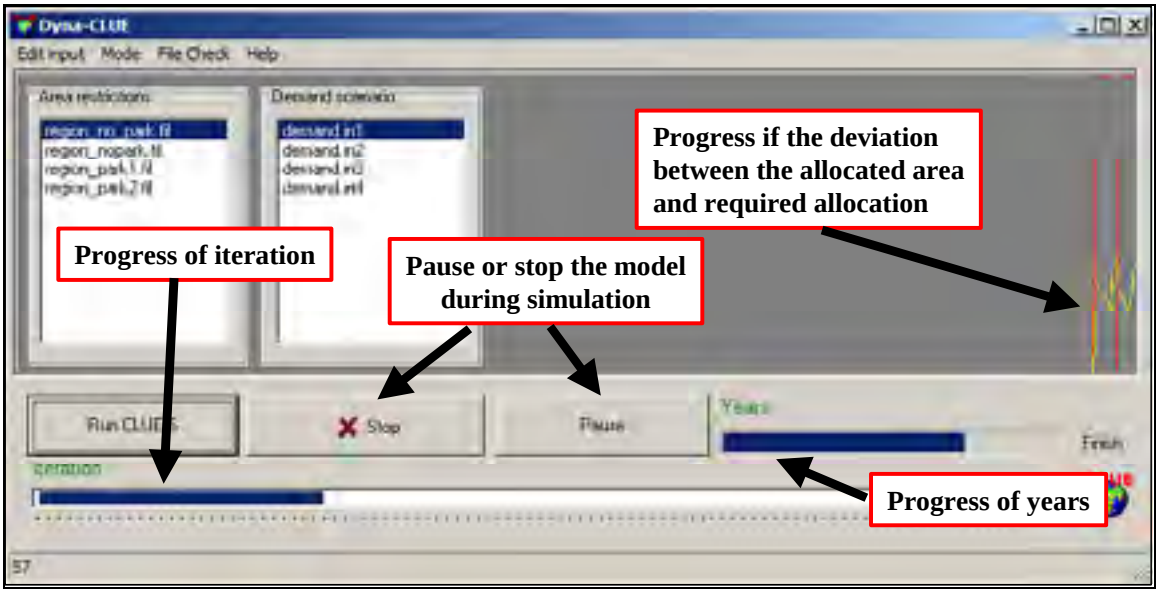


Figure 1-3. *Explanation of the CLUE-S model run and progress information*

1.4 END OF THE SIMULATION

When all simulations are made successfully the model will display the message 'finished' and a button that gives access to the LOG-file will appear (Fig. 1-4). The log file contains information on the input files and run-time information on the iterations and may be consulted when errors occur or unexpected results are found.

Figure 1-4. *Interface after successfully finishing the simulation*

1.5 DISPLAY OF SIMULATION RESULTS & ASCII TO RASTER CONVERSION

All results of the simulation are saved in the installation directory. To display the simulation results it is needed to use a GIS package. In this tutorial we will use ArcGIS 9.x with the Spatial Analyst Extension.

CLUE-S saves the simulated land use data in ASCII GRID format. This can easily be imported in both ArcView 3.x and ArcGIS 8.x/9.x. The simulation results are stored in files called: cov_all.* where * indicates the year after the start of the simulation. Select the file you want, e.g. cov_all.14 and click 'OK'. One minor complication is that CLUE-S does not save the files with an *.asc extension but with the year numbers as the extensions (.e.g, ***cov_all.0, cov_all.1, cov_all.2,*** …, ***cov_all.14***, where year 0 is the start year and year 14 is the end year of the simulation). We have to manually add the extension .asc otherwise the GIS import routine will not recognize the file:

► Follow the steps below to display a land use map generated by the CLUE-S model:

- Rename the simulation output file: Go to My Computer and browse to the CLUE-S installation directory. Right-click the cov_all.* file that has the highest number and add ".asc". For Sibuyan, you would rename **cov_all.14** to **cov_all.14.asc**.
- Open ArcMap: Click Start | Programs | ArcGIS | ArcMap.
- Activate Spatial Analyst extension: Tools | Extensions | Check 'Spatial Analyst' | and click OK.
- Open ArcToolBox (the red icon on the Standard toolbar) and import the simulated land use grid: Conversion Tools | To Raster | ASCII to Raster. The menu shown in Fig. 1-5 will now appear. Specify the following information:
  - Input ASCII raster file: from the CLUE-S directory select a cov_all.*.asc file. Set File of Types to "File (*.ASC)
  - Output raster: you may specify any name, but make sure you use a temporary directory. It is important that you do not save the file in the CLUE-S directory because if you do that many times the directory becomes cluttered with temporary files and CLUE-S program files.
  - Output data type: keep the default setting INTEGER.
  - Click OK when all data have been entered.

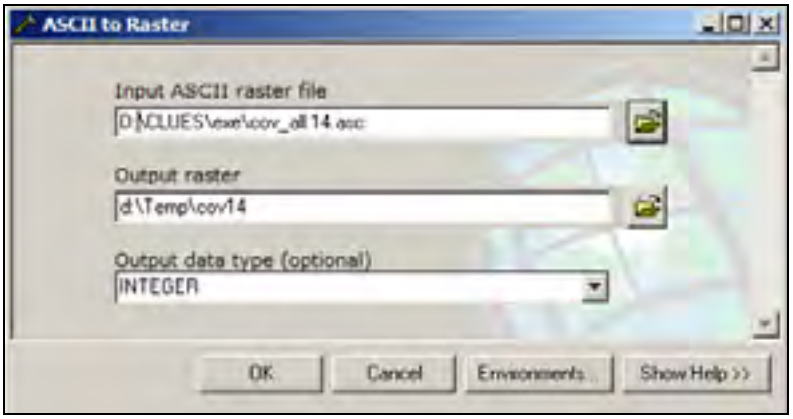


Figure 1-5. *Convert ASCII grid to raster using ArcToolBox*

The result of the simulation can now be seen and analysed using ArcMap (Fig. 1-6).

It is now possible to change the graphical presentation by changing the colours of the map into colors that are easily associated with the different land use type. For Sibuyan Island the suggested colors is the table below can be used.

***Table 1-1**: Land use types and suggested colors for Sibuyan Island.*

Land use code	Land use type	Color
0	Forest	Dark green
1	Coconut plantations	Orange
2	Grassland	Light green
3	Rice fields	Blue
4	Others (mangrove/beach/villages/etc)	Red

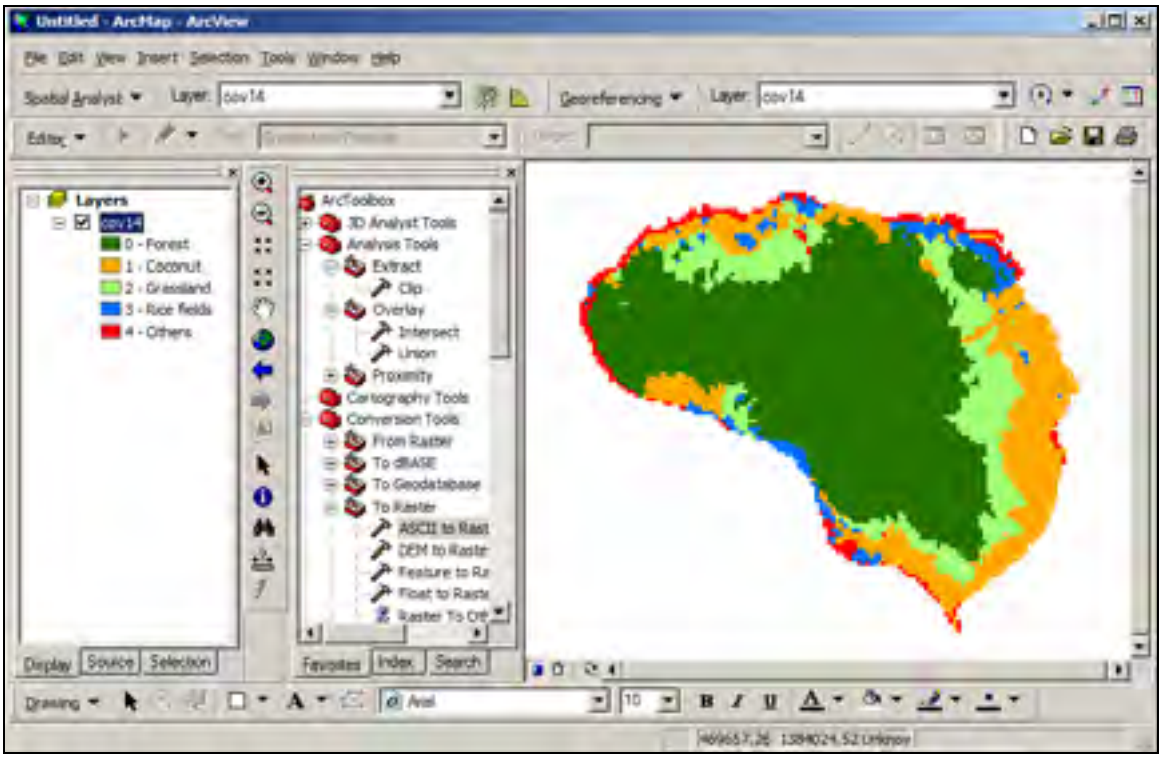


***Figure 1-6.** Simulation result displayed in ArcMap*

► Repeat the above steps for the results for different years of the simulation (for example, years 0, 5, 10 in addition to 14) with the Sibuyan data supplied with CLUE-S and see how results change over time.

[End of exercise 1]

Exercise 2: Parameter and input data files and simulating alternative scenarios

Objective: In this exercise you will learn about the different parameter and region-specific data files used by CLUE-S. You will run simulations using different scenario data files and modify some parameters, and then compare the results in ArcMap.

2.1 PARAMETER AND OTHER DATA FILES USED BY CLUE-S

CLUE-S stores model parameters and region-specific data files in various files. The table below gives an overview of all files that you may use. All files are plain text files that can be edited using CLUE-S or a text editor such as Notepad or TextPad. All files are located in the CLUE-S installation directory, **C:\Clues**.

► Please review the table below to get a general idea of the parameters being used.

Table 2-1. *Input files used by CLUE-S. The "created" column indicates what software is used to create the files and the "required" column indicates if the file is required. All files created CLUE-S are plain text files and may also be edited in a text editor.*

Filename	Description	Created	Required
Main.1	**Main parameters file**. Listed on exactly 19 lines. Some parameters settings will dictate whether the optional files must be specified or not.	CLUE-S	yes
Alloc1.reg	**Regression parameters**. The length of file depends on number of land use types and location factors.	CLUE-S	yes
Alloc2.reg	**Neighbourhood results**. Additional regression parameters based on the enrichment factor equation.	CLUE-S	no
Allow.txt	**Change matrix**. The number of rows and columns equal the land cover types, here 10x10.	CLUE-S	yes
Neighmat.txt	**Neighbourhood settings**. Defines the shape and size (in the form of a small weight matrix) of the analysis neighbourhood for every land use type.	CLUE-S	no
Regi*.*	**Area restriction file**. A grid that defines where land use changes can and cannot occur. The * is a wildcard here; it does not indicate the simulated year. All active cells must have the value 0, restricted cells a value of –9998, and all others cells –9999 (NoData).	ArcView	yes
Demand.in*	**Land use requirements**. Calculated at the aggregate level and organized by rows (simulated years starting at 0) and columns (for every land use types). The * denotes a unique number, not simulated year.	Excel / Textpad	yes
Cov_all.0	**Initial land use**. A grid of all land use types at the start (year 0). Grid values must match the land use codes in the main parameters file and numbering starts at 0.	GIS	yes
Sc1gr#.fil	**Static location factor grid**, where # is the number of the location factor;	GIS	yes
Sc1gr#.*	**Dynamic location factor grid**, where # is the number of a location factor. The * is the simulated year starting at 0, not a wildcard. Note that also the file src1gr#.fill is needed and it is identical to src1gr#.0.	GIS	no

2.1 SCENARIO CONDITIONS

The CLUE-S model has a number of parameters that need to be specified before a simulation can be made. The setting of these parameters is dependent on the assumptions made for a particular scenario. In this exercise we will explore four different scenario conditions, i.e., one or more of these settings will be different among scenarios.

1. Land requirements
2. Spatial policies (area restrictions)
3. Conversion elasticity
4. Land use conversion sequences

Different scenarios allow the comparison of different possible developments and give insight in the functioning of the model. Such analysis is most easy by visual comparison or through the calculation of the differences between the two scenarios in a GIS.

In this exercise you will first run the model with the baseline scenario: use the original settings of the 'main parameters', select '***region_nopark'*** and '***demand.in1'***. Import the results (e.g. for the start and end of the simulation, year 0 and year 14). Next, run the model again with four alternative settings as specified in the following sections (2.2 to 2.5). Compare the results in ArcView.

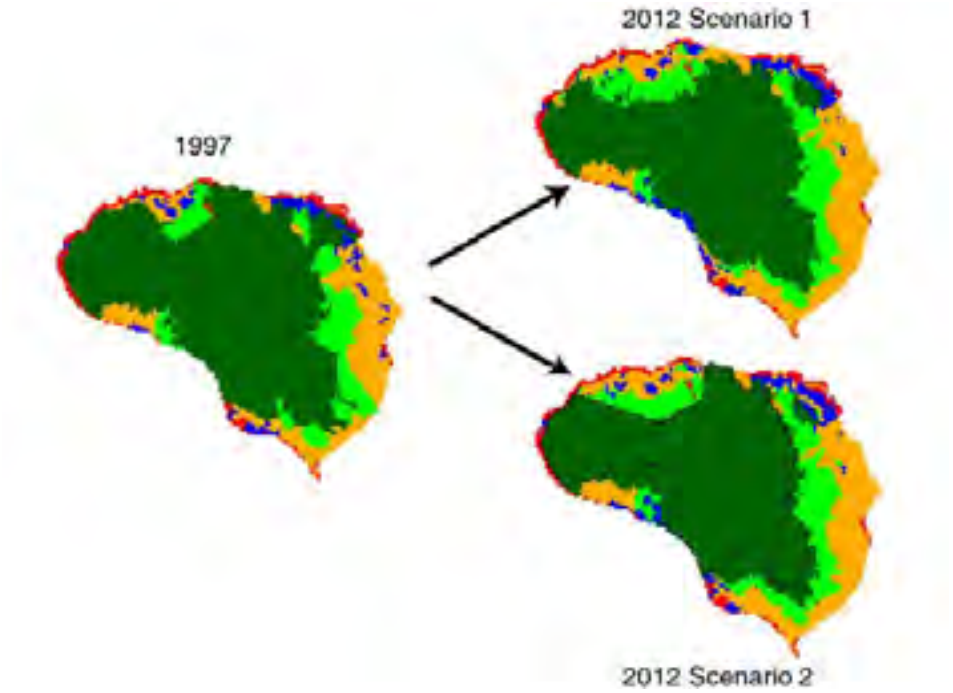


Figure 2-1. *Simulation results for two different scenarios*

2.2 LAND REQUIREMENTS (DEMAND)

The land requirements are input to the model. For each year of the simulation these requirements determine the total area of each land use type that needs to be allocated by the model. The iterative procedure will ensure that the difference between allocated land cover and the land requirements is minimized. Land requirements are calculated independently from the CLUE-S model itself, which calculates the spatial allocation of land use change only. The calculation of the land use requirements can be based on a range of methods, depending on the case study and the scenario. The extrapolation of trends of land use change of the recent past into the near future is a common technique to calculate the land use requirements. When necessary, these trends can be corrected for changes in population growth and/or diminishing land resources.

For policy analysis it is also possible to base the land use requirements on advanced models of macro-economic changes, which can serve to provide scenario conditions that relate policy targets to land use change requirements. For example, land demand for the Mesoamerican Barrier Reef (MAR) region were calculated using the IMAGE model.

2.2.1 Simulating scenarios with different land requirements

Four different files with land requirements are provided with the model for the period from 1997 to 2011. The land requirements in these scenarios are not very realistic for this short time period but allow us to clearly analyse the differences between the scenarios. The scenarios are based on the following assumptions:

demand.in1: Slow growth scenario, in this scenario a continuation of the land transformation rates of the past ten years is assumed, meaning deforestation and an increase in the area of coconut plantations, grassland and rice fields.

demand.in2: Fast growth scenario, in this scenario a higher rate of land transformation is assumed, leading to rapid conversions of forest to coconut, grassland and rice fields.

demand.in3: Food-focus scenario, a high rate of land transformation is foreseen, however, compared to the 'fast growth scenario' relatively more land is dedicated to rice cultivation in order to supply food for the population of the island.

demand.in4: Export oriented scenario, the same high land conversion rate applies. However, it is assumed that high copra prices make it profitable to dedicate most land to coconut plantations and less land to food crops.

► Select one of the land requirement scenarios and run the model keeping all other settings equal to the first run of the model. Analyze the results in ArcMap through displaying the land use pattern at the start of the simulation and at the end of the simulation. Repeat this for another scenario of land requirements and compare the results.

NOTE: Each simulation, the model will overwrite the results of a previous simulation. If you want to save the results, rename the output files or move the output files to another directory.

2.3 SPATIAL POLICIES (AREA RESTRICTIONS)

This option indicates areas where land use changes are restricted through spatial (land use) policies or tenure status. Maps that indicate the areas for which the spatial policy is implemented must be supplied. Some spatial policies restrict all land use change in a certain area, e.g., when in a forest reserve all logging is banned. Other land use policies restrict a set of specific land use conversions, e.g., residential construction in designated agricultural areas. In this exercise we will only address policies that restrict all land use changes in designated areas.

With the DEMO version of the model we supply three area restriction files that can be selected through the user-interface. Each file contains a map designating the areas where land use change is restricted. The maps are shown in Figure 14 but can also be imported in ArcView as ASCII Raster file similar to the procedure used to import the results of the simulations. The files are located in the installation directory.

Area restriction files:

region_nopark.fil: no spatial policies included

region_park1.fil: one large nature park following the boundaries of the Department of Environment and Natural Resources of the Philippines

region_park2.fil: instead of one large nature park protection is proposed for small areas which are assumed to face large land use change pressure.

Figure 2-2. *Maps of restricted areas (in black)*

► Run the CLUE-S model with the different area restriction files keeping all other settings equal to the first run of the model. Compare the results with the initial situation (1997, year 0) and compare the impact of the different area restrictions.

- Q: Is strict protection of the nature reserve needed for the developments until 2011 as simulated by the model?
- Q: Do the protected areas in 'park 2' protect areas that would otherwise be deforested? What is the consequence of strictly protecting these areas?

NOTE: Each simulation, the model will overwrite the results of a previous simulation. If you want to save the results, rename the output files or move the output files to another directory.

2.4 CONVERSION ELASTICITY

The conversion elasticity is one of the land use type specific settings that determine the temporal dynamics of the simulation. The conversion elasticity is related to the reversibility of land use changes. Land use types with high capital investment or irreversible impact on the environment will not easily be converted in other uses as long as there are land requirements for those land use types. Such land use types are therefore more 'static' than other land use types. Examples of relatively static land use types are residential areas, but also plantations with permanent crops (e.g., fruit trees). Other land use types are more easily converted when the location becomes more suitable for other land use types. Arable land often makes place for urban development while expansion of agricultural land can occur at the same time at the forest frontier. An extreme example is shifting cultivation: for this land use system the same location is mostly not used for periods exceeding two seasons as a consequence of nutrient depletion of the soil.

These differences in behavior towards conversion of the different land use types can be approximated by the conversion costs. However, costs cannot represent all factors that influence the decisions towards conversion such as nutrient depletion, esthetical value etc. Therefore, in the model we have assigned each land use type a dimensionless factor that represents the relative elasticity to conversion, ranging from 0 (easy conversion) to 1 (irreversible change). The user should specify this factor based on expert knowledge or observed behaviour in the recent past. An extended explanation of the possible values of the conversion elasticity and how behaviour changes when the land requirements increase or decrease in time is given below.

0: Means that all changes for that land use type are allowed, independent from the current land use of a location. This means that a certain land use type can be removed at one place and allocated at another place at the same time, e.g. shifting cultivation.

>0 and <1: Means that changes are allowed, however, the higher the value, the higher the preference that will be given to locations that are already under this land use type. This setting is relevant for land use types with high conversion costs.

1: Means that grid cells with one land use type can never be added and removed at the same time. This is relevant for land use types that are difficult to convert, e.g., urban settlements and primary forests. A value of one stabilizes the system and prevents that in case of deforestation other areas are reforested at the same time.

The conversion elasticities of all land use types are specified in the 'Main Parameters' input file (main.1, line 11) that can be edited through the user interface (click the 'Main Parameters' button). An explanation of all other parameters in this file can be found in the user manual). The first conversion elasticity corresponds with land use type 0, the second with land use type 1, etc.

Table 2-3. *Current settings of the conversion elasticities*

Land use code	Land use type	Conversion elasticity
0	Forest	1.0
1	Coconut plantations	0.8
2	Grassland	0.2
3	Rice fields	0.2
4	Others	1

► Run the baseline scenario for Sibuyan island with the CLUE-S model with the current settings and with alternative settings for the conversion elasticity. Change the conversion elasticity by:

- Click on the 'Main Parameters' button. The main parameters can now be edited.
- Line 11 contains the conversion elasticity settings of the different land use types in the same order as the land use type coding. Change these values to new values.
- Click on 'Save'.
- Run the model after selecting the 'Area restrictions file' and the 'Land requirements' file (similar to the first run of the model).
- Display the results with ArcView.
- Compare the differences in spatial pattern of land use change as result of the changes in conversion elasticity.

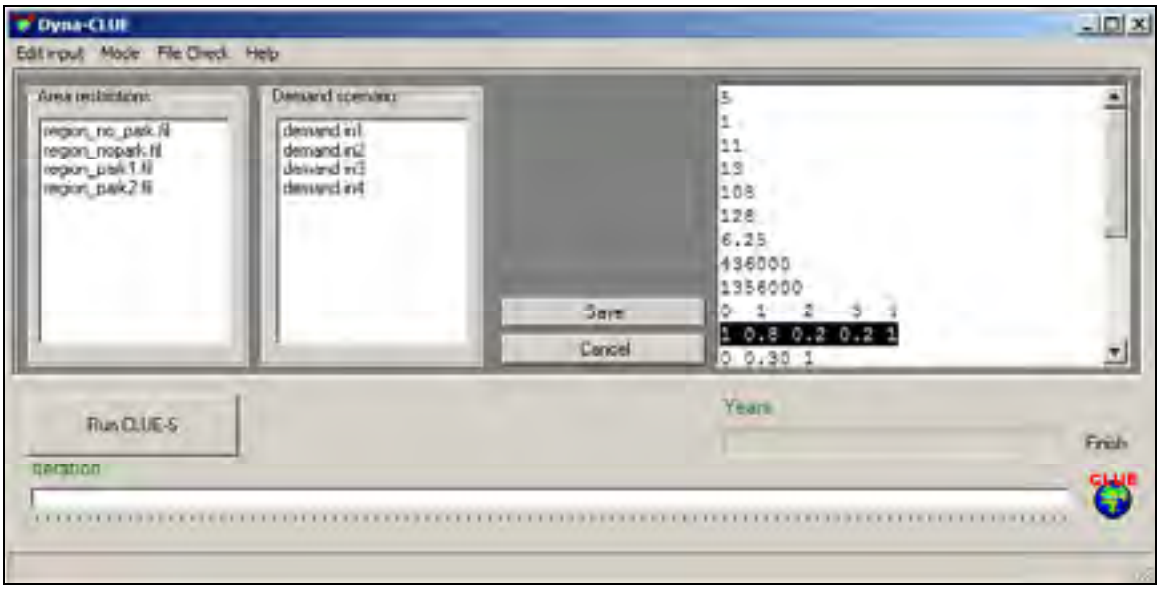


Figure 2-3. *Conversion elasticities are listed on line 11 in the parameter file main.1*

NOTE: Each simulation, the model will overwrite the results of a previous simulation. If you want to save the results, rename the output files or move the output files to another directory.

2.5 LAND USE CONVERSION SEQUENCES

Not all land use changes are possible and some land use changes are very unlikely (e.g., arable land cannot be converted into primary rain forest). Many land use conversions follow a certain sequence or cycle, e.g. fallow land and forest regrowth often follow shifting cultivation. Figure 2-4 indicates a number of possible land use trajectories identified on Sibuyan island.

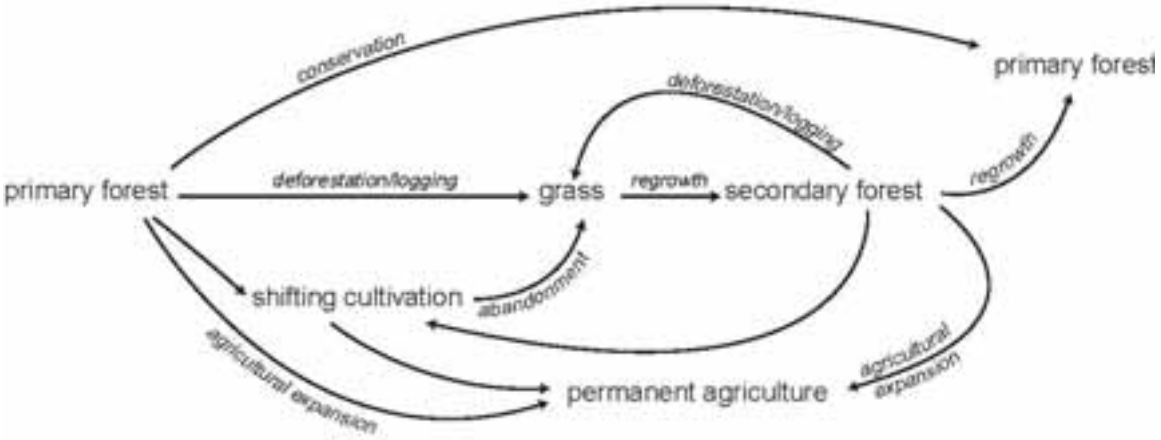
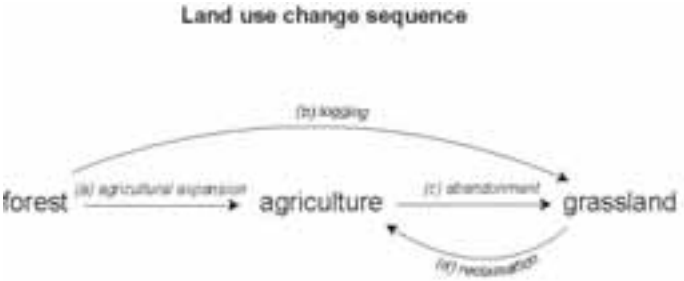


Figure 2-4. *Possible land use trajectories on Sibuyan island.*

The conversions that are possible and impossible are specified in a land use conversion matrix. For each land use type it is indicated in what other land use types it can be converted during the next time step. Figure 2-5 provides a simplified example of a land use transition sequence. Forest can be converted in either agricultural land or grassland, while it is impossible to obtain new (primary) forest through the conversion of agricultural land or grassland directly. The figure also illustrates the translation of these conversion sequences into a land use conversion matrix, which can be used by the model. Depending on the definition of this conversion matrix and the time-steps chosen, complex land use sequences are possible.



Land use conversion matrix

future land use → / present land use ↓	Forest	Agriculture	Grassland
Forest	+	+(a)	+(b)
Agriculture	-	+	+(d)
Grassland	-	+(e)	+

\+ conversion possible
\- conversion not possible

Figure 2-5. *Land use transition sequence*

The land use conversion matrix can be edited by clicking the 'Change matrix' button. It is also possible to use a text editor (e.g. Notepad) to edit the file '***allow.txt'*** in the installation directory. The rows of this matrix indicate the land use types during time step *t* and the columns indicate the land use types in time step *t+1*. If the value of a cell is 1 the conversion is allowed while a 0 indicates that the conversion is not possible. The rows and columns follow the number code of the land use types.

Example: in the matrix below all conversion are possible except the conversion from coconut plantation into rice fields.

From ↓ To →	Forest	Coconut	Grassland	Ricefields	Others
Forest	1	1	1	0	1
Coconut	1	1	1	1	1
Grassland	1	1	1	1	1
Rice fields	1	1	1	1	1
Others	1	1	1	1	1

► Run the baseline scenario for Sibuyan island with a different setting of the conversion matrix (keeping all other settings equal) and analyse the differences in outcome with ArcView. We suggest to compare a model run that allows all changes with a model run in which the conversion of grassland into agricultural land (coconut plantation and rice fields) is no longer possible due to soil degradation. Compare the results.

Note: Some land use conversion settings will have no effect because they are overruled by the conversion elasticity and land requirement settings. In the baseline scenario we have assumed that the 'others' land use type is not changing and forest cannot 're-grow' from other land use types as long as its total land area is decreasing. Consequently, changing the conversion settings for these land use types in the conversion matrix will have no effect on the simulation results.

[End of exercise 2]

Exercise 3: Defining spatial policies and creating new land requirements

Objective: In this exercise you will learn how to prepare a new land requirements file and also a new area restrictions file. The combination of these new files represents a new scenario and you will then simulate your own scenario.

3.1 INTRODUCTION

For some scenarios it is interesting to define areas where land use changes are restricted because of spatial policies, e.g. the conservation of nature. In the previous we have seen that spatial policies should be defined in an 'area restriction' file. This file contains a map of the study area indicating the extent of the case-study area and the zones of the case-study area where spatial restrictions apply.

The 'area restriction' file is located in the installation directory and called '**region*.fil'** where * can be defined by the user to indicate the conditions specified in the file. With the demo version of CLUE-S three different area restriction files are supplied, one without any spatial policy and two file indicating different extents of a nature reserve.

► Import these 'area restriction' files in ArcMap using the procedure as you used for the land cover grid in Exercise 1.5. It is best to copy these files to a temporary directory and then rename them there by adding ".asc" to the file.

- Question: What are the different grid values in the area restriction files? What value is used for a restricted area? And what value for a non-restricted area?

3.2 PREPARATION OF A NEW AREA RESTRICTION FILE

In this exercise you will create a new 'area restriction' file to simulate a scenario of the effects of a strict protection of all remaining lowland forest on Sibuyan island. Therefore we assume that during the simulations it is not possible to convert any of the remaining forest areas below an altitude of 100 meter.

To make the area restriction file we need to identify:
- The extent of the case study
- The locations below 100 meter altitude
- The locations with forest at the start of the simulations

Therefore it is needed to import the land use map of year 0 (the start of the simulation) in ArcView. This land use map shows the extent of the study area (all grid-cells that are designated to a land use type) and the locations with forest at the start of the simulations. This land use map can be found in the installation directory (C:\Clues) and is called '**cov_all.0'**.

To identify the locations below 100 meter an altitude map is needed. Since altitude is one of the location factors used in the simulations for Sibuyan island this map is already present in the installation directory. For this case study altitude is location factor number 7, so the elevation dataset in file '**sc1gr7.fil'**.

► Import both files using the *ASCII to Raster* option in ArcToolBox.

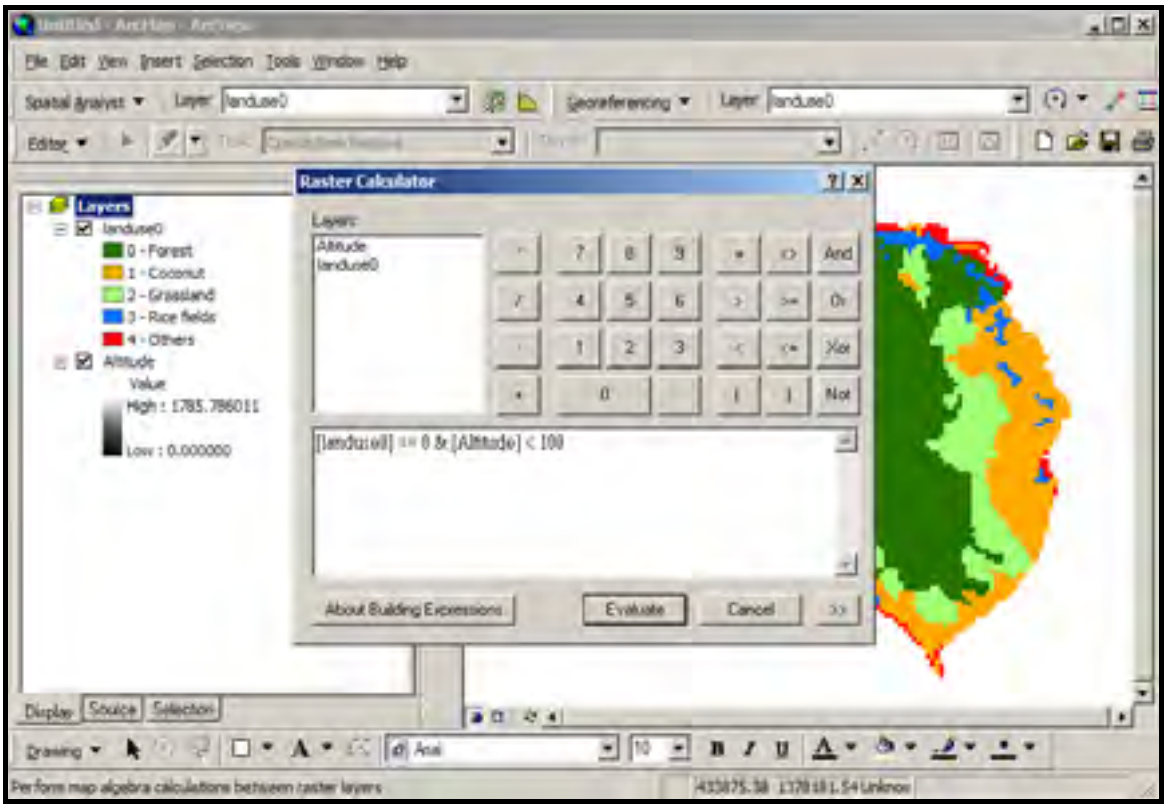


Figure 3-1. *Map query with the Raster Calculator in ArcMap*

In the 'area restriction' file the following coding should be used:

0	all grid cells that belong to the study area outside the 'restricted area'. These are the grid cells that are allowed to change.
-9998	all grid cells for which land use conversions are not allowed during the simulation (the 'restricted area')
-9999 (No Data)	all other grid cells (outside the simulation area)

► Prepare an 'area restriction' file to prevent any forest areas below an altitude of 100 meter from changing. You can follow the steps below or use your own procedure:

- Select all locations with forest located below an altitude of 100 meter at the start of the simulation by a 'map query' (Spatial Analyst | Raster Calculator) (Fig. 3-1). This will result in a new temporary theme '*Calculation'* indicating all selected locations by a value of 1.
- Classify the results of the previous step to the coding system of the area restriction file, as listed above (Spatial Analyst | Reclassify) (Fig. 3-2). This should create new temporary layer '*Reclass of Calculation'* with values of –9998 and 0.
- Export the result of the previous step as an ASCII file '**region5.asc'** in the CLUE-S installation folder (ArcToolBox | Conversion Tools | From Raster | Raster to ASCII). Note that you must specify either a *.txt* or *.asc* extension
- Using Windows Explorer browse to the installation directory and rename the file region5.asc to region5.fil (you may use a different number but you must use the **region*.fil** naming convention otherwise CLUE-S does not recognize it).

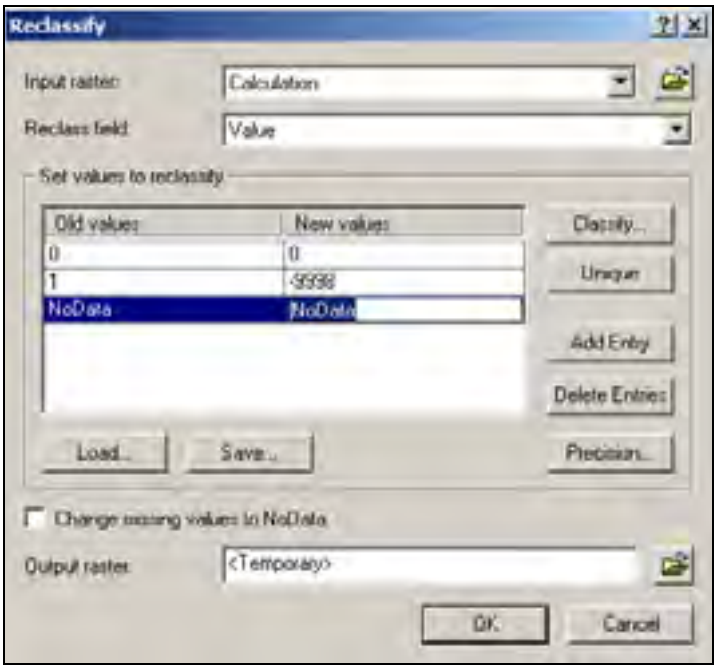


Figure 3-2. *Reclassifying a grid as an area restriction file.*

► Restart the CLUE-S model and the new area restriction file should appear in the list of area restriction files and can be selected for the simulation. Run the model with this file and compare the result with a simulation without protection of forest resources.

► Prepare your own area restriction file based on a hypothetical spatial policy. You can also prepare area restriction files by delineating areas in ArcView that need to be converted to grid cells.

Note: If the area restrictions violate the land requirements specified in the 'land requirements' file the model will not succeed in allocating land use changes and stop the simulation. This can occur when all forest is assumed to be protected while at the same time a decrease in land requirements for forest is specified.

3.3 CREATING YOUR OWN LAND REQUIREMENTS FILE

► You will now start defining your own scenario by generating a new land requirements input file for CLUE-S. Follow the steps and data guidelines below:

- Open Microsoft Excel to facilitate the calculations.
- Specify for each year (1997-2011) the land requirements of the different land use types in a table following the specifications below:
  Please note: Demand must always be expressed in hectares (10 000 m^2).
- Each row indicates a year; each column a land use type following the order of the land use coding.
- Make sure to include also the land requirements for 1997 (year 0). These should be similar to the land use map of 1997 (29518.75, 7237.5, 5243.75, 1400, 1762.5 ha for respectively forest, coconut, grassland, rice and others).
- The total land area required should equal the size of the island (45162.5 ha), i.e., the sum of the values on each row should equal 45162.5 for each year.

  Suggestion: you can temporarily add an extra column G or H and use a formula to verify that the row totals are always equal (for example: *G2 = SUM(A2:F2)).*

- We suggest not to change the land use requirements for the 'others' land use class and to create logical scenarios without sharp increases or decreases. This should prevent problems or very long run times during the simulation.

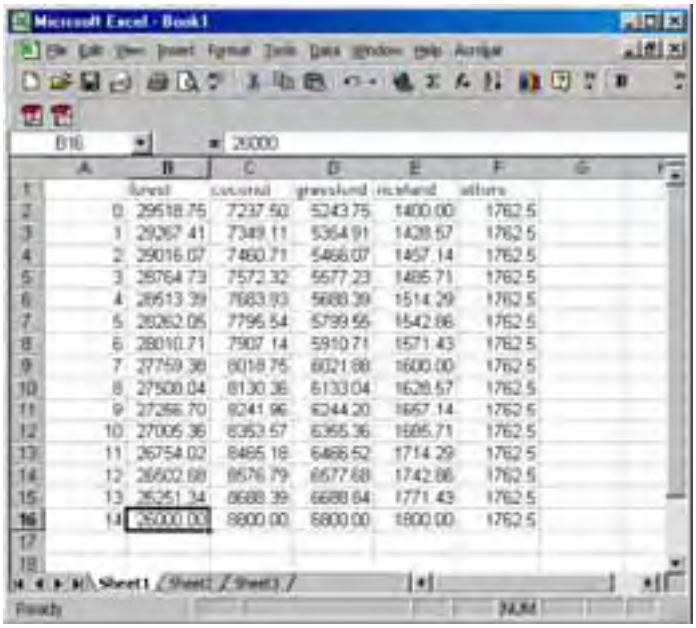


Figure 3-3. *Entering land use requirements in a spreadsheet.*

- When all values have been defined, select the values (without land use type names and year numbers) and paste the contents into a text editor (e.g. Notepad). Insert a line at the top of the file with the number of lines (years) for which the land requirements are specified (15 in our example).

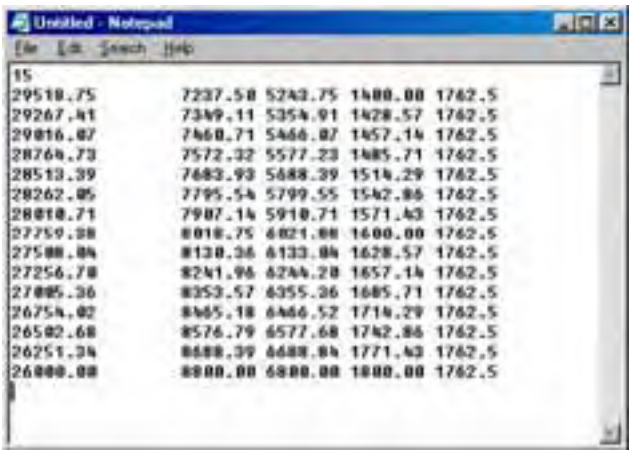


Figure 3-3. *Land use requirements copied to a text file demand.in**

- Save this file in the installation directory as '**demand.in***' where * can be defined by the users, e.g. demand.in5.
- Restart the CLUE-S model; it is now possible to select the new land requirement file and simulate the land use changes.
- Import and analyse the results in ArcMap.

[End of exercise 3]

Background on the MAR Land Use Change Simulations

In the previous exercises you worked with data for Sibuyan Island. This is a very small dataset and simulations ran very quickly, which made it very suitable for a relatively short training day and allowed you to quickly inspect the changes in simulation outcomes after you made adjustments in area restriction files, land demand and conversion elasticities. Now you will start working with some actual data for that we used for the MAR.

The MAR catchment is approximately 190,400 km^2 large, with 41% of the area in Honduras, 29% in Mexico, 18% in Guatemala and 12% in Belize. Those 12% represent the entire country of Belize whereas only parts of the other countries are included.

Dataset prepared for each country

First of all, it is important to know for that the regression analysis and the CLUE-S simulations were done separately for each country (or part of it). The reasons are:

- Land use pattern and the drivers of land use change are different for the countries because of different policies, biophysical conditions or other factors, so performing a separate analysis allows a more accurate analysis.
- Smaller data files by country facilitate easier data management.

Nevertheless, these size of the data even for an individual country is much larger that for Sibuyan Island. For all four countries the smallest possible spatial extent was defined and the country grid were clipped to these extents.

Size of the grid for Sibuyal Island and the MAR countries. Cell size is 250 m. Simulation times are observed on a laptop with a 2GHz Pent. M processor and 2GB of RAM

Country	# Rows in grid	# Columns in grid	# Data cells (not Null)	Average time for a simulation run
Sibuyal	108	128	7,226	< 10 seconds
Belize	1151	604	349,762	½ - 1 hour
Guatemala	1503	1310	542,309	2 - 3 hours
Mexico	1674	1262	886,433	3 - 4 hours
Honduras	1005	2131	1,267,903	4 - 5 hours
All of MAR	3484	3016	3,046,407	N/A

	West (xmin)	East (xmax)
Belize	261,500	412,500
Mexico	213,250	528,750
Guatemala	41,250	368,750
Honduras	260,250	793,000
	South (ymin)	**North (ymax)**
Belize	1,757,500	2,045,250
Mexico	1,971,250	2,389,750
Guatemala	1,596,500	1,972,250
Honduras	1,521,000	1,772,250

Figure 1: Spatial extents and mask for raster datasets for the four MAR counties. Coordinates are in UTM zone 16 with NAD 1927 Central American datum.

GEO-4 Scenarios

We adapted three of the four Global Environment Outlook 4 (GEO-4) scenarios Latin America and the Caribbean for use within the ICRAN MAR project. The scenarios envisage differing social, political and economic trajectories, emphasizing outcomes for the environment and human well-being.

1. **Markets First**: Under this scenario economic growth is prioritized over social and environmental objectives. Everything becomes merchandise, including natural resources and basic goods such as water and culture. In general, regional environmental degradation continues to worsen.

2. **Policy First:** Environmental awareness develops within government more rapidly than in the private sector or amongst the general public. The resource base is better managed, with policies being developed to alleviate the more serious environmental problems.

3. **Sustainability First:** In this world, economic, social and environmental dimensions combine to shift the trajectory towards environmentally sustainable development. International cooperation within the region increases, with policies being directed to achievement of the Millennium Development Goals and sound natural resource management.

More details about the scenarios can be found in Miles (2006), which is included in the readings list and as a PDF file on the CD.

Land requirements

Land requirements for every scenario were calculated using the IMAGE model. In the next exercise we will focus on Belize. The table below gives the distribution of land use at present and the calculated land demand under the scenarios in 2025 for Belize. The total area is *21860.13 km^2*. The area of land use types 0 and 9 is assumed to remain constant.

Land use distribution at present and for the scenarios in Belize.

	Present (2004)	Markets First 2025	Policy First 2025	Sustainability First 2025
0. Other/Unknown	0.06%	0.06%	0.06%	0.06%
1. Broad-leaved forest	58.02%	54.33%	56.69%	57.78%
2. Pine forest	3.53%	3.31%	3.45%	3.52%
3. Agriculture/pasture	19.37%	23.20%	20.64%	18.85%
4. Scrub	1.26%	1.23%	1.13%	1.37%
5. Savanna	8.63%	8.23%	8.35%	8.65%
6. Wetland/Swamp	4.26%	4.07%	4.12%	4.27%
7. Mangroves	3.29%	3.08%	3.22%	3.28%
8. Urban	0.87%	1.79%	1.64%	1.51%
9. Water	0.70%	0.70%	0.70%	0.70%

Exercise 4: Working with actual scenario data for Belize

Objective: In this exercise you will learn some of the actual data that were used for the Belize simulations, and how dynamic location factors were used. You will also create and review probability surfaces. At the end of the day you should have a sufficient knowledge of the data to simulate and analyze the actual different scenarios yourself.

4.0 COPY THE CLUE-S MODEL AND DATA FOR BELIZE FROM CD

- Using Windows Explorer, browse to the folder *C:\Training\Data\CLUE-S* on your computer (or the CD). This folder has 4 zip files that contain all land use and location factor grids in regular grid and ASCII format.
- Double-click BZ.ZIP and unzip (extract) the file in a temporary location on your computer, e.g., c:\temp. Remember where you extracted the file.
- Also copy the entire CLUE_BZ folder from the CD to a place on the harddisk. Then right-click the folder, select Properties,uncheck "read-only", and apply it to all subfolders and files. CLUE-S will give an error if the folder is read-only!

4.1 REVIEW OF THE LAND USE DATA

The baseline land cover map was based on the 2004 version of the Belize Ecosystem Map and the revised 2003 Ecosystem Map for Central America land use data. The original land cover classification was reduced to 10 classes (Table 4-1) and the data was converted from a vector to a raster format with a 250 m grid cell size.

Note: CLUE-S requires that the land use numbering to start at 0, not 1.

***Table 4-1**: Reduced land use classification used for the MAR*

Value	Land use type	Value	Land use type
0	Other/unknown	5	Savanna
1	Broad-leaved forest	6	Wetland/Swap
2	Pine forest	7	Mangroves
3	Agriculture/pasture	8	Urban
4	Scrub	9	Water

► Let's now look at the reclassified 2004 land use data for Belize:

- Open ArcMap and load the layer file '*Belize Present land Cover (2004).lyr*' that is in the BZ data folder (the layer file source grid is *..\BZ\grid\bzecomap*).
- Review the land cover data. Keep in mind that these data were based on the 2004 Ecosystem Map for Belize (Meerman & Sabido. 2001), reclassified and converted from vector to raster data with a cell resolution of 250 m.

4.2 STATIC AND DYNAMIC LOCATION FACTORS

For every region you must specify a number of driving factors of land use change. These 'location factors' were determined by a statistical regression analysis. Table 4-2 lists all location factors that were analyzed for the MAR. The numbering must starts at 0.
A location factor can be static of dynamic, as is indicated in the last column of the table.

- **Static**: the location factor is constant over the entire simulation grid. The grid is saved in ASCII format with the following naming convention: SR**x**GR.FIL

- **Dynamic**: the location factor changed over time. Instead of a single ASCII grid we have to prepared a grid for every year: SR**x**GRD.**y**

  where
  x = the number of the location factor (0 to 11)
  y = the simulated year started at 0 (for belize, 0 to 21)

For the MAR land use simulations only one location factor was dynamic: No. 11, protected areas with partial protection. Of course, population density will also change over time, and accessibility to markets and road may also change if no roads are built. However, the scenario descriptions that were developed described the future changes for the country as a whole and did not provide sufficient details about exactly what, where and how changes might occur on a regional or local scale.

Table 4-2: Location factors (LF) used for the MAR land use simulations.

No	Description [unit]	CLUE-S file	Original GRID file	Dynamic
0	Population density [# per km^2]	**SC1GR0.FIL**	**POPDEN**	No
1	Soil depth [meter]	**SC1GR1.FIL**	**SDEPTH**	No
2	Soil drainage [0-1]	**SC1GR2.FIL**	**SDRAIN**	No
3	Mean annual rainfall [mm]	**SC1GR3.FIL**	**RAINYR**	No
4	Length dry period [consecutive months with < 60 mm rain]	**SC1GR4.FIL**	**DRYMON**	No
5	Elevation [meter]	**SC1GR5.FIL**	**ELEVAT**	No
6	Slope [degrees]	**SC1GR6.FIL**	**SLPDGS**	No
7	Accessibility to markets [travel time in hours]	**SC1GR7.FIL**	**ACSMKT**	No
8	Accessibility to roads [travel time in hours]	**SC1GR8.FIL**	**ACSRDS**	No
9	Coastal area / tourism hotspots [0/1]	**SC1GR9.FIL**	**TOURIS**	No
10	Protected areas / full protection [0/1]	**SC1GR10.FIL**	**WDPAR1**	No
11	Protected area / partial protection [0/1]	**(SC1GR11.FIL)** **SC11GR.0** - - - - - **SC11GRD.21**	**WDPAR2**	Yes

► You will now review the location factor grids.

- Browse to the 'BZ' folder that you just extracted. You should see two sub-folders, "*ascii*" and "*grid*". Both folders contain the same dataset but in different formats. It is easier to work with the data in the "*grid*" folder because these data can be readily loaded as a layer in ArcMap.
- Open a new ArcMap document and load location factor 8, "Accessibility to Markets" (*bz*ACSMKT). The unit of this data is travel time in hours. It was calculated using a methodology developed by researchers at CIAT, Colombia. Do you think the travel times are fairly realistic?
- Also load location factor grid 10 (*bz*WDPAR1) and 11 (bzWDPAR2). A grid value of 1 means that the grid cell is a protected area, a value of 0 not. Are you familiar with the protected areas in the country?
- Load all other grids location factor (i.e., don't load the "bzLUC_" grids – these are grids for individual land use types). Review all location factor grids and make sure that you understand these grids and their units.

4.3 REGRESSION EQUATIONS AND PROBABILITY SURFACES

Note: in this part of the exercise you will be learning about some of the more advanced features of CLUE-S. Nonetheless, you will need to understand these features if you are planning to use CLUE-S for actual simulation modeling of land use change.

The allocation of land across the region is done by CLUE-S based on probabilities, which, in turn, are calculated using regression equations that account for the effect of one or more location factors. For example, the regression analysis showed a significant relationship with Urban land and three location factors, as follows:

Probability $LU_8 = 0.5 + 0.01\ LF_0 - 0.37\ LF_7 + 0.70\ LF_9$

where LU_8 = Land use type 8, Urban
LF_0 = Population density
LF_7 = Accessibility to markets
LF_9 = Coastal area / tourism hotspot

Note the negative relationship for LF_7. Thus, the farther away a grid cell is from a market, the lower the probability that land use at that location changes to Urban.

► The regression equation above and similar equation for other land use types are specified in the file **alloc1.reg**. You will now briefly review that file.

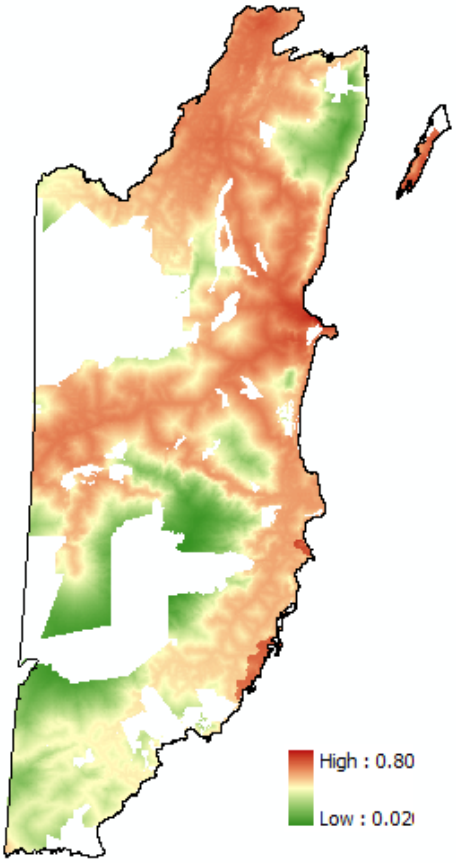
- Browse to the folder CLUE_BZ that contains all files for Belize.
- Right-click on the file ***alloc.1reg*** and open the file in a text editor such as Notepad or Textpad. You can select NotePad by choosing "*Open With*" and the selecting Notepad from the list of available programs.
- Scroll to the end of the file. Do you recognize the parameters from the equation above? Please refer to pages 22-23 of the CLUE-S user manual for more information about the precise format of this file.

The regression equations are important because during run-time CLUE-S uses these equations to create probability surface for every land use type. These surfaces show the probability of changes towards that land use type across the entire study area.

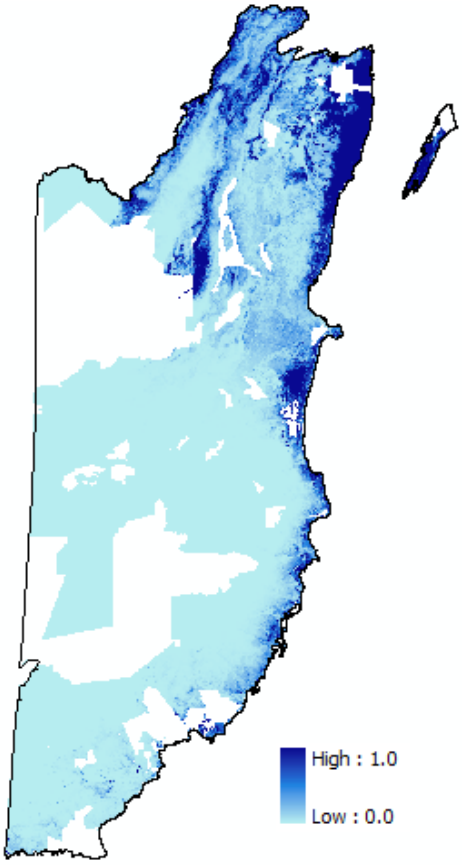
► Let's look at some of these probability surfaces.

- Using Windows Explorer, browse to the *..\Training/CLUES_BZ* directory and double-click **clues.exe** to start the model.
- Select "*Calculate Probability Maps*" from the Mode main menu.
- Select one of the area restriction files and one of the demand files.
- Press the "Run CLUE-S" button to start the model. The model will now only calculate the probability maps. This will take about 1-2 minutes. Press the "Calculations Finished" button but do not close the application.
- Go back to Windows Explorer in the CLUE_BZ folder and refresh the contents of the folder view. You should now see the probability surfaces that were created with the names ***prob1_0.1***, ***prob1_1.1***, …, and ***prob1_9.1***.
- Rename the extension of all ten probability files from ".1" to ".asc".
- Open ArcMap and ArcToolBox. Use the "ASCII to Raster" tool to import the files ***prob1_6.asc*** (probability for Wetland) and ***prob1_8.asc*** (probability surface for Urban). Make sure to select "FLOAT" as the Output data type.

- Review the output. It should look like the next figure (colors may be different). The highest probability for Urban should be near Belize City, near some other coastal areas, and close to the main highways. The probability for Wetland should be highest in the northeastern part of the country.



Probability surface for Urban



Probability surface for Wetland

Note: No probabilities are calculated for restricted areas ("no change" areas). These are *NoData* cells and are white coloured in the maps below. The probability surfaces are very useful for verification of the validity (significance) of regression equations and the restricted areas: Areas with the higher probabilities should correspond to where the land use type presently is.

4.3 Running a complete simulation run

► A full simulation run for Belize may take ½ to 1 hour, so it is unlikely that there is enough time during the training day to do this. However, you can try it, of course.

- In CLUE-S, unselect "*Calculate Probability Maps*" from the Mode main menu.
- Select an area restriction files and a land demand files. Note that you must combine files that have the same number (1 = Markets First; 2 = Policy First; 4 = Sustainability First). Then click the "Run CLUE-S button.
- When the simulation has completed, rename the file ***cov_all.21*** to ***cov_all_21.asc*** and import this file in ArcMap. Make sure to select "INTEGER" as the Output data type.Review the land use pattern.

[End of exercise 4]

ANNEX. 8. BELIZE COASTAL ATLAS

Belize Audubon Society · Forest Department · Belize Coastal Zone Management Authority & Institute · Friends of Nature · BTFS Belize Tropical Forest Studies · http://biological-diversity.info · Land Information Centre · SAN MBRS · The Nature Conservancy · TIDE · Wildlife Conservation Society · World Resources Institute · WWF

ICRAN International Coral Reef Action Network · UNEP · Caribbean Environment Programme · USAID

Mesoamerican Reef Alliance - ICRAN-MAR

Workshop on Watershed Management, Land Cover Change Analysis, and Modeling of Land-based Sources of Pollution and Sediment Discharge to the MAR

Proceedings

Galen University

SAN IGNACIO, BELIZE, AUGUST 15-18, 2006

Eric van Praag, Consultant for UNEP-WCMC
Joep Luijten, Consultant for UNEP-WCMC
Lauretta Burke, WRI
Liza Agudelo, ICRAN-MAR

September, 2006

List of Acronyms

BMP	Better Management Practices
CATHALAC	Water Center for the Humid Tropics of Latin America & the Caribbean
CLUE-S	The Conversion of Land Use and its Effects
DEM	Digital Elevation Model
GIS	Geographic Information System
IABIN	Inter-American Biodiversity Information Network
ICRAN-MAR	Mesoamerican Reef Alliance
INEGI	Instituto Nacional de Estadística, Geografía e Informática, México
JICA	Japan International Cooperation Agency
LAC	Latin America and the Caribbean
LU/LC	Land use/Land cover
MAR	Mesoamerican Reef
MBRS	Mesoamerican Barrier Reef System
N-SPECT	Nonpoint Source Polution and Erosion Comparison Tool
SeaWifs	Sea-viewing Wide Field-of-view Sensor (SeaWiFS)
SERVIR	Mesoamerican Regional Visualization and Monitoring System
SIDA	Swedish International Development Cooperation Agency
SRTM	Shuttle Radar Topography Mission
UNEP	United Nations Environment Programme
UNF	United Nations Foundation
UNFCCC	United Nations Framework Convention on Climate Change
USAID	U.S. Agency for International Development
USGS	U.S. Geological Survey
WCMC	UNEP World Conservation Monitoring Centre
WRI	World Resources Institute
WWF	World Wildlife Fund
WRIScS	Watershed-Reef Interconectivity Scientific Study

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INTRODUCTION

ICRAN-Mesoamerican Reef Alliance (ICRAN-MAR)

The International Coral Reef Action Network (ICRAN), was established in the year 2000 as an innovative and dynamic global partnership of many of the world's leading coral reef science and conservation organizations. It is a collaborative effort that operates at different levels to help to stop and reverse the decline in health of the world's coral reefs. ICRAN partners create alliances around the world to facilitate inter-linked and complementary actions in reef monitoring and management, at local, national, and global scales.

In the ICRAN Mesoamerican Reef Alliance (ICRAN-MAR), several partners have come together in a three-year initiative to support regional efforts in response to the Tulum Declaration of 1997 for the conservation of the Mesoamerican Barrier Reef (Mexico, Belize, Guatemala, and Honduras). With the kind contribution of the United States Agency for International Development (USAID), and the United Nations Foundation (UNF), and under the overall supervision of the United Nations Environment program (UNEP), the ICRAN-MAR Alliance seeks to develop and facilitate innovative tools that promote the voluntary adoption of best management practices in the areas of Tourism, Fisheries and Watershed Management. The project therefore, offers a holistic approach that recognizes the strong relationship between these three components and their potential impact on the health of the Mesoamerican reef, and promotes and seeks cooperation with other institutions and initiatives in the region.

The Watershed Management component of the ICRAN-MAR project was designed recognizing that appropriate land use practices are critical for proper management of watersheds in the Mesoamerican region, and to ensure that transport of sediment, nutrients and other pollutants to the coral reef system is minimized. Developing appropriate land use strategies requires gathering information on the potential impact of different land use and development options in the region, as well raising awareness and coordination with the different stakeholders.

ICRAN-MAR partners in the Watershed Management component contribute to these regional efforts by forming alliances with the private sector to reduce the impact of agricultural activities on the reef, and by developing innovative Geographic Information Systems tools that can be used to simulate watershed dynamics and inform decision makers in the Mesoamerican region.

With respect to the GIS tools, the work of the ICRAN-MAR project is complementary to the ongoing and past work of other regional initiatives such as the MBRS, SERVIR and IABIN-DGF projects. It is the first to engage a regional-scale analysis and spatial modeling of the environmental impacts of watersheds on the Mesoamerican Reef. This work also builds on the World Resources Institute's *Reefs at Risk of the Caribbean* initiative.

The current proceedings summarize the dynamics and outcomes of a successful workshop held in San Ignacio, Belize in August 2006, in which project partners presented the results of two years of project implementation and requested feedback from regional experts.

Watershed Management Workshop

The objectives of the meeting were twofold: inform regional participants of the land use modeling results and the initial findings for the region, and train regional GIS technical experts who could in turn become trainers of other experts in their particular countries.

The workshop was divided in two sessions: a Policy Session and a Technical Session. The policy session was geared towards senior managers and decision makers of participating institutions; its main objective was to help them understand the usefulness and applicability of the data products and models developed by ICRAN-MAR for watershed management. This session lasted for one and a half days and took place on August 15th and the morning of August 16th.

The technical session's objective was to allow specialists from participating countries to become familiar with and get hands-on training in the use of the data products and models aforementioned. This session lasted for two and a half days and took place on the afternoon of August 16th, and on August 17 th and 18th.

Both sessions provided a great opportunity for national specialists to acquire new technological knowledge, coordinate activities, plan their modeling efforts, exchange experiences with colleagues from other countries, and acquire geospatial information developed or collated by ICRAN-MAR.

The following sections provide an overview of the contents, results, discussions and resolutions attained in the course of the two sessions of the workshop.

POLICY SESSION

The Policy Session was held on August 15 and the morning of August 16, 2003, at Galen University in San Ignacio, Belize (see workshop agenda in Appendix 1).

Senior staff and specialists from national and regional institutions that deal with marine and coastal issues attended the meeting (see list of participants to policy session in Appendix 2).

The objectives of the policy session were the following:

1) Inform policy makers and other potential information users of the information outputs and tools that have been developed under this project.
2) Learn about the ICRAN MAR watershed project and the analytical components on land cover change analysis, watershed delineation, hydrologic modeling and circulation modeling.
3) Review scenarios of land cover change and provide feedback on these scenarios.
4) Review results of predictive modeling of land-based sources of pollution and sediment discharge to the Mesoamerican Reef
5) Raise awareness of the linkages between human activities on the land and threats to the Mesoamerican Reef.
6) Identify policy questions/applications for the analytic tools, as well as future users of the analytic tools.

During the morning of August 15 an introduction to the ICRAN-MAR project and the role of its partners in the watershed component was offered, together with the following keynote presentations:

Health of Corals and threats to the Mesoamerican Reef (by Melanie McField)

Dr. McField gave a thorough presentation on the most pressing threats (dredging, tourism, aquaculture-overfishing, poor port management and shipping, climate change, and natural disasters) to the Mesoamerican Reef (MAR). She discussed the concept of a "healthy" reef and the different reef attributes (structure and function) and human dimensions (drivers of change, social well being, and governance) that must be taken into account when defining the level of disturbance (i.e. health). Eventually we need to make use of the reef resources and we need to identify the best ways to do so.

Conceptual evolution of watershed management in the Mesoamerican Region (by Carlos Rivas)

Dr. Rivas presented the evolution of the watershed management efforts in the region during the last 20-30 years. He began by introducing the topographic characteristics of the region and the socio-economic drivers that have defined regional development models, and the traditional agricultural uses of the land. Extractive economy, poverty and expansion of the urban and agricultural frontiers have caused changes in the landscape and the watershed dynamics over the past decades. The need to control flooding and guarantee the provision of water resources to cover the increasing needs of the population and industry led to the early watershed management efforts imported from developed countries to the region. With time, there has been a shift from anthropocentric ('rational/economic') to more biocentric ('sustainable') rationales when developing strategies to manage watersheds. With this shift in mentality, the social component is included and participatory planning is encouraged; however, the strategies are not always economically attractive and very often conflicts arise. There is a generalized need for more government support and development of coherent policies for the sustainable use of the water resources.

Following the keynote presentations, Joep Luijten (UNEP-WCMC) and Lauretta Burke (WRI) respectively offered an overview of the different methodologies and results in land use change and hydrologic modeling[1]; immediately afterwards, Jose Vasquez (WWF) presented results of the on-the-ground work with agricultural companies for the adoption of better agricultural practices.

Overview of scenario development (by Joep Luijten)

Joep Luijten began his presentation by explaining the concept and descriptive nature of the scenarios, and how they can inform policies. Scenarios are not predictions of the future, but rather present "different assumptions about how current trends will unfold, how critical uncertainties will play out and what new factors will come into play" (UNEP, 2002). The 3 scenarios developed for this project were adapted from the Global Environment Outlook 4 scenarios for LAC that will be released in 2007. These scenarios looked at the current regional situation of the natural resources and

[1] Please refer to the Workshop Data CD for detailed documentation on the development of the scenarios, land use change modeling, and hydrologic and circulation modeling.

the potential situations by 2025 under three hypothetical world-wide and regional situations (Markets First, Policy First, and Sustainability First). These scenarios would have different impacts on the socio-economic and natural dimensions of the region and could serve to influence decision makers.

Overview land use change modeling (by Joep Luijten)

Once the descriptive scenarios were developed, a multi-scale modeling approach was applied to quantify the potential changes in land cover in the MAR. Three models were utilized (International Futures, IMAGE, and CLUE-S) to explain the dynamics of the different variables involved in land cover change processes. Thus, the *International Futures* model estimates the proportion of regional land use change that occurs in each country, and provides socio-economic drivers to the *IMAGE* model. *IMAGE* in turn, is a global integrated assessment model that simulates the rate of change in the region, and the proportion of change that occurs in each land use type.

CLUE-S is the land use change (allocation) model and adds a spatial dimension that simulates where land cover change occurs within the MAR region.

For quantification of the changes in land demand under each scenario the year 2000 was used as the base year because that was the year for which the latest land cover data were available for most countries.

Overview of Hydrologic and Circulation Modeling for the MAR (by Lauretta Burke)

Lauretta Burke began her presentation highlighting that the purpose of this analytical modeling exercise of the ICRAN-MAR was to model present and future impact of land cover change and agricultural activities on coral reefs and identify land most vulnerable to erosion. The outcomes of the modeling exercises could eventually guide stewardship of vulnerable areas in the region. Likewise, the project sought to identify tools and a methodology that could be easily be transferred to analysts and land stewards in the MAR region for more detailed local application.

The first step in this exercise was to delineate the watershed for the region. Basins were delineated from 90m resolution NASA SRTM data and 300 basins (of 5 km^2 minimum size) were identified within the MAR region. This exercise took several months and was especially difficult for the Yucatan peninsula due to the geological characteristics of the terrain and the presence of underground rivers. She invited participants to provide inputs to improve the accuracy of the delineation.

The following step was to run the "Nonpoint-Source Pollution & Erosion Comparison Tool" (N-SPECT) to evaluate sediment and pollutant delivery into coastal waters. The N-SPECT model, developed by NOAA, is in the public domain and is easy to run in ArcMAP. N-SPECT provides estimates of erosion across the landscape as well as sediment and pollutant (N and P) delivery and concentrations at the river mouths.

Using the land cover scenarios from CLUE-S, coupled with the N-SPECT hydrologic model, sediment and pollutant delivery at 300 river mouths can be estimated. The University of Miami is implementing a high resolution 4-dimensional model to examine sediments and pollutants transport within the region's lagoonal system. The sediment and nutrient transport predictions will be calibrated using the SeaWifs sensor.

Lauretta commented that the hydrologic results need to be calibrated (and validated) using data from several sources. Project collaborators from Texas A&M University are taking sediment samples; WWF is taking sediment samples and is looking at

bioaccumulation of toxics in reef organisms. AGRRA reef assessments will be used to examine the location of sediment impacts on coral reefs. She discussed the limitations of the analysis and invited workshop participants to make recommendations for data to calibrate the model.

Results of Hydrologic and Circulation Modeling (by Lauretta Burke)

Keeping all inputs but land cover equal, WRI produced estimates for the present day and future scenarios of accumulated runoff, as well as accumulation and concentration of sediment, nitrogen, phosphorous, and total suspended solids. Annual model runs were implemented for current land cover, hypothetical natural land cover, and the three 2025 scenarios for the MAR region. Analysis of results allowed the identification of those areas with the highest sediment and nutrient delivery, and of how much sediment and nutrient delivery has increased due to human activities. It was also possible to see the influence that future land cover might have on sediment and nutrient delivery, as well as the areas that are the most vulnerable to erosion, and which parts of the MAR are affected by sediment and nutrients. Maps and summary tables were presented, and later discussed with workshop participants.

Activities with Agribusiness for the adoption of Better Management Practices (BMPs) (by José Vasquez).

José Vasquez presented the efforts WWF is leading in the region to raise awareness and persuade agricultural companies into the adoption of BMPs. He began by highlighting that agrochemicals (fertilizers and pesticides) are known for their effect on global reef health. In 2004 WWF conducted a preliminary monitoring analysis to identify the levels of toxic substances in marine organisms and identified the need to reduce the presence of particular 'priority' pesticides in the MAR. To accomplish this, and to control soil erosion, they have engaged in conversations with some of the major agricultural companies in the region, and are currently developing partnerships for the adoption of BMPs in banana, citrus, palm oil, pineapple and sugar cane crops. Based on the preliminary results presented by WRI and WCMC, WWF will select a pilot watershed to collect specific data to validate the models, and to pursue the implementation of BMPs.

In the afternoon participants broke into four national groups (Honduras, Belize, Mexico, and Guatemala) to review the modeling results by country Each group presented a summary of their observations and suggestions at the plenary session in the morning of August 16 (see summaries in the following section).

Data dissemination through the Mesostor portal (by Emil Cherrington)

During the morning policy session on August 16, the representative from the Water Center for the Humid Tropics of Latin America & the Caribbean (CATHALAC) presented briefly on how the ICRAN-MAR Project's data and information products will be disseminated through the USAID-supported Regional Visualization & Monitoring System (SERVIR) at: http://servir.nasa.cathalac.org or http://servir.nsstc.nasa.gov. Mr. Cherrignton mentioned that the MAR data will be added to the variety of public domain spatial datasets and satellite imagery already available through SERVIR for the Mesoamerican region. As such, long after project completion, researchers and decision-makers will continue to have access to the rich database developed by the ICRAN-MAR Project regarding land-based impacts on the Mesoamerican Reef

ecosystem. With regard to synergies between these two USAID-supported initiatives, SERVIR and the ICRAN-MAR Project have collaborated on data development, and SERVIR representatives provided technical support during the August 2006 Regional Watershed Modeling workshop in Belize.

During the discussion session, Dr. Barbara Best – Coastal Resources and Policy Advisor for the Office of Natural Resources Management with USAID, and Cognizant Technical Officer for the ICRAN-MAR Alliance – presented on opportunities for partnerships within the region and on a broader spatial scale. In particular she described the USAID Global Development Alliance, which works through public-private partnerships, and the Central America Free Trade Agreement (CAFTA), through which Central American countries could access financial support for follow-up activities in the region. She highlighted the emphasis these initiatives give to capacity building efforts, water issues, and tourism, and encouraged participants to communicate the results of this workshop's discussions to their governments and seek additional funding for capacity building. As another opportunity for capacity building Dr. Best recommended linking US Universities with local Universities.

SUMMARY OF BREAKOUT GROUP REVIEWS

BELIZE

1. The watershed boundaries look good, but must be re-drawn to reflect the 18 major watersheds of Belize. Small coastal watersheds must be merged with larger ones rather than leaving them out.

   Note: In response to this, Lauretta Burke mentioned that N-SPECT calculates using much larger watersheds, with the smaller coastal watersheds being merged, though she emphasized that these larger watersheds are incorrect because they reflect the combined catchments of multiple rivers that drain into the sea.
2. N-SPECT outputs need to be explored further / validated.
3. Land Use scenarios – the group would like to know more about how the scenario narratives were translated to IMAGE 2 outputs.
4. Numerous possible applications of project outputs exist (e.g. overall land use planning, reporting to UNFCCC).
5. The results are good and reveal worthwhile / critical investment of effort.

MEXICO

1. Model validation is necessary and accurate data is missing. Mexican colleagues encourage workshop participants to develop a campaign to collect field data to calibrate the models.
2. A legend should be added to the maps to clarify that the results are estimates. Mexican participants can contribute recent national data to jointly validate the models.
3. Some aspects of the N-SPECT and CLUE-S methodologies are not clear in particular with respect to concepts and variables. For example, it is not clear what were the criteria to reduce the LU/LC classes in the GEO scenarios.

4. Meteorological sporadic or extraordinary events should be incorporated into the N-SPECT model. Evaluate the possibility to run the model for different time periods (e.g., quarterly, monthly).
5. The Markets First and the Policy First scenarios showed similar results. Evaluate if a new or intermediate scenario can be created. The scenarios for a 25-year period don't show drastically different results.
6. The Yucatan Peninsula should be treated as a special case in the N-SPECT model since its underground water flow is difficult to estimate. The Mexican group estimated that the preliminary model results are not representative of the real flow dynamics and should be taken out of the maps (or highlighted as preliminary). Need to incorporate the results of the JICA study on underground water flow into N-SPECT (when it becomes available).
7. The N-SPECT model does not show "real" results for Yucatan and can lead decision makers to judge that the sediment and pollution flow to the MAR is not significant.
8. Keep in mind that the Yucatan peninsula does not suffer from what is normally termed as soil erosion. Instead, if suffers from dissolution of the bedrock due to soil characteristics.
9. Consider including higher resolution data for the Rivera Maya to pinpoint the effects of large coastal developments (e.g., Cancun, Playa del Carmen).
10. Consider the development of a special N-SPECT model only for the Yucatan Peninsula.

GUATEMALA

1. First impression of the work is very good, but there is the need to incorporate more detailed data and national datasets.
2. It is essential to calibrate the model and adjust its variables.
3. Results seem logical, but are they significant?
4. Recommendation to look at extreme events, not necessary a second Hurricane Mitch, but something more dramatic than the monthly and annual data that the models have used. Looking at rainfall events could be a good first step.
5. Recommendation to create maps that better illustrate the differences between the scenarios. This is not clear from the maps presented, though maps highlighting the differences are presented in the CLUE-S technical report on the training CD.
6. Further information is needed about the assumptions that were made and restrictions of the models/methodologies. Joep Luijten mentioned that for CLUE-S some information of this nature can be found in the technical report on the training CD.
7. It must be made clear that if two scenarios show the same percentage land cover for a particular land use type, there could still be significant differences in the spatial distribution of land use. Thus, just having a table that lists the percentages of area covered by each land use type is misleading.
8. Need to include socio-economic variables in the models. For example, if the area of forest decrease with 5%, what is the $ value of the change? How much do the changes affect tourism?
9. Largest differences on forest and cropping. Application is useful for sustainable forest management and integrated watershed management.

HONDURAS

1. The delineation of watersheds looks good but small coastal watersheds should be merged with larger adjacent ones so that the overall delineation better matches the country's official watersheds.
2. Would like to see a method to include dams in the model. At present there is a hydro-power dam in the Ulua watershed and the Honduras team will be interested in calculating the accumulation of sediment behind the dam. How could this variable (i.e. existence of dams) be incorporated into the model?
3. Results will help the team prioritize areas where reforestation programs and soil conservation programs could take place.
4. The results are valuable for decision-makers in both the private and public sector. This would be an excellent tool for the land-use planning that recently started in Honduras.
5. Work collaboratively at the regional level to promote the use of the same GIS technologies for better management of natural resources.
6. The datasets and products provided by ICRAN-MAR in the workshop are not final; instead they should be viewed as intermediate products that need to be refined at the national level to provide scientific information useful for decision-making.
7. The model should include socio-economic data that can be presented to decision makers.
8. Participants should reach a formal compromise whereby they agree to apply and improve the models provided in accordance with the local capacities and existing informational needs.
9. Need to work at higher resolutions: 90 or 30 meters. It should be noted that such small resolution are not practical when the models are applied to a country or the MAR region as a whole because the required simulation times would be far too long.

DISCUSSION AND RECOMMENDTATIONS

The policy session ended with a two-hour review, conducted by the whole group, on the ICRAN-MAR watershed component and the workshop results and follow-up activities; it centered on the need to inform policy makers in participating countries about the results of the ICRAN-MAR exercise, and on the need to provide follow-up support to agencies that decide to use the models and datasets produced by the watershed component of ICRAN-MAR.

A summary of the main issues raised during the review follows:

- **Results are useful for some specific purposes.** The MAR-drainage-wide watershed analysis was regarded as ambitious. Participants recognize the amount of effort that went into the analysis; appreciate the region-wide comparable results; but recommend that the results be shared with instructions about appropriate and inappropriate use. These are estimates of sediment and nutrient delivery from coastal watersheds given current land cover and given several scenarios of future land cover.
- **Scenario results are not that different:** Differences between the scenarios are not large; most participants had expected to see greater contrasts. This could be related to the relatively short time period (2000-25) or be because the scenarios

are too general and are unable to adequately reflect critical changes that appear on a local level or in the immediately coastal areas.

- **Model results need to be validated.** There is a need to better calibrate the models and validate model results. There is ongoing work with SeaWifs (with the University of Miami) and there are data from the WRISC project that can be used to evaluate the estimates for several watersheds. WRI asked participants to provide data for validation.
- **Information can influence policy.** A participant asked how ICRAN-MAR can use results to preserve forests. Lauretta Burke responded that having a good, integrated information infrastructure (to support sound spatial analysis) and having channels to decision-makers is key.
- **Local application of modeling tools will produce the most useful, detailed results.** Technology transfer and capacity building is an important part of the workshop. Participants will be able to use local data (as inputs and for validation), and therefore can do more detailed analysis and obtain more accurate results back in their agencies.
- **Results are not final:** The analysis results are not a final product. ICRAN-MAR needs to build capacity to use the models offered during the workshop within the region, so that people can use local information to refine results and validate the modeling.
- **Extreme Events.** The N-SPECT modeling focused on mean annual precipitation. Extreme events such as hurricanes and tropical storms are the major source of sediment. It would be valuable to model extreme events and the seasonality of discharge.
- **Clarification on N-SPECT Units.** The MBRS representative thought that the N-SPECT model outputs were “relative” and not in meaningful units. WRI’s experience is that N-SPECT output is in liters for discharge and kilograms for sediment and pollutants.
- **Basin Delineation style.** There was some discussion of the MAR basin delineation, focusing on the small coastal watersheds. Many participants would prefer to have these small watersheds lumped into the larger, adjacent basins. WRI cannot do such lumping, as it would be inconsistent with hydrologic flow within the DEM. However, N-SPECT uses an algorithm that does merge small adjacent watersheds. These results are provided on the data CD.
- **Yucatan.** WRI acknowledged that the basin delineation for the Yucatan is not very good due to underground rivers and few perennial surface rivers. The group from Mexico also pointed out this limitation, and mentioned that JICA is now working on estimating underground water flow. As policy-makers will dismiss the Yucatan results, they encouraged WRI to consider excluding the basins in the Yucatan from the results, or issue strong and appropriate disclaimers about the problems with the model in the Yucatan.
- **Scenario results.** The analysis of change in sediment between natural and current land cover is striking and clearly shows the extent of human impact. The results of the N-SPECT modeling for the three future land cover scenarios, however, do not look very different. This is because

a) the land cover scenario data sets are not so extremely different

b) the results are presented at the basin-level. WRI can explore presenting them at the sub-watershed level.

- **Management Practices.** Due to the lack of regional data on agricultural crops and the fact that the management practices module of the N-SPECT model is not yet implemented, WRI's analysis focuses on the impact of land cover change on sediment and pollutant delivery. It would be very valuable to include management practices in the model in the future.
- **Dams.** Some participants asked WRI to look into the possibility of incorporating dams into the N-SPECT model as a sediment trap. WRI will research the issue further.
- **Relevance of Results to Policy.** There was discussion of the difficulty of moving from analysis results to changes in policy. The inclusion of socio-economic values was encouraged.
- **Erosion monitoring.** WWF is monitoring soil erosion on citrus, palm oil and sugar cane plantations. This data would be very valuable if WRI could, under a future project or future project phase, attempt to include different crops and management practices in the hydrologic analysis.
- **Economic Valuation.** Several participants encouraged including economic variables in the results, such as the value of lost soil, lost agricultural productivity, and damage to coral reefs. The models are very technical and the simulation results are very scientific. It is essential to make this information more accessible to decision-makers by adding monetary values to some of the results.
- **National datasets:** Participants pointed out that for some countries (and for certain regions inside countries) there are newer or more detailed datasets that could be incorporated into future versions of the models.
- **Running models at a smaller scale.** The models should be run at higher resolutions (30 meter or 90 meter) when operated in the countries. The Mexican participants highlighted the need of more detailed models for coastal areas to analyze the impact of coastal development (e.g., new golf courses, hotels).
- **Land use demand for scenarios.** Participants expressed the desire for more details about the use of the International Futures and IMAGE models for calculating the future demand (i.e., area) for each land cover type and why we chose to use these models. As these models were not covered during the training, participants wanted to know whether they could deploy these models themselves to analyze different parameters (e.g. different population growth rates). What alternative methods are available for calculating land demand?
- **Explanatory factors (location factors).** Participants struggled with the concepts and practical application of the explanatory factors (location factors) that were used as part of the land use modeling methodology. This is arguably the most complicated part of the CLUE-S model development. Participants wanted to know whether they could include additional location factors.
- **Land Cover Validation.** Participants asked whether the land cover data had been validated by WCMC. No validation was undertaken. It should be noted that WCMC used well-known land cover data from reputable sources. The Ecosystem

Map datasets were created as part of a multi-year, multi-partner effort. Validation of these third-party datasets was not part of the project plan.

- **Follow-up activities**. Participants expressed their desire to be part of a group that helps move this work forward. A participant mentioned that existing national groups dealing with water issues or geospatial issues could lead this task.

TECHNICAL SESSION

The technical session was held at the GIS lab of Galen University on the afternoon of August 16 and on August 17 and 18. Twenty-two participants from Honduras, Guatemala, Belize, and Mexico attended (see the list of participants in Appendix 3).

The objective of the technical session was to provide hands-on training so that participants can carry out their own watershed analyses in the future. Training was provided in hydrologic modeling using ArcMAP GIS, the Nonpoint Source Polution and Erosion Comparison Tool (N-SPECT) and the CLUE-S models, and as well as guidance on datasets developed by the watershed component of the ICRAN-MAR project. These tools allow users to delineate watersheds; model runoff and sediment and pollution loads at river mouths across the region, and simulate land use changes under alternative scenarios. SERVIR Viz software was also distributed to participants by Emil Cherrington on behalf of the Mesoamerican Regional System for Visualization & Monitoring (SERVIR), hosted at CATHALAC, Panama.

During the first component of this session (afternoon of August 16) Lauretta Burke (WRI) explained and conducted an exercise on how to delineate watersheds using the SRTM 90-meter dataset and Spatial Analyst tools available in ArcMAP. A detailed explanation of how the MAR watersheds were delineated was offered. In addition, Lauretta guided an exercise on evaluating the vulnerability of land to erosion (on a grid cell basis).

On August 17 Zachary Sugg (WRI) led a training session on the use of the N-SPECT model for estimating river runoff and sediment and pollutant loads. Participants ran the model using different land use scenarios for several MAR watersheds. WRI gave each participant a CD containing the model software, the results of running N-SPECT for different land use scenarios for the MAR region, and the complete MAR watershed delineation, together with a wide array of white papers and background documents that provide in-depth information about the model.

On August 18 Joep Luijten (WCMC) gave training in land cover change modeling using the CLUE-S model. First he introduced the model and the different types of input parameters and the datasets that define different scenarios. Much of the day was spent in hands-on exercises. Initially a small sample dataset was used that allowed the participants to rapidly become familiar with the model's user-interface and analyze the effects of changes in selected model parameters. In the afternoon participants looked at some more advanced model features and worked with the complete dataset for Belize. Joep provided to participants a CD that contained the CLUE-S model software, the complete datasets for Belize, Mexico, Guatemala and Honduras, the MAR GEO scenario results (25 year period), and background materials.

An evaluation sheet presented to participants can be found in Appendix 4, and a summary of the results of the evaluation in Appendix 5.

Participants also filled out another questionnaire designed to help ICRAN-MAR evaluate what type of follow-up activities are useful and can be supported by the project. Most participants clearly identified a need for additional training/outreach in the MAR countries, in the short term, at two different levels:

- **LEVEL 1. Training/outreach seminars for managers and decision-makers**: Participants recommended the organization of seminars targeted at managers and decision makers on the basic functionality and the usefulness of the models, emphasizing how their results can be incorporated into decision-making. The models should be tested using local and national data - at high resolutions – in order to improve their results and facilitate their use in the national context.

- **LEVEL 2. Technical training for GIS and ICT specialists**: Responses to the questionnaire also clearly show that the countries could benefit from additional in-depth training in the models. Participants requested additional training that will reach a broader group of specialists on each country.

The following general recommendations were also offered by the technical group:

- Offer additional and more in-depth training on the CLUE-S and N-SPECT models that incorporates:
    - the use of national and local datasets,
    - detailed explanations of the parameters used,
    - a review of the methodologies used for the creation of the model input datasets.
- Increase efficiency of the training by offering train-the-trainers workshops, where national specialists learn the basic operation of the models and are able to conduct seminars geared towards decision-makers.
- Support remote technical assistance to participants who implement the models in order to support their use in real scenarios.
- Assist in the creation of a technical users' group whose core will be formed by workshop participants. The group can offer its members basic technical assistance and support on the use of the models provided in the workshop. ICRAN-MAR could support it with seed funding needed to start its operation.

WCMC and WRI will evaluate the feedback received from participants, will contact participants to ascertain their current needs, and will design and conduct follow-up activities to the extent possible with remaining ICRAN-MAR funds during the first semester of 2007.

The follow-up evaluation sheet presented to participants can be found in Appendix 6, and a summary of the results of the evaluation can be found in Appendix 7.

APPENDIX 1. Workshop Agenda

PART 1: POLICY WORKSHOP

Policy Workshop on Land-based threats to the Mesoamerican Reef (Duration: 1.5 days)

Goals:

1) Inform policy makers and other potential information users of the information outputs and tools that have been developed under this project.
2) Learn about the ICRAN MAR watershed project and the analytical components on land cover change analysis, watershed delineation, hydrologic modeling and circulation modeling.
3) Review scenarios of land cover change and provide feedback on these scenarios.
4) Review results of predictive modeling of land-based sources of pollution and sediment discharge to the Mesoamerican Reef
5) Raise awareness of the linkages between human activities on the land and threats to the Mesoamerican Reef.
6) Identify policy questions / applications for the analytic tools, as well as future users of the analytic tools.

Day 1 - Tuesday August 15 *(All-day Policy Workshop)*

Facilitator: *Eric Van Praag,*

08:30 Registration

09:00 National Anthem

09:03 Invocation. *Father Kevin Nederman at the Sacred Heart Parish*

09:05 Opening remarks, introduction to the ICRAN-Mesoamerican Reef Alliance (ICRAN-MAR Project). *Liza Agudelo, Project Coordinator*

09:10 Workshop goals, introductions of participants and organizers. *Eric Van Praag, UNEP-WCMC Consultant*

09:30 Key note presentation: Health of Corals and threats to the Mesoamerican Reef. *Dr. Melanie McField, Healthy Reefs Initiative.*

09:50 Key note presentation: "Conceptual evolution of watershed management in the Mesoamerican Region". *Dr. Carlos Rivas, Senior Advisor for Mesoamerica, Swedish International Development Cooperation Agency (SIDA).*

10:10 Overview of the Watershed Theme (Component) of the ICRAN-MAR project. *Lauretta Burke, World Resources Institute*

10:20 Coffee/Tea Break

10:40 Overview of scenario development. *Joep Luijten, UNEP-WCMC*

- Scenario studies with regional land use change modeling
- Adaptation of GEO-4 scenarios for the MAR region; storylines
- Discussion/feedback

11:20. Overview land use change modeling. *Joep Luijten, UNEP-WCMC*

- Quantification of change in land demand (IFS, IMAGE models)
- Modeling the allocation of land over time and space (CLUE-S model)
- Model results. Changes in land use distribution over time.
- Discussion/feedback

12:15 Lunch

13:15 Overview of Hydrologic and Circulation Modeling for the MAR. *Lauretta Burke, WRI*
- Watershed delineation
- Vulnerability analysis
- Hydrologic analysis using N-SPECT
- Circulation modeling
- Model calibration

14:00 Results of Hydrologic and Circulation Modeling. *Lauretta Burke, WRI*
- How much has sediment and nutrient delivery already increased due to human activities?
- Which coastal areas are most heavily impacted at present?
- How much is sediment and nutrient delivery likely to increase under future scenarios?

14:30 Review of results by participants
- Review of watersheds
- Review of sediment and nutrient delivery estimates
- Discussion

15:15 Coffee/Tea Break

15:40 Results from activities with Agribusiness for the adoption of Better Management Practices. *Jose Vasquez, WWF Honduras*

16:00 Group Discussion. Four country breakout groups to:
- review of land cover change scenarios and hydrologic model results;
- discussion of potential policy applications of the modeling tools;
- discussion of alternative pathways of development for region

17:30 Close for day

Day 2 - Wednesday August 16 *(Policy Session - morning only)*

09:00 Brief review of modeling results from previous day

09:15 Plenary:
Feedback from break groups (in open discussion format) on:
- utility and validity of the land cover scenario modeling;
- utility and validity of hydrologic / sediment transport modeling

10:00 Discussion
- policy applications of these tools
- alternative pathways for development in the region

10:30 Coffee/Tea Break

10:45 Introduction to the Data CD and data products

11:30. Closing Discussion

12:00 Lunch

PART 2: TECHNICAL WORKSHOP

Technical workshop on land cover change modeling and hydrologic modeling for different scenarios for the Mesoamerican Reef (Duration: 2.5 days)

Goals:

1) Learn how to delineate basins (watersheds) from digital elevation data

2) Learn how to use ArcMAP Spatial Analyst to identify land most vulnerable to erosion.
3) Learn how to use the Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) extension to evaluate the impact of land cover change on sediment and nutrient delivery to the coastal zone.
4) Understand how to perform a statistical analysis of explanatory factors of land use patterns, and the different data that must be collected and prepared.
5) Learn how to install and use the CLUE-S model for analyzing different scenarios of land cover change (for this data for a smaller area will be used)
6) Learn how the data collection, data preparation and the use of the model as it been done for the MAR region, country by country, and review results.

Day 2 (Wednesday August 16) *(Technical session - afternoon only)*

Overview and Watershed Delineation

13:30 Overview of Model Components \ Program and Workshop Goals.
a) Models and associated software
b) Order of analysis
14:00 Introduction to Data CD for MAR region
14:30 Watershed Delineation (using Spatial Analyst)
- Includes discussion of Sinks, flow direction and flow accumulation, "burning of rivers," delineation of basins, identification of pour points
- Prepare DEM for later use in N-SPECT delineation

15:30 Break

15.45 Spatial Analysis Erosion Vulnerability Analysis (using Spatial Analyst)
- Derive slope;
- use map calculator to combine grids to map relative vulnerability to erosion
- Summarize by watershed

17:30 Close for day

Day 3 - Thursday August 17 – Erosion and Pollution Modeling using N-SPECT

9:00 Introduction to N-SPECT
a. Overview of the N-SPECT modeling Tool
i. Capabilities / Functions
ii. RUSLE
iii. Where data and outputs live
iv. Processing time estimates
10:00 Watershed Delineation Using N-SPECT
b. Preparing the DEM
c. Options
d. Exercise on watershed delineation
11:00 Erosion and pollution analysis using N-SPECT
e. Data requirements
f. FACTORS
g. Options
h. Outputs

12:00 Lunch

13:00 Exercise on erosion modeling
14:00 Exercise on Local Effect modeling (RUSLE)

Break

15:00 Exercise on pollutant modeling
16:00 Discussion on implementation of other scenarios

17:00 Close

Day 4 (Friday 18th August) - Land cover change modeling and the CLUE-S model

09:00 Introduction to land use change modeling and the CLUE-S model
- Different types of land use change models
- History and applications of CLUE-S in the world
- CLUE-S model structure and key input files
- Separate regression analysis of driving factors in SPSS

10:00 Introduction to case study area (Sibuyan island, Philippines)

10:15 Break

10:30 Practical CLUE-S
- System requirements and installation. Demo *vs.* full version
- Exercise 1: Learning to know the user-interface and displaying results.
- Overview of input data files and model parameters files
- Exercise 2: Parameter files and simulating alternative scenarios

12:00 Lunch

13:00 Practical CLUE-S (continued)
- Regression equation parameters files and probability surfaces
- Land use conversion matrix and conversion sequences
- Creating land use requirement (demand) files
- Spatial policies and area restriction files
- Conversion elasticities and crop rotations
- Exercise 3: Creating new area restriction and land requirement files

14:30 Background on the MAR land use change scenario simulations, and CLUE-S data sets for Belize, Guatemala, Mexico and Honduras
- Separate data and simulation per country
- Calculation of the land demand for different scenarios
- Dynamic and static driving factors; protected areas data

14:45 Break

15:00 MAR simulations, continued
- Regression equations and probability surfaces
- Exercise 4: Working with actual scenario data for Belize

16:30 End

APPENDIX 2. Policy Session Participants

Name	Organization	Country	Email
Liza Agudelo	ICRAN-MAR	Belize	lagudelo@icran.org
Leonel Aquino	MARN	Guatemala	laquino@marn.gob.gt
Barbara Best	USAID	US	BBEST@USAID.GOV
Ed Boles	University of Belize	Belize	ubboles@yahoo.com
Lauretta Burke	WRI	US	LAURETTA@wri.org
Ramon Carcamo	Fisheries Department	Belize	ramalive@yahoo.com
Laura Carrillo	ECOSUR	Mexico	lc_oceanografa@yahoo.com.mx
Fernando Castro	CONAP Guatemala	Guatemala	fercastro@conap.gob.gt
Shalini Cawich	WWF	Belize	shalini@wwfca.org
Marion Cayetano	Galen University	Belize	mcayetano@galenu.edu.bz
Ivis Chan	Belize Audubon Society	Belize	research@belizeaudubon.org
Emil Cherrington	CATHALAC	Panama	Emil.cherrington@cathalac.org
Edgar Ek	Land Information Center	Belize	edgar_ek@yahoo.com
Ramon Frutos	Meteorological Department	Belize	rfrutos01@yahoo.com
Jose Herrero	USAID/MIRA – FUCSA	Honduras	jherrero@mirahonduras.org
Sergio Hoare	WCS	Belize	shoare@wcs.org
Joshua Lopez	Ministry of Natural Resources	Belize	jal20075@hotmail.com
Joep Luijten	UNEP-WCMC	UK	joepluijten@yahoo.com
Miguel Martínez Tuna	WWF-Central America	Guatemala	mmartinez@wwfca.org
Melanie McField	Healthy Reefs Initiative	Belize	mcfield@btl.net,mmcfield@wwfca.org
Jan Meerman	Belize Tropical Studies	Belize	meerman@biological-diversity.info
Nestor Meneses	USAID/MIRA	Honduras	nestor.meneses@gmail.com
Nelson Muñoz	SERNA	Honduras	nmunoz@serna.gob.hn
Efrain Novelo	US Embassy	Belize	NoveloER@state.gov

Name	Organization	Country	Email
Juan Manuel Núñez	Centro Geo	México	jnunez@centrogeo.org.mx
Gerardo Rios	CONANP	Mexico	grios@conanp.gob.mx
Carlos Rivas	SIDA	Honduras	carlos.rivas@sida.se
Julianne Robinson	TNC Belize	Belize	jrobinson@mail.usf.edu
Jose Rodriguez Rocha	INEGI	Mexico	jose.rodriguez@inegi.gob.mx
Victor Romero Benitez	INEGI	Mexico	manuel.romero@inegi.gob.mx
Antonio Salaverria	Unidad de Pesca	Guatemala	antoniosalaverria@gmail.com
Linda Searle	Seasports Belize	Belize	info@seasportsbelize.com
Zachary Sugg	WRI	US	zsugg@wri.org
Armeid Thompson	ICRAN-MAR	Belize	athompson@icran.org,chicarule@yahoo.com
Victor Valencia	Universidad del Valle	Guatemala	vhva1976@yahoo.es
Eric van Praag	UNEP-WCMC	Venezuela	evan@cantv.net
Jorge Enrique Vargas	MARN	Guatemala	enriquevargasm@marn.gov.gt
Jose Vasquez	WWF	Honduras	jvasquez@wwfca.org
Mary Vasquez	MBRS / SAM	Belize	queenconch@mbrs.org.bz
Mauricio Mejia	WWF	Belize	mmejia@wwfca.org
Ramadan Salazar	CONANP	Mexico	litbios16mm@hotmail.com
Roy E. Polonio	TIDE	Belize	banjahni@yahoo.com
Mauro Salazar	WWF	Guatemala	msalazar@wwfca.org
Candy Gonzalez	BELPO	Belize	belpobz@starband.net
Aldo Cansio (for Martin Alegria)	Department of Environment	Belize	envirodept@btl.net

APPENDIX 3. Technical Session Participants

Name	Organization	Country	Email
Barbara Best	USAID	US	BBEST@USAID.GOV
Ramon Carcamo	Fisheries Department	Belize	ramalive@yahoo.com
Laura Carrillo	ECOSUR	Mexico	lc_oceanografa@yahoo.com.mx
Marion Cayetano	Galen University	Belize	mcayetano@galenu.edu.bz
Ivis Chan	Belize Audubon Society	Belize	research@belizeaudubon.org
Emil Cherrington	CATHALAC	Panama	Emil.cherrington@cathalac.org
Ramon Frutos	Meteorological Department	Belize	rfrutos01@yahoo.com
Sergio Hoare	WCS	Belize	shoare@wcs.org
Joshua Lopez	Ministry of Natural Resources	Belize	jal20075@hotmail.com
Miguel Martínez Tuna	WWF-Central America	Guatemala	mmartinez@wwfca.org
Jan Meerman	Belize Tropical Studies	Belize	meerman@biological-diversity.info
Nestor Meneses	USAID/MIRA	Honduras	nestor.meneses@gmail.com
Juan Manuel Núñez	Centro Geo	México	jnunez@centrogeo.org.mx
Gerardo Rios	CONANP	Mexico	grios@conanp.gob.mx
Julianne Robinson	TNC Belize	Belize	jrobinson@mail.usf.edu
Victor Romero Benitez	INEGI	Mexico	manuel.romero@inegi.gob.mx
Antonio Salaverria	Unidad de Pesca	Guatemala	antoniosalaverria@gmail.com
Victor Valencia	Universidad del Valle	Guatemala	vhva1976@yahoo.es
Jorge Enrique Vargas	MARN	Guatemala	enriquevargasm@marn.gob.gt
Jose Vasquez	WWF	Honduras	jvasquez@wwfca.org
Mary Vasquez	MBRS / SAM	Belize	queenconch@mbrs.org.bz
Mauricio Mejia	WWF	Belize	mmejia@wwfca.org
Ramadan Salazar	CONANP	Mexico	litbios16mm@hotmail.com
Roy E. Polonio	TIDE	Belize	banjahni@yahoo.com
Aldo Cansino	Department of Environment	Belize	envirodept@btl.net

APPENDIX 4. Technical Session Evaluation Sheet

EVALUACIÓN DEL TALLER
Proyecto ICRAN-MAR

Taller sobre Manejo de Cuencas, Modelaje de Escenarios de Cambio en la Cobertura Terrestre y Modelaje de Descarga Hídrica de Sedimentos y Nutrientes

San Ignacio, Belice, 15 – 18 de Marzo de 2006

Agradecemos su tiempo para responder algunas preguntas que nos permitirán mejorar aspectos del curso y evaluar su impacto. Utilice la siguiente escala de valores para responder a las preguntas:
[1 = muy pobre, no adecuado, no útil, 5 = muy bueno, muy buena capacidad, muy útil]

1. El curso
Marque con un círculo el valor de su respuesta

¿Qué tan útil resultó el taller para Ud.?	1	2	3	4	5
¿Fueron valiosas las presentaciones de la Sección de Políticas?	1	2	3	4	5
Las sesiones teóricas fueron:	1	2	3	4	5
Las sesiones prácticas fueron:	1	2	3	4	5
El nivel de los instructores fue:	1	2	3	4	5
La calidad del entrenamiento fue:	1	2	3	4	5
¿Fue el curso compatible con sus intereses, conocimiento previo y responsabilidades laborales?:	1	2	3	4	5
¿Qué tan útil fue el entrenamiento en CLUE-S?	1	2	3	4	5
¿Qué tan útil fue el entrenamiento en N-SPECT?	1	2	3	4	5
¿Qué tan útil fue el componente sobre ArcMAP y herramientas hídricas?	1	2	3	4	5

2. Resultados del entrenamiento en N-SPECT
¿Ud. se siente capaz de?:

Realizar una delimitación de cuencas	1	2	3	4	5
Calcular escorrentía (runoff) y acumulación de sedimentos	1	2	3	4	5
Calcular acumulación de contaminantes	1	2	3	4	5
Calcular local effects (erosión local)	1	2	3	4	5
Utilizar sus propios datos en el modelo N-SPECT	1	2	3	4	5

3. Resultados del entrenamiento en CLUE-S
¿Ud. se siente capaz de?:

Entender los distintos datos y parámetros de entrada	1	2	3	4	5
Preparar los datos de entrada para CLUE-S	1	2	3	4	5
Visualizar los resultados de CLUE-S en un SIG	1	2	3	4	5
Preparar y comparar sus propios escenarios para CLUE-S (land demand, area restriction files)	1	2	3	4	5
Trabajar con los datos de su país contenidos en el CD	1	2	3	4	5
Calcular nuevos coeficientes de regresión utilizando software de estadísticas y el manual de CLUE-S	1	2	3	4	5

4. Desarrollo del curso
Evalúe el curso de acuerdo a los siguientes criterios

Habilidad de transmitir conocimiento de formar clara	1	2	3	4	5
Habilidad de generar interés en los temas	1	2	3	4	5
Capacidad de transmitir conocimiento sobre el modelo CLUE-S a otros especialistas	1	2	3	4	5
Capacidad de transmitir conocimiento sobre el modelo N-SPECT a otros especialistas	1	2	3	4	5

5. Recursos del curso
Ofrezca su opinión sobre los siguientes recursos

El salón de entrenamiento:	1	2	3	4	5
Los computadores:	1	2	3	4	5
El material audiovisual:	1	2	3	4	5
El material impreso:	1	2	3	4	5
El CD de entrenamiento:	1	2	3	4	5
La traducción simultánea (sesión de políticas)	1	2	3	4	5
La traducción en la sesión técnica	1	2	3	4	5

6. Agenda
Agradecemos sus comentarios sobre la agenda del curso. ¿Le pareció correcta? ¿Se cubrieron los temas con el tiempo adecuado? ¿Hay temas que se debieron dar mas a fondo o mas rápido? ¿Qué aspectos de la agenda se pueden mejorar?
(See summary of responses in Appendix 5)

7. Por favor especifique cómo los temas ofrecidos en el curso le apoyarán en su trabajo

(See summary of responses in Appendix 5)

8. ¿Piensa que usará estos modelos en el futuro? Por favor especifique su respuesta para CLUE-S y N-SPECT y el tipo de aplicaciones donde los usaría?

(See summary of responses in Appendix 5)

9. ¿Cómo visualiza que los resultados de los modelos serán presentados y explicados a tomadores de decisiones y autoridades? Favor explicar:

(See summary of responses in Appendix 5)

10. Comentarios generales:

(See summary of responses in Appendix 5)

APPENDIX 5. Summary of Technical Evaluation Results.

Question 6: Please provide comments on the workshop agenda: was it appropriate? Did it offer enough time to cover each topic correctly? Are there topics that should have been covered in more detail? Can the agenda be improved?

Summary of responses:

Responses suggested that it would be useful to:

- Provide more information on the development of the scenarios and on the generation of the model parameters.
- Have additional time (i.e., longer workshop) to cover some of the topics in more detail.
- Explain better where the models' input data came from and how it was developed.
- Provide more time to complete the exercises.
- Give more time to explain the CLUE-S model.
- Have the workshop in one language only or using instant translation. Too much time was lost due to the need to translate to Spanish.

Question 7: How will the training received help you in your work?

Summary of responses:

- It supports some agencies' mandate to monitor watersheds.
- It offers tools useful for decision-making.
- It is useful in evaluating the hydrological cycle and sedimentation patterns.
- It complements one agency's work, where satellite imagery is being used to model hydrological resources.
- It supports some agencies' need to identify and measure threats to turtle nesting and feeding sites.

Question 8: Are you likely to apply these models? Please refer to CLUE-S and N-SPECT specifically and explain how these models could be used by your agency.

Summary of responses:

- CLUE-S will be very useful for modelling vegetation cover in NPAs in Mexico.
- N-SPECT won't be useful for the Yucatan Peninsula, unless underground water flow is incorporated into the model.
- One respondee wishes to test both models in an area with great environmental degradation and to evaluate the results.
- The USAID MIRA project will use N-SPECT as part of its watershed project component.
- Some agencies will use the models to simulate the impact of major climatic events.
- N-SPECT will prove useful for the scientific community and general decision makers who need better information on sedimentation and pollution patterns.
- N-SPECT can be useful in estimating community health needs/status/trends in Southern Belize.
- The models will be most useful if national datasets can be incorporated and tested.
- Some agencies will compare N-SPECT results with existing model results.

- Some agencies commented that further training in the use of CLUE-S is needed since the model is so complex.
- CLUE-S will be useful for planning land use in the framework of UN conventions such as UNCCD and UNFCCC.
- The set of models is useful for explaining the connections between forest cover and the health of the sea.

Question 9: How can the model results be presented and explained to senior management and decision makers?

Summary of responses:

- ICRAN-MAR should train more specialists in the use of the models, who in turn will inform decision makers locally about the models' benefits.
- The countries should run the models using national and local datasets in order to generate a greater impact when presenting to decision makers.
- In presenting the results, we should emphasize the economic impact of misguided management decisions, both through greater pollution and sedimentation, and through impacts of land cover changes on the tourism sector.
- Special care should be taken in explaining the "relative nature" of the results, lest decision makers consider the model results as absolute value predictions.
- There is a need to prepare training material for different types of seminars geared at users with different needs.

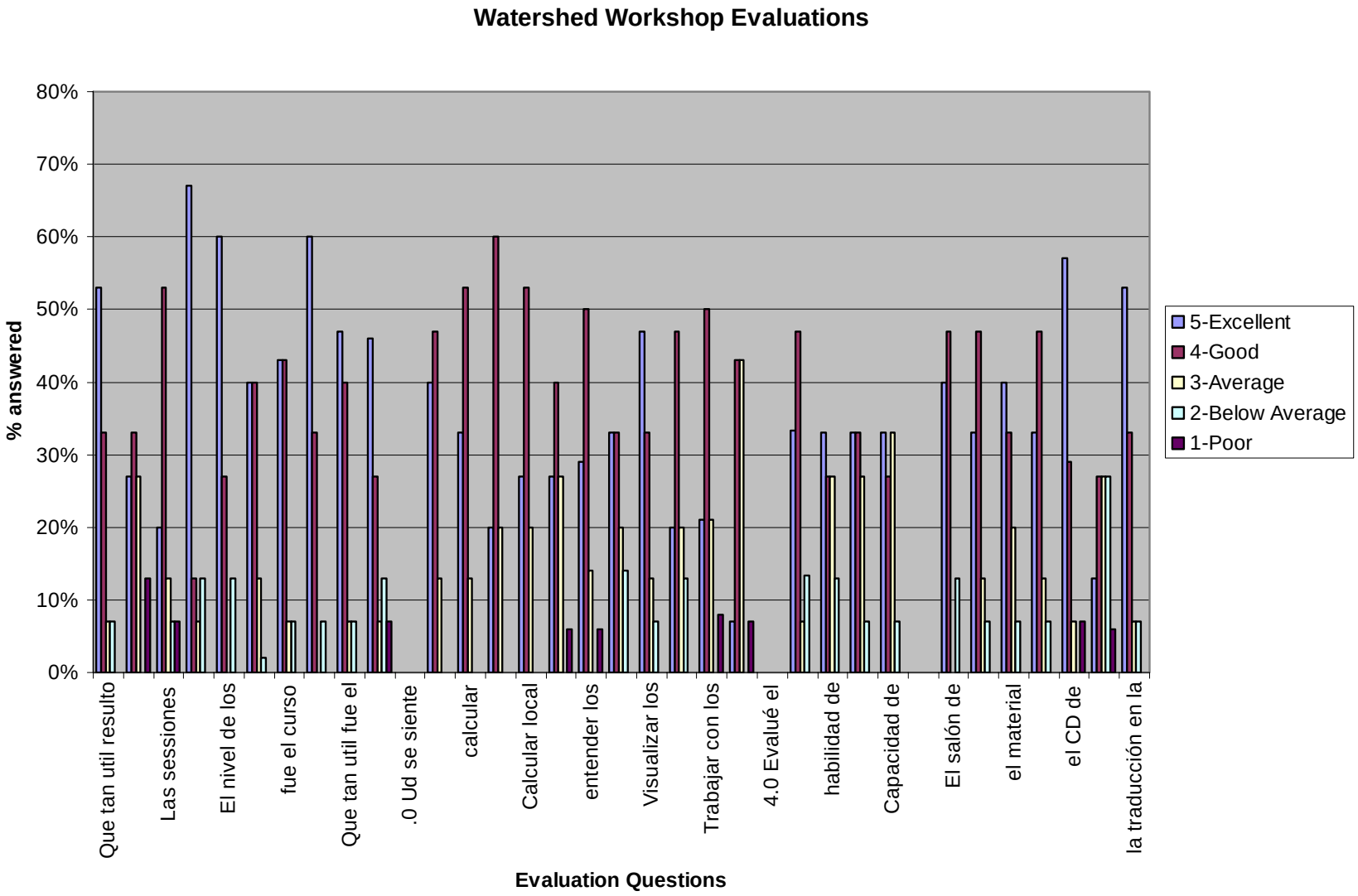
Question 10: General comments.

Summary of responses:

- Need to incorporate socio-economic variables in the models.
- Need to translate all the training and support material to Spanish.
- Need to conduct follow-up activities.
- Need to establish a MAR monitoring network that will allow for the calibration and improvement of the models and for comparing the different outputs and scenarios.

Many of the responses commented on how useful the workshop was and thanked the organizers for conducting it.

ICRAN MAR WATERSHED WORKSHOP EVALUATIONS					
	5-Excellent	4-Good	3-Average	2-Below Average	1-Poor
Que tan util resulto el taller para ud	53%	33%	7%	7%	
Fueron valiosas las presentaciones de la seccion de politicas	27%	33%	27%		13%
Las sessiones teoricas fueron	20%	53%	13%	7%	7%
Las sesiones practicas fueron	67%	13%	7%	13%	
El nivel de los instructores fue	60%	27%		13%	
La calidad del entrenamiento fue	40%	40%	13%	2%	
fue el curso compatible con sus intereses, conocimiento previo y responsabilidades laborales	43%	43%	7%	7%	
que tan útil fue el entrenamiento en CLUE-S	60%	33%		7%	
Que tan util fue el entrenamiento en N-SPECT	47%	40%	7%	7%	
que tan util fue el componente sobre Arc Map y herramientas hidricas	46%	27%	7%	13%	7%
.0 Ud se siente capaz de					
Realizar una delimitacion de cuencas	40%	47%	13%		
calcular escorrentía (runoff) y acumulación de sedimentos	33%	53%	13%		
calcular acumulación de contaminantes	20%	60%	20%		
Calcular local effects (erosion local):	27%	53%	20%		
Utilizar sus propios datos en el modelo N-SPECT	27%	40%	27%		6%
entender los distintos datos y parámetros de entrada	29%	50%	14%		6%
preparar los datos de entrada para CLUE-S	33%	33%	20%	14%	
Visualizar los resultados de CLUE-S en un SIG	47%	33%	13%	7%	
. Preparar y comprar sus propios escenarios para CLUE-S (land demand, area restriction files):	20%	47%	20%	13%	
Trabajar con los datos de su país contenidos en el CD	21%	50%	21%		8%
Calcular nuevos coeficientes de regresión utilizando software de estadísticas y el manula de CLUE-S	7%	43%	43%		7%
4.0 Evalué el curso de acuerdo a los siguientes criterios					
habilidad de transmitir conocimiento de formar clara	33.30%	47%	7%	13.30%	
habilidad de generar interese en los temas	33%	27%	27%	13%	
capacidad de transmitir conocimientos sobre el modelo CLUE-S a otros especialistas:	33%	33%	27%	7%	
Capacidad de transmitir conocimiento sobre el modelo N SPECT o otros especialistas	33%	27%	33%	7%	
0 Ofrezca su opinión sobre los siguientes recursos					
El salón de entrenamiento	40%	47%		13%	
los computadores	33%	47%	13%	7%	
el material audiovisual	40%	33%	20%	7%	
el material impreso	33%	47%	13%	7%	
el CD de entrenamiento	57%	29%	7%		7%
La traducción simultanea	13%	27%	27%	27%	6%
la traducción en la sesión técnica	53%	33%	7%	7%	


Watershed Workshop Evaluations
% answered
80%
70%
60%
50%
40%
30%
20%
10%
0%
Que tan util resulto
Las sessiones
El nivel de los
fue el curso
Que tan util fue el
.0 Ud se siente
calcular
Calcular local
entender los
Visualizar los
Trabajar con los
4.0 Evalué el
habilidad de
Capacidad de
El salón de
el material
el CD de
la traducción en la
Evaluation Questions
5-Excellent
4-Good
3-Average
2-Below Average
1-Poor

APPENDIX 6. Follow-up Technical Questionnaire

EVALUACIÓN DE OPORTUNIDADES PARA CAPACITACIÓN Y SEGUIMIENTO

Proyecto ICRAN-MAR

Taller sobre Manejo de Cuencas, Modelaje de Escenarios de Cambio en la Cobertura Terrestre y Modelaje de Descarga Hídrica de Sedimentos y Nutrientes
San Ignacio, Belice, 15 – 18 de Marzo de 2006

Nombre:

Institución:

Teléfono:

Email:

Agradecemos su tiempo para responder algunas preguntas que nos permitirán planificar potenciales actividades de capacitación posteriores al taller

1. **¿Qué tipo de entrenamiento adicional y complementario considera que se podría ofrecer a Ud. y su institución relacionado con los temas cubiertos en el taller?**

(See summary of responses in Appendix 7)

2. **Por favor indique que instituciones de su país considera que podrían beneficiarse de una capacitación similar a la ofrecida durante el taller actual (indique para cada una nombre de persona contacto y lista especialistas que deben asistir).**

(See summary of responses in Appendix 7)

3. **Por favor describa los beneficios que tendría una capacitación adicional para su institución y para otras instituciones de su país.**

(See summary of responses in Appendix 7)

4. **¿Qué temas ofrecidos durante el taller considera de mayor interés para su institución (u otras instituciones de su país) para una futura capacitación? Por favor describa.**

(See summary of responses in Appendix 7)

5. **¿Cuenta su institución con un laboratorio SIG adecuado para ofrecer capacitación similar a la ofrecida en el taller? En caso contrario, por favor indique si conoce de otra institución que podría ofrecer un laboratorio adecuado para el entrenamiento.**

(See summary of responses in Appendix 7)

6. **¿Qué entrenamiento adicional es requerido para garantizar que los resultados de los modelos apoyen acciones concretas?**

(See summary of responses in Appendix 7)

APPENDIX 7. Summary of Results Follow-Up Questionnaire.

The following table offers a summary of the responses to the following questions:

1. What additional training do you consider should be offered to your institution associated with the topics offered in the workshop?

and,

6. What additional training is required to guarantee that the results of the models support concrete actions?

Responses	From
In Mexico	
Support field data collection to improve the models	UNIPESCA
Organize a seminar for decision makers to explain the benefits of the models	UNIPESCA Centro GEO
Development of scenarios	CONANP
Better explain the use of certain parameters and details of the model not covered during the training	CONANP
Basic GIS training for non-specialists to allow them to benefit from the models	CONANP
More detailed training of the models using local datasets to develop parameters appropriate to the MAR region	ECOSUR INEGI
Training on the generation of the model input datasets	ECOSUR INEGI
In Honduras	
Training to develop better source data as input for models, such as precipitation grids or land cover maps.	USAID MIRA
In Belize	
Training to establish a methodology to validate N-SPECT using real data from selected MAR watersheds	Hydrology and Meteorology Service (HMS)
Assist to establish a national network that monitors erosion and sedimentation in river channels	Hydrology and Meteorology Service
Test the models incorporating local datasets. Ideally, have countries validate these datasets previously	TNC Belize
Guidelines to collect data for model calibration	TIDE Belize
Support the establishment of a regional network of specialists on the modeling tools	TIDE Belize
Obtain funding for additional follow-up support	TIDE Belize
Training in ArcGIS 9 and basic GIS data handling to improve the data input to the models	WCS Belize HMS
In Guatemala	
Economic valuation of the different model scenarios	Univ. Valle
Organize a seminar that shows how the results of the models can be used to solve real problems	Univ. Valle
Support policy formulation based on model results	MARN
Development of indicators to assist the testing of the models	MARN
Concept and context of general scenario development	MARN

Summary of responses to Question No 2: Please indicate which institutions in your country can benefit from training such as the one offered in this workshop.

- **Mexico**: Universities (related to agronomy and environment), disaster management unit of the government. CONANP, CONAFOR, Amigos de Sian Koan, CINVESTAN (Merida), PRONATURA, UQROO, EPOMEX, Instituto Nacional de Ecología, Comisión Nacional de Agua, CONABIO, SEMARNAT, INEGI, Secretaría de Marina.
- **Honduras**: Dirección de Recursos Hídricos, COHDEFOR.
- **Belize**: Private sector (e.g., fruit growers). SATTIM, YATCHE, TASTE, TIDE, Belize Agricultural Health Authority, Agricultural Department, Department of Oil and Mining, Belize University, Program for Belize.
- **Guatemala**: Instituto de Hidrología, Vulcanología y Meteorología (INSIVUMEH), Secretarìa General de Planificación (SEGEPLAN), Instituto de Estadística (INE), Instituto Geográfico Nacional, Ministerio de Agricultura (MAGA), Instituto Nacional de Bosques (INAB), Consejo Nacional de Areas Protegidas, Ministerio del Ambiente (MARN).

Summary of responses to Question No 3: Please describe the benefits of further training to your institution and other institutions in your country.

Mexico:

- Spread of results to a wider public.
- Change of attitude by decision-makers. Development of sensitivity to themes such as water management.
- Better GIS capacity for technicians and planners.
- New users will improve the model results and will help improve the input datasets.
- Development of legislation using scientific data.
- Centro GEO could consider training trainers on the models to spread these technologies in Mexico.

Belize:

- Better developmental planning.
- Identify areas with threat from runoff.
- Establishment of mitigation measures for natural disasters.

Guatemala:

- Stimulus to use new technologies and methodologies at the national level.

Summary of responses to question No. 4: What topics offered in the workshop do you consider more important for future training.

Mexico:

- Pollution.
- Deforestation.
- CLUE-S (4 responses) and IMAGINE (1 response).
- N-SPECT for watershed analysis (3 responses).

Honduras:

- N-SPECT.

Belize:

- CLUE-S (2 responses).
- Development of better land use policies.
- Water quality and monitoring of sedimentation.
- Development of scenarios

Guatemala:

- N-SPECT.

Summary of responses to Question No 5: Which institutions in your country have GIS labs where additional training could be offered?

Mexico: Consejo Nacional de Áreas Protegidas, MAGA. Ministerio de Agricultura, ECOSUR, INEGI, Centro GEO.

Honduras: Zamorano.

Belize: TNC Belize, Land Information Center.

Guatemala: Universidad del Valle.

APPENDIX 8. Useful Links

Introduction and Key Note Presentations:

- http://www.icranmar.org
- http://www.healthyreefs.org/

Land Cover Modeling and Scenarios:

- http://www.ifsmodel.org/
- http://www.mnp.nl/image/
- http://www.cluemodel.nl/
- http://www.unep.org/geo
- http://www.scenariosforsustainability.org

Hydrologic – Circulation Modeling:

- http://reefsatrisk.wri.org

GIS data dissemination links

- Biodiversity and Environmental Resource Data System of Belize: http://www.biodiversity.bz
- Belize Clearing House Mechanism: http://www.chm.org.bz
- The Mesoamerican Regional System for Visualization & Monitoring - SERVIR: http://servir.nsstc.nasa.gov
- N-SPECT page: http://www.csc.noaa.gov/crs/cwq/nspect.html

Watershed modelling discussion group

- http://groups.google.com/group/mar-watersheds

Alianza para el Arrecife Mesoamericano - ICRAN-MAR

Taller Sobre el Manejo de Cuencas, Análisis del Cambio de Cobertura Terrestre y Modelamiento de la Contaminación Proveniente de Actividades en Tierra y de la Descarga de Sedimentos al MAR

Memorias

Universidad de Galen

SAN IGNACIO, BELICE, 15-18 de AGOSTO, 2006

Eric van Praag, Consultor para UNEP-WCMC
Joep Luijten, Consultor para UNEP-WCMC
Lauretta Burke, WRI
Liza Agudelo, ICRAN-MAR

Septiembre, 2006

Lista de Acrónimos

BMP	Better Management Practices (*Mejores Prácticas de Manejo*)
CATHALAC	Centro del Agua del Trópico Húmedo para América Latina y el Caribe
CLUE-S	The Conversion of Land Use and its Effects (*Conversión del Uso del Suelo y sus Efectos*)
CMNUCC	Convención Marco de las Naciones Unidas sobre el Cambio Climático
DEM	Digital Elevation Model (*Modelo de Elevación Digital*)
IABIN	Inter-American Biodiversity Information Network (*Red Interamericana de Información sobre Biodiversidad*)
ICRAN-MAR	Mesoamerican Reef Alliance (*Alianza para el Arrecife Mesoamericano*)
INEGI	Instituto Nacional de Estadística, Geografía e Informática, México
JICA	Japan International Cooperation Agency (*Agencia Japonesa de Cooperación Internacion*al)
LAC	Latin America y el Caribe
MAR	Mesoamerican Reef (*Arrecife Mesoamericano*)
MBRS	Mesoamerican Barrier Reef System (*Sistema Arrecifal Mesoamericano*)
N-SPECT	Nonpoint Source Polution and Erosion Comparison Tool (*Herramienta de comparación de contaminación sin punto de origen y erosión*)
PMM	Prácticas de Manejo Mejores
PNUMA	Programa de las Naciones Unidas para el Medio Ambiente
SeaWifs	Sea-viewing Wide Field-of-view Sensor (SeaWiFS)
SERVIR	Sistema Regional de Monitoreo y Visualización para Mesoamérica
SIDA	Swedish International Development Cooperation Agency (*Agencia Sueca de cooperación para el desarrollo internacional*)
SIG	Sistema de Información Geográfica
SRTM	Shuttle Radar Topography Mission (*Misión topográfica de Radar Shuttle*)
UNEP	PNUMA en inglés
UNEP-WCMC	UNEP World Conservation Monitoring Centre (*Centro Mundial de Vigilancia de la Conservación del PNUMA*)
UNF	United Nations Foundation (*Fundación Naciones Unidas*)
USAID	U.S. Agency for International Development (*Agencia de los Estados Unidos para el Desarrollo Internacional*)
US/CT	Uso del Suelo/ Cobertura terrestre
USGS	U.S. Geological Survey
WRI	World Resources Institute (*Instituto de los Recursos Globales*)
WWF	World Wildlife Fund (*Fondo Mundial para la Naturaleza*)
WRIScS	Watershed-Reef Interconectivity Scientific Study (*Estudio Científico sobre la interconectividad Cuenca-Arrecife*)

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INTRODUCCIÓN

ICRAN -Alianza para el Arrecife Mesoamericano (ICRAN-MAR)

La Red de Acción Internacional de Arrecifes de Coral (ICRAN), fue establecida en el año 2000 como una sociedad, innovadora y dinámica, de varias organizaciones líderes en la ciencia y conservación de los arrecifes de coral. La red es un esfuerzo colaborativo que opera a diferentes niveles con el fin de contribuir a detener y retroceder el deterioro de la salud de los arrecifes de coral alrededor del mundo. Los socios de ICRAN crean alianzas, alrededor del mundo, para facilitar acciones interrelacionadas y complementarias en el monitoreo y manejo de los arrecifes, a escalas local, nacional y global.

En el caso de ICRAN-Alianza para el Arrecife Mesoamericano (ICRAN-MAR), varios socios se han unido en una iniciativa de tres años, para apoyar esfuerzos regionales en respuesta a la Declaración de Tulum, de 1997, para la conservación del Arrecife Mesoamericano de Barrera (México, Belice, Guatemala, Honduras). Con la amable contribución de Agencia de los Estados Unidos para el Desarrollo Internacional (USAID), y la Fundación de las Naciones Unidas (UNF) y bajo la supervisión general del Programa de las Naciones Unidas para el Medio Ambiente, la Alianza ICRAN-MAR busca desarrollar y facilitar herramientas innovadoras que promuevan la adopción voluntaria de practicas de manejo mejores en las áreas de administración turística, pesquera y manejo de cuencas. Por tanto, el proyecto ofrece un enfoque holístico que reconoce la fuerte relación entre estos tres componentes y su impacto potencial en la salud del arrecife mesoamericano y, promueve y busca la cooperación de otras instituciones e iniciativas en la región.

El componente de Manejo de Cuencas del proyecto ICRAN-MAR fue diseñado reconociendo que las prácticas adecuadas de uso de la tierra son críticas para el manejo apropiado de las cuencas en la región Mesoamericana, y para asegurar que el transporte de sedimentos, nutrientes y otros contaminantes hacia los sistemas arrecifales sea minimizado. El desarrollo de estrategias adecuadas de uso del suelo requiere reunir información sobre el impacto potencial de los diferentes usos del suelo y opciones de desarrollo en la región, así como crear conciencia y coordinación con los diferentes actores involucrados.

Los socios de ICRAN-MAR en el componente de Manejo de Cuencas contribuyen con estos esfuerzos regionales formando alianzas con el sector privado, para reducir el impacto de las actividades agrícolas sobre el arrecife, y desarrollando herramientas innovadoras de Sistemas de Información Geográficas que puedan ser utilizadas para simular las dinámicas de las cuencas e informar a los tomadores de decisión en la región Mesoamericana.

Con respecto a las herramientas de SIG, el trabajo del proyecto de ICRAN-MAR es complementario al trabajo de otras iniciativas regionales, como el Proyecto MBRS, SERVIR y el Proyecto IABIN-DGF. Es también el primero en impulsar un análisis a escala regional y un modelamiento espacial de los impactos ambientales de las cuencas sobre el Arrecife Mesoamericano. Este trabajo también se apoya en la Iniciativa *Arrecifes del Caribe en Peligro* liderada por el World Resources Institute.

Estas memorias resumen las dinámicas y productos de un exitoso taller realizado en San Ignacio, Belice, en agosto del 2006, donde los socios del proyecto presentaron los resultados de dos años de implementación del proyecto y pidieron retroalimentación a los expertos regionales.

Taller sobre Manejo de Cuencas

La reunión tenía dos objetivos primordiales: informar a los participantes regionales sobre los resultados del ejercicio de modelamiento de uso del suelo y las conclusiones preliminares para la región, y, entrenar técnicos regionales, expertos en SIG, que a su vez podrían convertirse en capacitadores de otros expertos en sus respectivos países.
.
El taller se dividió en dos sesiones: una Sesión sobre Política y una Sesión Técnica. La sesión sobre política estaba dirigida a los rangos superiores y tomadores de decisiones de las instituciones participantes de los cuatro países. El objetivo principal era ayudarles a entender la utilidad y aplicabilidad de los datos producidos y modelos desarrollados por ICRAN-MAR para el manejo de cuencas. Esta sesión duró un día y medio y se llevó a cabo el 15 de agosto y la mañana del 16 de agosto.

El objetivo de la sesión técnica era facilitar que los especialistas de los países participantes se familiarizaran y recibieran capacitación práctica en el uso de los datos producidos y de los modelos mencionados anteriormente. Esta sesión duró dos días y medio y se llevó a cabo en la tarde del 16 de agosto y durante el 17 y 18 de agosto.

Ambas sesiones fueron una gran oportunidad para los especialistas nacionales de adquirir conocimiento tecnológico nuevo, coordinar actividades, planificar sus esfuerzos en modelamiento, intercambiar experiencias con colegas de otros países y obtener información geo-espacial desarrollada y/o recopilada por el ICRAN-MAR.

Las siguientes secciones presentan un resumen de los contenidos, resultados, discusiones y resoluciones alcanzadas durante el curso de las dos sesiones del taller.

SESIÓN DE POLITICA

La sesión de política se realizó durante el día 15 de agosto y la mañana del 16 de agosto del 2003 en la Universidad de Galen, en San Ignacio, Belice (ver agenda del taller en el Apéndice 1).

Oficiales de cargos superiores y especialistas de las instituciones nacionales y regionales que trabajan en asuntos costeros y marinos asistieron a la reunión (ver lista de participantes a la sesión de política en el Apéndice 2).

Los objetivos de la sesión de política eran los siguientes:

1) Informar a los encargados del desarrollo de políticas y a otros usuarios potenciales de la información, sobre los productos y herramientas que han sido desarrollados durante este proyecto.

2) Aprender sobre el proyecto de manejo de cuencas del ICRAN-MAR y sobre los componentes analíticos en el análisis del cambio cobertura terrestre, delineación de cuencas, modelamiento hidrológico y modelamiento de circulación.

3) Revisar los escenarios de cambio de cobertura terrestre y proporcionar

retroalimentación sobre estos escenarios

4) Revisar los resultados del modelo de predicción de las fuentes de contaminación en tierra y descarga de sedimentos al arrecife Mesoamericano.
5) Crear conciencia sobre los vínculos entre actividades humanas en tierra y las amenazas al Arrecife Mesoamericano
6) Identificar preguntas/aplicaciones de las políticas en las herramientas analíticas, así como a futuros usuarios de las herramientas analíticas.

En la mañana del 15 de agosto se presentó una introducción del proyecto ICRAN-MAR y del papel de sus socios en el componente de cuencas, además de las siguientes presentaciones introductorias claves:

Salud de los Corales y Amenazas al Arrecife Mesoamericano (por Melanie Mc Field)

La Dra. McField realizó una presentación detallada sobre las amenazas más críticas (dragados, turismo, sobrepesca-acuacultura, mal manejo de puertos y navíos, cambio climático y desastres naturales) al Arrecife Mesoamericano (MAR). Discutió el concepto de arrecife "saludable" y los diferentes atributos de los arrecifes (estructura y función) y dimensiones humanas (propulsores de cambio, bienestar social, y gobernabilidad) que deben ser considerados cuando se define el nivel de disturbio (i.e. salud). En definitiva, necesitamos hacer uso de los recursos del arrecife y necesitamos identificar las mejores formas de hacerlo.

Evolución conceptual del manejo de cuencas en la Región Mesoamericana (por Carlos Rivas)

El Dr. Rivas presentó la evolución de los esfuerzos del manejo de cuencas en la región durante los últimos 20-30 años. Empezó introduciendo las características topográficas de la región y los propulsores socioeconómicos que han definido los modelos de desarrollo regional y los usos agrícolas tradicionales del suelo. La economía extractiva, la pobreza y la expansión de las fronteras urbana y agrícola han ocasionado cambios en el paisaje y en las dinámicas de las cuencas durante las últimas décadas. La necesidad de controlar las inundaciones y de garantizar la provisión del recurso agua para cubrir las crecientes necesidades de la población y la industria, llevaron a la pronta adopción de modelos de manejo de cuencas importados de países desarrollados, a la región. Con el tiempo, ha habido un cambio de visión moviéndose de razones Antropocéntricas ("racional/económico") a razones más biocéntricas ("sostenible") cuando se desarrollan estrategias para el manejo de cuencas.. Con este cambio en la mentalidad, el componente social se incluye y se impulsa el manejo participativo; sin embargo, no siempre, las estrategias son atractivas económicamente y muy a menudo surgen conflictos. Hay una necesidad generalizada de mayor apoyo del gobierno y de desarrollar políticas coherentes para el uso sostenible del recurso agua.

Después de las presentaciones clave, Joep Luijten (UNEP-WCMC) y Lauretta Burke (WRI) ofrecieron un resumen sobre las diferentes metodologías y los resultados en cambio del uso del suelo y modelamiento hidrológico[1], respectivamente.

[1] Por favor referirse al CD de datos del taller para obtener documentación detallada en el desarrollo de escenarios, modelamiento del cambio de uso del suelo y modelamiento hidrológico y de circulación.

Inmediatamente después, José Vásquez (WWF) presentó los resultados del trabajo en campo con las compañas agrícolas para la adopción de mejores prácticas agrícolas.

Generalidades sobre el desarrollo de escenarios (por Joep Luijten)

Joep Luijten inició su presentación explicando el concepto y la naturaleza descriptiva de los escenarios y, sobre como pueden ser utilizados para informar sobre políticas. Los escenarios no son predicciones del futuro, mas bien presentan "diferentes supuestos relacionados a como las tendencias actuales se desarrollarán, sobre el papel que jugarán incertidumbres críticas y que otros factores nuevos entraran en el juego" (UNEP, 2002). Los 3 escenarios desarrollados para este proyecto fueron adaptados de los escenarios del *Global Environmental Outlook 4* para Latinoamérica y el Caribe (LAC) que será publicado en el 2007. Estos escenarios observan la situación actual de los recursos naturales en la región y las posibles situaciones para el 2025 según tres estados hipotéticos del mundo (Primero mercados, Primero política, Primero Sostenibilidad). Estos escenarios tendrían diferentes impactos en las dimensiones socioeconómicas y natural de la región y podrían servir para influir sobre los tomadores de decisión.

Generalidades sobre el modelamiento del cambio del uso del suelo (por Joep Luijten)

Una vez desarrollados los escenarios descriptivos, se aplicó un enfoque de modelamiento multiescala para cuantificar los cambios potenciales en la cobertura terrestre en MAR. Se utilizaron tres modelos (Futuros Internacionales, IMAGE, y CLUE-S) para explicar las dinámicas de las diferentes variables involucradas en los procesos de cambio de cobertura terrestre. Así pues, el modelo de *Futuros Internacionales* examina la proporción de cambio regional que ocurre en cada país y proporciona propulsores socio-económicos al modelo *IMAGE*. *IMAGE* a su vez, es un modelo de evaluación global integral que permite determinar la tasa de cambio en la región y la proporción de cambio que ocurre con cada categoría de uso del suelo. *CLUE-S* es el modelo de cambio en uso del suelo (asignación) y suma una dimensión espacial que permite determinar donde ocurre el cambio de cobertura del suelo dentro de la región MAR.

Para la cuantificación de los cambios en la demanda de tierra para cada escenario y modelamiento, se utilizó el año 2000 como año base porque en ese año se produjeron los datos de cobertura del suelo más recientes y accesibles.

Generalidades sobre el Modelamiento Hidrológico y de Circulación en el MAR (por

Lauretta Burke inició su presentación resaltando que el propósito de este ejercicio analítico de modelamiento de ICRAN-MAR era modelar los impactos, presentes y futuros, del cambio de la cobertura terrestre y de las actividades agrícolas en los arrecifes de coral e identificar los suelos más vulnerables a erosión. Los productos de los ejercicios de modelamiento podrían a la postre guiar en el manejo de zonas vulnerables en la región. Asimismo, el proyecto debería identificar herramientas y una metodología que pudiesen ser fácilmente transferidas a analistas y administradores territoriales de la región MAR, para una aplicación local más detallada.

El primer paso en este ejercicio era delinear la Cuenca (hoya hidrográfica) para la región. Las cuencas se delinearon con datos de NASA SRTM con resolución de 90m y se identificaron 300 cuencas (de 5 km^2 de tamaño mínimo) a lo largo de MAR. Este ejercicio tomó varios meses y fue particularmente difícil en la península de Yucatán debido a las características geológicas del terreno y a la presencia de ríos subterráneos. Ella invitó a los participantes a contribuir para mejorar la precisión de la delineación.

El paso siguiente fue correr la "Herramienta de comparación de la contaminación sin punto de origen y de la erosión" ("*Nonpoint-Source Pollution & Erosion Comparison Tool*") (N-SPECT) para evaluar la descarga de sedimento y contaminantes en las aguas costeras. El N-SPECT, desarrollado por NOAA, es del dominio público y es fácil de ejecutar en ArcMap. N-SPECT proporciona estimaciones de erosión a lo largo del paisaje así como de descarga y concentración de sedimentos y contaminantes (N y P) en las desembocaduras de los ríos.

Usando los escenarios de cobertura terrestre de CLUE-S acoplados con el modelo hidrológico de NSPECT, se pueden estimar las descargas de sedimentos y contaminantes en 300 desembocaduras de ríos. La Universidad de Miami está implementando un modelo de alta resolución de 4 dimensiones para examinar el transporte de sedimentos y contaminantes en el sistema lagunar de la región. Las predicciones de transporte de sedimentos y nutrientes serán calibradas usando el sensor SeaWifs.

Lauretta comentó que los resultados hidrológicos deben ser calibrados (y validados) usando datos de varias fuentes. Colaboradores del proyecto, de la Universidad A&M de Texas, están tomando muestras de sedimento; WWF está tomando muestras de sedimento y observando la bioacumulación de tóxicos en organismos arrecifales. Las evaluaciones del arrecife de AGRRA se utilizarán para examinar la ubicación de los impactos de los sedimentos en los arrecifes de coral. Lauretta también discutió las limitaciones del análisis e invitó a los participantes del taller a hacer recomendaciones sobre datos para calibrar el modelo.

Resultados del Modelamiento Hidrológico y de Circulación (por Lauretta Burke)

Manteniendo todos los componentes iguales, menos la cobertura del suelo, el WRI produjo estimaciones de escorrentías acumuladas (para el momento actual y los escenarios futuros), así como acumulación y concentración de sedimento, nitrógeno, fósforo y sólidos suspendidos totales. Se practicaron ejecuciones anuales del modelo para la cobertura de la tierra actual, la cobertura natural hipotética, y para los tres escenarios de 2025 en la región MAR. El análisis de los resultados permitió identificar las áreas que presentan mayor descarga de sedimentos y nutrientes, y en que medida ha aumentado la descarga de sedimentos y nutrientes por las actividades humanas. También fue posible ver la influencia que podría tener, la cobertura de tierra en un futuro, en la descarga de sedimentos y nutrientes; así como las áreas que son más vulnerables a erosión, y que partes del MAR son afectados por sedimentos y nutrientes. Se presentaron mapas y tablas resumen, luego se discutió con los participantes al taller.

Actividades con compañías agrícolas para la adopción de Mejores Prácticas de Manejo (por José Vásquez).

José Vásquez presentó los esfuerzos que WWF está liderando en la región para crear conciencia y persuadir a las compañías agrícolas a adoptar Mejores Prácticas de Manejo (BMP). Empezó resaltando que los agroquímicos (fertilizantes y pesticidas) son conocidos por sus efectos en la salud global de los corales. En 2004 WWF realizó un análisis de monitoreo preliminar para identificar los niveles de substancias tóxicas en organismos marinos e identificó la necesidad de reducir la presencia de pesticidas prioritarios en MAR. Para lograr esto, y para controlar la erosión del suelo, han establecido conversaciones con algunas de las mayores compañías agrícolas de la región, y actualmente están desarrollando sociedades para la adopción de PMM en cultivos de banano, cítricos, aceite de palma, pina y cana de azúcar. Con base en los resultados premilitares presentados por el WRI y WCMC, WWF seleccionará una cuenca piloto para colectar datos específicos para validar los modelos, y para lograr la implementación de BMP.

En la tarde los participantes se dividieron en cuatro grupos nacionales (Honduras, Belice, México y Guatemala) para revisar los resultados de la modelación por país. Cada grupo presentó un resumen de sus observaciones y sugerencias durante la sesión plenaria en la mañana de agosto 16 (ver resúmenes en la siguiente sección).

Diseminación de datos a través del portal Mesostor (por Emil Cherrington)

Durante la sesión de política de la mañana de agosto 16, el oficial representante del Centro del Agua del Trópico Húmedo para América Latina y el Caribe (CATHALAC), presentó brevemente sobre la forma como los datos y resultados de información del proyecto ICRAN-MAR serán diseminados a través del Sistema Regional de Visualización y Monitoreo para Mesoamérica (SERVIR) apoyado por USAID (http://servir.nasa.cathalac.org, o, http://servir.nsstc.nasa.gov). El señor Cherrington mencionó que los datos del ICRAN-MAR serán adicionados a la variedad de datos espaciales e imágenes satélite para la región del MAR que ya están disponibles a través de SERVIR y que son de dominio público. De esta manera, aún después de la terminación del proyecto, investigadores y tomadores de decisiones seguirán teniendo acceso a esta rica base de datos sobre impactos del uso del suelo en el ecosistema del MAR, desarrollada por el ICRAN-MAR. Con relación a las sinergias entre estas dos iniciativas apoyadas por USAID, SERVIR y el proyecto ICRAN-MAR han colaborado en el desarrollo de datos para esta iniciativa; adicionalmente, representantes de SERVIR facilitaron apoyo técnico durante el taller de Modelamiento de Cuencas en Agosto.

Durante la sesión de discusión, la Doctora Bárbara Best, Consejera de Política y Recursos Costeros para la Oficina de Manejo de Recursos Naturales de USAID, y Oficial Técnico para la alianza ICRAN-MAR, comentó sobre las oportunidades de alianzas en la región y a escala global. En particular hizo mención a la Alianza de Desarrollo Global de USAID, la cual funciona a través de alianzas públicas y privadas, y al Tratado de Libre Comercio entre Centroamérica y Estados Unidos (CAFTA), a través del cual los países Centroamericanos podrían tener acceso a ayudas financieras para actividades de seguimiento en la región. Resaltó el énfasis que estas iniciativas dan a los esfuerzos de desarrollo de capacidades, de manejo de agua y turismo, e invitó a los participantes a que comuniquen los resultados de las discusiones de este taller a sus gobiernos y busquen fondos adicionales para fortalecer capacidades. Como otra

oportunidad para crear capacidades, la doctora Best recomendó vincular a las universidades de los Estados Unidos con las universidades locales.

RESUMEN DE LA REVISIÓN POR GRUPOS

BELICE

1. Los límites de las cuencas se ven bien, pero deben ser re-dibujadas para reflejar las 18 cuencas principales en Belice. Las cuencas costeras pequeñas deben ser unidas con las más grandes en lugar de dejarlas por fuera.

   Nota: En respuesta a esto, Lauretta Burke mencionó que N-SPECT calcula cuencas mucho más grandes con la unión de las pequeñas cuencas costeras, aunque ella enfatiza que estas cuencas mayores son, de hecho, incorrectas por el reflejo combinado de captación de múltiples ríos drenando al mar.
2. Los productos de N-SPECT deben ser más explorados/validados.
3. Escenarios de uso del suelo - Al grupo le gustaría saber más sobre como las narraciones de los escenarios se tradujeron a productos IMAGE 2.
4. Las aplicaciones posibles de los productos del proyecto son numerosas (e.g. planificación general del uso del suelo, reportes a CMNUCC).
5. Los resultados son buenos y revelan una inversión de esfuerzo merecida/ critica.

MÉXICO

1. Es necesario validar el modelo y faltan datos precisos. Los colegas mexicanos animaron a los participantes del taller a desarrollar una campaña para recoger datos en campo para calibrar los modelos.
2. Se le debería agregar una leyenda a los mapas para clarificar que los resultados son estimaciones. Los participantes mexicanos pueden contribuir con datos nacionales recientes para validar los modelos conjuntamente
3. Algunos aspectos de las metodologías de N-SPECT y CLUE-S no están muy claros, en particular con respecto a los conceptos y las variables. Por ejemplo, no es claro cual fue el criterio para reducir las categorías de US/CT en los escenarios GEO.
4. Los eventos meteorológicos esporádicos o extraordinarios deberían ser incorporados al modelo N-SPECT. Evaluar la posibilidad de ejecutar el modelo para diferentes periodos de tiempo (e.g. trimestralmente, mensualmente)
5. Los escenarios Primero Mercados y Primero Políticas arrojan resultados similares. Evaluar si un escenario nuevo o intermedio puede ser creado. Los escenarios para el periodo 25 años no muestran resultados drásticamente diferentes.
6. La Península de Yucatán debería ser considerada como un caso especial en el modelo N-SPECT ya que el flujo de aguas subterráneas es muy difícil de estimar. El grupo mexicano estimó que los resultados preliminares del modelo no son representativos de las dinámicas de flujo reales y deberían ser eliminados del mapa (o resaltados como preliminares). Se deben incorporar los resultados del estudio JICA, sobre flujo de aguas, subterráneas en el N-SPECT (cuando éste sea accesible)

7. El modelo N-SPECT no muestra resultados “reales” para Yucatán y puede llevar a los tomadores de decisión a interpretar que los flujos de sedimento y contaminación al MAR no son considerables.
8. Tener en cuenta que la Península de Yucatán no sufre de lo que se conoce comúnmente como erosión del suelo. En cambio, sufre de disolución del manto rocoso debido a las características del suelo.
9. Considerar incluir datos con mayor resolución para la Rivera Maya para determinar los efectos de los grandes desarrollos costeros (e.g. Cancún, Playa del Carmen).
10. Considerar el desarrollo de un modelo especial N-SPECT solo para la Península de Yucatán.

GUATEMALA

1. La primera impresión del trabajo es que es muy bueno, aunque es necesario incorporar datos más detallados y bases de datos nacionales.
2. Es esencial calibrar el modelo y ajustar sus variables
3. Los resultados parecen lógicos pero, ¿son significativos?
4. Se recomienda revisar los eventos extremos, no necesariamente un segundo Mitch pero algo más dramático que los datos mensuales y anuales que han sido utilizados en el modelo. Revisar los eventos de lluvias seria un buen primer paso.
5. Se recomienda crear mapas que muestren mejor las diferencias entre los escenarios. Esto no es claro en los mapas presentados, aunque mapas que resaltan las diferencias se presentan en el reporte técnico de CLUE-S que se encuentra en el CD de entrenamiento.
6. Se necesita más información sobre los supuestos que se hicieron y sobre las restricciones de los modelos/metodologías. Joep Luijten mencionó que se puede encontrar alguna información de este tipo para el CLUE-S, en el reporte técnico en el CD de entrenamiento.
7. Debe hacerse claro que si dos escenarios muestran el mismo porcentaje de cobertura terrestre para un uso particular del suelo, aun podrían existir diferencias significativas en la distribución especial del uso del suelo. Así pues, tener una tabla enlistando los porcentajes de área cubierta por cada tipo de uso del suelo, confunde.
8. Se deben incluir variables socio-económicas en los modelos. Por ejemplo, si el área de bosques disminuye un 5%, ¿cual es el cambio en valor monetario? ¿Cuánto afectan los cambios al turismo?
9. Grandes diferencias en bosques y cultivos. Su aplicación es útil para el manejo sostenible de bosques y el manejo integrado de cuencas.

HONDURAS

1. La delineación de las cuencas parece buena pero las cuencas costeras pequeñas deberían unirse a las adyacentes de mayor tamaño para que la delineación total coincida mejor con las cuencas oficiales del país.
2. Les gustaría ver un método que incluya las represas en el modelo. Actualmente existe un embalse hidroeléctrico en la cuenca del Ulua y el equipo de Honduras estaría interesado en calcular la acumulación de sedimento detrás de la presa. ¿Cómo podría esta variable (i.e. la existencia de represas) ser incorporada en el modelo?.

3. Los resultados le ayudaran al equipo a priorizar áreas donde se deberían llevar a cabo proyectos de reforestación y conservación del suelo.
4. Los resultados son valiosos para los tomadores de decisión tanto en el sector público como en el privado. Esta sería una herramienta excelente para la planificación del uso del suelo iniciada recientemente en Honduras.
5. Trabajar en colaboración en el ámbito regional para promover el uso de las mismas tecnologías SIG para un mejor manejo de los recursos naturales.
6. El conjunto de datos y los productos proporcionados por ICRAN-MAR en el taller no están terminados; al contrario deberían ser vistos como productos intermedios que deben ser refinados a nivel nacional para proporcionar información científica útil a los tomadores de decisión.
7. El modelo debería incluir datos socioeconómicos que puedan ser presentados a los tomadores de decisión.
8. Los participantes deberían llegar a un compromiso formal en el cual acuerden aplicar y mejorar los modelos proporcionados de acuerdo con las capacidades locales y las necesidades de información existentes.
9. Debe trabajar a resoluciones mayores: 90 o 30 metros. Debería ser notado, y los participantes estaban al tanto de esto, que resoluciones tan pequeñas no son prácticas cuando los modelos son aplicados a un país o la región MAR como un todo, pues los tiempos de simulación requeridos serian demasiado largos.

DISCUSIÓN Y RECOMENDACIONES

La sesión de política finalizó con una revisión de dos horas, realizada por todo el grupo, sobre el componente de cuencas de ICRAN-MAR, y los resultados del taller y actividades siguientes; se centró en la necesidad de informar a los encargados de la formulación de políticas en los países participantes sobre los resultados del ejercicio ICRAN-MAR, y en la necesidad de proporcionar apoyo con seguimiento a las agencias que decidan utilizar los modelos y los datos producidos por el componente de cuencas de ICRAN-MAR.

A continuación se presenta un resumen de los temas tratados durante la revisión:

- **Los resultados son útiles para algunos propósitos específicos.** El análisis de drenaje de cuencas para todo el MAR fue considerado como ambicioso. Los participantes reconocen la cantidad de esfuerzo incorporado a este análisis, aprecian los resultados comparativos a nivel regional, pero recomiendan que los resultados sean compartidos con instrucciones sobre usos apropiados e inapropiados. Estos son estimativos de descargas de sedimentos y nutrientes de las cuencas costeras según la cobertura de tierra actual y según varios escenarios futuros de cobertura terrestre.
- **Los resultados de los escenarios no son tan diferentes:** No existen grandes diferencias entre los escenarios; la mayoría de los participantes esperaban ver más contrastes. Esto puede deberse al relativamente corto periodo de tiempo (2000-25) o al hecho que los escenarios son demasiado generales y no pueden reflejar adecuadamente los cambios críticos que aparecen a nivel local o en las zonas costeras inmediatas.

- **Los resultados del modelo tienen que ser validados.** Es necesario calibrar mejor los modelos y validar los resultados del modelo. Existe un trabajo continuo con SeaWifs (con la Universidad de Miami) y hay datos del proyecto WRISC que pueden ser utilizados para evaluar las estimaciones para varias cuencas. El WRI pidió a los participantes proporcionar datos para la validación
- **La información puede influir en la política.** Un participante preguntó como ICRAN-MAR puede utilizar los resultados para preservar los bosques. Lauretta Burke respondió que teniendo una buena infraestructura de información integrada (para apoyar análisis espacial con detenimiento) y tener canales con los tomadores de decisión es clave.
- **La aplicación local de las herramientas de modelamiento producirá los resultados detallados más útiles.** La transferencia de tecnología y la capacitación es una parte importante del taller. Los participantes podrán usar datos locales (como aportes y para la validación), y por tanto podrán realizar un análisis mas detallado y obtener resultados más precisos al regresar a sus agencias.
- **Los resultados no son finales:** Los análisis de los resultados no son un producto final. ICRAN-MAR debe construir capacidad para usar los modelos ofrecidos durante el taller dentro de la región, así las personas pueden usar la información local para refinar los resultados y validar el modelo.
- **Eventos extremos.** El modelo N-Spect se centró en la precipitación anual promedio. Los eventos extremos como los huracanes y las tormentas tropicales son la mayor fuente de sedimentos. Seria valioso modelar los eventos extremos y la estacionalidad de la descarga.
- **Clarificación de las Unidades N-SPECT.** El representante de MBRS comentó que los resultados del modelo SPECT están en unidades “relativas” y no en significativas. La experiencia de WRI es que los productos de NSPECT son en litros de descarga y en kilogramos para sedimentos y contaminantes.
- **Estilo de delineación de cuencas.** Hubo discusión sobre la delineación de la cuenca MAR, enfocándose en las pequeñas cuencas costeras. Varios participantes preferirían haber visto estas cuencas pequeñas unidas a las cuencas adyacentes más grandes. El WRI no puede hacer esa unión, pues sería inconsistente con el flujo hidrológico dentro de DEM. Sin embargo, N-SPECT utiliza un algoritmo que si une a las cuencas pequeñas adyacentes. Estos resultados se proporcionan en el CD de datos.
- **Yucatán.** El WRI reconoció que la delineación de la cuenca para Yucatán no es muy buena debido a los ríos subterráneos y a algunos ríos perennes en la superficie. El grupo de México también señaló esta limitación y menciono que JAICA esta trabajando actualmente en la estimación del flujo de aguas subterráneas. Como los tomadores de decisión descartarán los resultados de Yucatán, ellos animaron a WRI a considerar excluir las cuencas en Yucatán de los resultados, o emitir una exoneración de responsabilidad adecuada y firme sobre los problemas del modelo en Yucatán.
- **Resultados de los escenarios.** El análisis del cambio de sedimento entre la cobertura del suelo actual y la natural es sorprendente, y muestra claramente el alcance del impacto humano. Sin embargo, los resultados del modelo N-SPECT

para los tres escenarios futuros de cobertura terrestre no se ven muy diferentes. Esto se debe a:

a) los datos de cobertura terrestre en los escenarios no son extremadamente diferentes

b) los resultados se presentan a nivel cuenca. El WRI puede explorar presentarlos a nivel sub-cuenca.

- **Prácticas de Manejo.** Debido a la ausencia de datos regionales sobre cultivos agrícolas y a que el módulo de prácticas de manejo, del modelo N-SPECT, no se ha implementado todavía, el análisis del WRI está enfocado en el impacto del cambio de la cobertura terrestre sobre la descarga de sedimentos y contaminantes. Seria muy valioso incluir las prácticas de manejo en el modelo en un futuro.
- **Represas.** Algunos participantes pidieron a WRI mirar la posibilidad de incorporar las represas en el modelo N-SPECT como trampas de sedimento. El WRI investigará más el tema.
- **Pertinencia de los Resultados en la Política.** Se dio una discusión sobre la dificultad de pasar de resultados del análisis a cambios en las políticas. Se animó a incluir valores socio-económicos.
- **Monitoreo de la Erosión.** La WWF está monitoreando la erosión del suelo en plantaciones de cítricos, aceite de palma y caña de azúcar. Estos datos serían muy valiosos si WRI pudiese, en un proyecto futuro o en una etapa futura del proyecto, intentar incluir los diferentes cultivos y las prácticas de manejo en el análisis hidrológico.
- **Valoración Económica.** Varios participantes recomendaron incluir variables económicos en los resultados, tales como el valor de la pérdida del suelo, la pérdida en la productividad agrícola, el daño a los arrecifes de coral. Los modelos son muy técnicos y los resultados de la simulación son muy científicos. Es esencial hacer más accesible esta información para los tomadores de decisiones, agregando valoraciones monetarias a algunos de los resultados.
- **Datos nacionales.** Los participantes señalaron que para algunos países (y para regiones particulares dentro de los países) existen datos más recientes y detallados que podrían ser incorporados en versiones futuras de los modelos.
- **Ejecutar los modelos a escalas menores.** Los modelos deberían ser ejecutados en resoluciones mayores (entre 30 y 90 metros) cuando se operen en los países. Los participantes mexicanos resaltaron la necesidad de modelos más detallados en las zonas costeras para analizar el impacto del desarrollo costero (e.g. canchas de golf nuevas, hoteles).
- **Demanda del uso del suelo para los escenarios.** Los participantes expresaron deseo por tener más detalles sobre el uso de los modelos *Futuros internacionales* e *IMAGE* para calcular la demanda en el futuro (i.e. área), para cada tipo de cobertura y, el motivo por el cual escogimos utilizar estos modelos. Como estos modelos no se trataron durante el entrenamiento, los participantes querían saber si ellos podrían utilizar estos modelos para analizar parámetros diferentes (e.g. diferentes tasas de crecimiento de población). ¿Qué otros métodos alternativos hay disponibles para calcular la demanda de tierra?

- **Factores explicativos (factores de ubicación).** Los participantes debatieron con los conceptos y la aplicación práctica de los factores explicativos (factores de ubicación) utilizados como parte de la metodología de modelamiento del uso del suelo. Esta es, discutiblemente, la parte más complicada del desarrollo del modelo CLUE-S. Los participantes querían saber si podrían incluir factores de ubicación adicionales.
- **Validación de la cobertura terrestre.** Los participantes preguntaros si los datos de cobertura terrestre habían sido validados por WCMC. No se hizo validación. Se debe destacar que WCMC utilizó datos bien conocidos de cobertura terrestre, de fuentes acreditadas. Los datos del Mapa de Ecosistemas se crearon como parte de un esfuerzo multi-anual con varios socios. La validación de los datos de estas terceras partes no fue parte del plan del proyecto.
- **Actividades de seguimiento.** Los participantes expresaron su deseo en ser parte de un grupo que ayude a continuar con este trabajo. Un participante mencionó que los grupos nacionales, existentes, que estén tratando temas referentes al agua o temas geoespaciales podrían liderar esta tarea.

SESIÓN TÉCNICA

La sesión técnica se llevó a cabo en el laboratorio SIG de la Universidad de Galen durante la tarde del 16 de agosto y el 17 y 18 de agosto. Atendieron veintidós participantes de Honduras, Guatemala, Belice y México (ver lista de participantes en el Apéndice 3).

El objetivo de la sesión técnica era proporcionar capacitación práctica para que en el futuro los participantes puedan realizar por sí mismos el análisis de las cuencas. Se capacitó en modelamiento hidrológico usando los modelos ArcMap SIG, *Nonpoint Source Pollution* (Contaminación sin punto de origen especifico), La Herramienta Comparativa de Erosión (N-SPECT) y el CLUE-S, también se guió en el conjunto de datos desarrollado por el componente de cuencas del proyecto ICRAN-MAR. Estas herramientas permiten a los usuarios delinear cuencas, modelar escorrentías y cargas de sedimentos y contaminación en las desembocaduras de los ríos a lo largo de la región y simular cambios en el uso del suelo bajo escenarios alternativos. El software de *SERVIR Viz* fue distribuido por Emil Cherrington a nombre del Sistema Regional de Monitoreo y Visualización para Mesoamérica (SERVIR), que opera en las oficinas de CATHALAC, Panamá.

Durante el primer componente de la sesión (tarde del 16 de agosto) Lauretta Burke (WRI) explicó y realizó un ejercicio sobre como delinear cuencas utilizando el conjunto de datos SRTM de 90 metros y las herramientas de análisis espacial disponibles en ArcMap. Se ofreció una explicación detallada sobre cómo las cuencas de MAR fueron delineadas. Además Lauretta guió un ejercicio sobre la evaluación de vulnerabilidad a la erosión de la tierra (con base en *grid cell*).

El 17 de agosto, Zachary Sugg (WRI) lideró la sesión de entrenamiento sobre el uso del modelo N-SPECT para estimar la escorrentía de los ríos y las cargas de sedimentos y contaminantes. Los participantes corrieron el modelo usando escenarios diferentes de uso del suelo para varias cuencas del MAR. WRI dio a cada participante, un CD con el programa del modelo, los resultados de ejecutar el N-SPECT en diferentes escenarios de uso de la tierra en la región MAR y la delineación completa de la cuenca MAR, además de una gran variedad de artículos y documentos de contexto que proporcionan información con más profundidad sobre el modelo.

El 18 de agosto, Joep Luijten (WCMC) proporcionó entrenamiento sobre el modelamiento de cambio en la cobertura terrestre usando el modelo CLUE-S. Primero introdujo el modelo y los diferentes tipos de parámetros y los conjuntos de datos de definen los diferentes escenarios, aunque la mayor parte del día se utilizó haciendo ejercicios prácticos. Inicialmente se utilizo una pequeña muestra de datos que permitió a los participantes familiarizarse rápidamente con la interfase usuario del modelo y analizar los efectos de los cambios en los parámetros seleccionados del modelo. Durante la tarde los participantes vieron algunas características mas avanzadas del modelo y trabajaron con el conjunto de datos completo de Belice. Joep proporcionó a los participantes un CD con el programa del modelo CLUE-S, la base de datos completa para Belice, México, Guatemala y Honduras, los resultados del escenario GEO MAR (25 años) y materiales de contexto.

La hoja de evaluación presentada a los participantes puede ser encontrada en el

Apéndice 4 y el resumen de los resultados de la evaluación en el Apéndice 5.

Los participantes también llenaron un cuestionario diseñado para ayudar al ICRAN-MAR a evaluar el tipo de actividades de seguimiento que pueden ser útiles y que pueden ser apoyadas por el proyecto. La mayoría de los participantes identificaron claramente la necesidad de entrenamiento/alcance adicional en los países del MAR en el corto plazo y en dos niveles diferentes:
:

- **Nivel 1. Seminarios de entrenamiento/alcance para administradores y tomadores de decisiones**. Los participantes recomendaron la organización de seminarios enfocados a administradores y tomadores de decisiones sobre la funcionalidad básica y la utilidad de los modelos, enfatizando cómo los resultados pueden incorporarse en la toma de decisiones. Los modelos deben ser probados utilizando datos locales y nacionales – a altas resoluciones – para poder mejorar los resultados y facilitar su uso en el contexto nacional.
- **Nivel 2. Entrenamiento técnico para especialistas en SIG y ITC**. Las respuestas al cuestionario también mostraron claramente que los países podrían beneficiarse de mayor entrenamiento y profundización en los modelos. Los participantes solicitaron entrenamiento adicional que abarque un rango más amplio de especialistas en cada país.

Las siguientes recomendaciones generales también fueron ofrecidas por el grupo técnico:

- Ofrecer entrenamiento adicional y profundización en los modelos CLUE-S y N-SPECT que incorporan:
    - El uso de grupos de datos locales y nacionales
    - Explicaciones detalladas de los parámetros utilizados
    - Revisión de las metodologías utilizadas para la creación de los datos de insumo para los modelos
- Aumentar la eficiencia del entrenamiento al ofrecer talleres de “entrenamiento de entrenadores”, donde especialistas nacionales aprendan la operación básica de los modelos y sean capaces de conducir seminarios dirigidos hacia tomadores de decisiones.
- Apoyar la asistencia técnica remota a los participantes que implementan los modelos para apoyar su uso en escenarios reales.
- Ayudar en la creación de un grupo de usuarios técnicos cuyo núcleo será conformado por participantes al taller. El grupo puede ofrecer a sus miembros asistencia técnica básica y apoyo en el uso de los modelos proporcionados en el taller. ICRAN-MAR podría apoyar con capital semilla para comenzar su operación.

WCMC y WRI evaluarán las observaciones recibidas de los participantes, los contactarán para determinar sus necesidades actuales y conducirán actividades de seguimiento en la medida de lo posible, utilizando los fondos restantes del ICRAN-MAR durante el primer semestre del 2007.

La hoja de evaluación presentada a los participantes puede encontrarse en el Apéndice 6 y un resumen de los resultados de la evaluación se encuentra en el Apéndice 7.

APÉNDICE 1. Agenda del Taller

PARTE 1: TALLER SORE POLÍTICA

Taller de Política sobre las amenazas de origen terrestre al Arrecife Mesoamericano
(Duración: 1.5 días)

Metas:

1) Informar a los formuladotes de políticas y a otros usuarios potenciales de la información, acerca de los productos y herramientas que han sido desarrollados durante este proyecto.
2) Aprender sobre el proyecto de cuencas de ICRAN MAR y los componentes analíticos en el análisis de cambio de cobertura del suelo, delineación de cuencas, modelamiento hidrológico y modelamiento de circulación.
3) Revisar escenarios de cambio de cobertura terrestre y proporcionar retroalimentación de dichos escenarios.
4) Revisar los resultados del modelo de predicción de fuentes de contaminación con origen terrestre y de descarga de sedimentos en el Arrecife Mesoamericano.
5) Crear conciencia acerca de los vínculos entre las actividades humanas en tierra y las amenazas al arrecife mesoamericano.
6) Identificar preguntas/aplicaciones de políticas para las herramientas analíticas así como usuarios futuros de las herramientas analíticas

Día 1 – Martes 15 de Agosto *(Taller de política todo el día)*

Facilitador: *Eric Van Praag,*

08:30 Registro

09:00 Himno Nacional.

09:03 Invocación. *Padre Kevin Nederman en la Parroquia del Sagrado Corazón*

09:05 Comentarios de Apertura, introducción a la Alianza para el Arrecife Mesoamericano ICRAN (Proyecto ICRAN-MAR)
Liza Agudelo, Coordinadora del proyecto

09:10 Metas del taller, presentación de los participantes y los organizadores. *Eric Van Praag, UNEP-WCMC. Consultor*

09:30 Presentación Clave: Salud de los Corales y amenazas al Arrecife Mesoamericano. *Dr. Melanie McField, Healthy Reefs Initiative.*

09:50 Presentación Clave: “Evolución conceptual del manejo de cuencas en la región Mesoamericana”. *Dr. Carlos Rivas, Asesor Superior para Mesoamérica, Agencia Sueca de Cooperación y Desarrollo Internacional (Swedish International Development Cooperation Agency -SIDA)).*

10:10 Generalidades del Tema Cuencas (Componente) en el proyecto ICRAN-MAR. *Lauretta Burke, World Resources Institute*

10:20 Descanso café/te

10:40 Generalidades sobre el desarrollo de escenarios *Joep Luijten, UNEP-WCMC*

- Estudios sobre escenarios con modelamiento en el cambio de uso del suelo regional
- Adopción de los escenarios GO-4 para la región MAR; guiones
- Discusión/retroalimentación

11:20. Generalidades sobre el modelamiento del cambio del uso del suelo *Joep Luijten, UNEP-WCMC*

- Cuantificación del cambio en la demanda de tierra (modelos IFS, IMAGE)
- Modelamiento de la distribución de la tierra en tiempo y espacio (modelo CLUE-S)
- Resultados del modelo. Cambios en la distribución del uso del suelo en el transcurso del tiempo
- Discusión/ retroalimentación

12:15 Almuerzo

13:15 Generalidades sobre el Modelamiento Hidrológico y de Circulación en el MAR. *Lauretta Burke, WRI*

- Delineación de cuencas
- Análisis de vulnerabilidad
- Análisis hidrológico utilizando NSPECT
- Modelamiento de la circulación
- Calibración del modelo

14:00 Resultados del Modelamiento Hidrológico y de Circulación. *Lauretta Burke, WRI*

- ¿Cuánto ha aumentado la descarga de sedimentos y nutrientes como consecuencia de actividades humanas?
- ¿Cuales áreas costeras están más impactadas en el presente?
- ¿Cuánto podría aumentar la descarga de sedimentos y nutrientes según los escenarios del futuro?

14:30 Revisión de los resultados por parte de los participantes

- Revisión de las cuencas
- Revisión de las estimaciones de descarga de sedimentos y nutrientes
- Discusión

15:15 Descanso Café/Te

15:40 Resultados de las actividades con los Agronecocios para la adopción de Prácticas de Manejo Mejores. *José Vásquez, WWF Honduras*

16:00 Discusión en grupo. División por país en cuatro grupos para:

- revisar los escenarios de cambio en cobertura terrestre y los resultados de los modelos hidrológicos;
- discutir sobre las aplicaciones potenciales de las herramientas de modelamiento en política;
- discusión de vías alternativas de desarrollo para la región.

17:30 Clausura por el día

<u>Día 2 – Miércoles, 16 de Agosto</u> *<u>(Sesión de Política – únicamente en la mañana)</u>*

09:00 Resumen breve sobre los resultados del modelamiento del día anterior

09:15 Plenaria:
Retroalimentación de los grupos (en discusión abierta) sobre:

- utilidad y validez del modelamiento de escenarios en cobertura de la tierra
- utilidad y validez del modelamiento hidrológico/ transporte de sedimento

10:00 Discusión

- Aplicaciones de estas herramientas en políticas
- Vías alternativas para el desarrollo en la región

10:30 Descanso café/te

10:45 Introducción al CD de datos y a los datos producidos
11:30. Discusión de Clausura

12:00 Almuerzo

PARTE 2: TALLER TÉCNICO

Taller técnico sobre el modelamiento del cambio en el uso del suelo y modelamiento hidrológico de escenarios diferentes en el Arrecife Mesoamericano (Duración: 2.5 días)

Metas:

1) Aprender como delinear cuencas a partir de datos digitales de elevación
2) Aprender a usar el Análisis Espacial ArcMap para identificar los suelos más vulnerables a erosión.
3) Aprender a usar la extensión de la Herramienta de Comparación de Contaminación sin Punto de Origen y de Erosión (*Nonpoint Source Pollution and Erosion Comparison Too*l) (N-SPECT) para evaluar el impacto del cambio en la cobertura terrestre sobre la descarga de sedimentos y nutrientes en las zonas costeras.
4) Entender como realizar un análisis estadístico de factores descriptivos en los patrones de uso del suelo, y los datos diferentes que deben ser colectados y preparados.
5) Aprender a instalar y utilizar el modelo CLUE-S para analizar escenarios diferentes de cambio en la cobertura terrestre (para estos un área más pequeña se utilizará).
6) Aprender sobre la colección de datos, la preparación de datos y el uso del modelo como se ha hecho para la región MAR, país por país y revisar los resultados.

Día 2 – Miércoles, 16 de Agosto *(Sesión Técnica – únicamente durante la tarde)*

Generalidad de la Delineación de Cuencas

13:30 Resumen de los Componentes del Modelo \ Programa y metas del taller.
a) Modelos y programas asociados (*software*)
b) Orden del análisis
14:00 Introducción al CD de datos para la región MAR
14:30 Delineación de Cuencas (usando Análisis Espacial)

- Incluye discusión de sumideros, dirección y acumulación del flujo, “quema de ríos ”, delineación de cuencas, identificación de vertederos
- Preparar DEM para el posterior uso en la delineación de N-SPEC

15:30 Descanso

15.45 Análisis Espacial Análisis de la Vulnerabilidad a Erosión (utilizando Análisis Espacial)

- Dilucidar la pendiente;
- Usar el *map calculator* (calculador del mapa) para combinar cuadriculas para trazar un mapa con la vulnerabilidad relativa a la erosión
- Resumen por cuenca

17:30 Clausura por el día

Día 3 – Jueves 17 de agosto – Modelamiento de Erosión y Contaminación usando N-SPECT

9:00 Introducción a N-SPECT

a. Generalidades de la herramienta de modelamiento N-SPECT
    i. Capacidades / Funciones
    ii. RUSLE
    iii. Donde están los datos y los productos
    iv. Procesamiento de las estimaciones de tiempo

10:00 Delineación de Cuencas Usando NSPECT
b. Preparación de DEM
c. Opciones
d. Ejercicio en delineación de cuencas
11:00 Análisis sobre erosión y contaminación utilizando N-SPECT
e. Datos requeridos
f. FACTORES
g. Opciones
h. Productos

12:00 Almuerzo

13:00 Ejercicio sobre modelamiento de erosión
14:00 Ejercicio sobre modelamiento de efecto local (RUSLE)

Descanso

15:00 Ejercicio sobre modelamiento de contaminación
16:00 Discusión sobre la implementación de otros escenarios

17:00 Clausura

Día 4 (Viernes 18 de agosto) – Modelamiento del cambio en la cobertura terrestre y el modelo CLUE-S

09:00 Introducción al modelamiento del cambio en el uso de la tierra y el modelo CLUE-S
- Diferentes tipos de modelos en cambio de uso del suelo
- Historia y aplicaciones de CLUE-S en el mundo
- Estructura del modelo CLUE-S y archivos de aporte claves
- Análisis de regresión separado en SPSS sobre los factores propulsores

10:00 Introducción al área caso de estudio (Isla de Sibuyan, Filipinas)

10:15 Descanso

10:30 CLUE-S Práctico
- Requerimientos del sistema e instalación. Demo vs. Versión completa.
- Ejercicio 1: Aprendiendo a conocer la interfase del usuario y visualización de resultados.
- Resumen de los archivos de datos de entrada y los archivos de parámetros del modelo
- Ejercicio 2: Archivos de parámetros y simulación de escenarios alternativos

12:00 Almuerzo

13:00 CLUE-S Práctico (continuación)
- Archivos de los parámetros de la ecuación de regresión y probabilidades de superficies
- Matriz de conversión de uso de la tierra y secuencias de conversión

- Archivos de creación de requerimientos de uso del suelo (demanda)
- Archivos de políticas espaciales y de restricción de área
- Conversión de elasticidades y rotación de cultivos
- Ejercicio 3: Creación de archivos para restricciones nuevas en área y requerimientos de tierra

14:30 Antecedentes de las simulaciones del escenario de cambio de uso del suelo en MAR y conjuntos de datos CLUE-S para Belice, Guatemala, México y Honduras

- Datos separados y simulación por país
- Cálculo de la demanda de tierra para escenarios diferentes
- Factores promotores dinámicos y estáticos; datos sobre áreas protegidas

14:45 Descanso

15:00 Simulaciones MAR, continuación

- Ecuaciones de regresión y probabilidades de superficies
- Ejercicio 4: Trabajar con los datos del escenario actual para Belice

16:30 Fin

APÉNDICE 2. Participantes a la Sesión de Política

Nombre	Organización	País	E-mail
Liza Agudelo	ICRAN-MAR	Belice	lagudelo@icran.org
Leonel Aquino	MARN	Guatemala	laquino@marn.gob.gt
Barbara Best	USAID	US	BBEST@USAID.GOV
Ed Boles	Universidad de Belice	Belice	ubboles@yahoo.com
Lauretta Burke	WRI	US	LAURETTA@wri.org
Ramon Carcamo	Departamento de Pesquerías	Belice	ramalive@yahoo.com
Laura Carrillo	ECOSUR	México	lc_oceanografa@yahoo.com.mx
Fernando Castro	CONAP Guatemala	Guatemala	fercastro@conap.gob.gt
Shalini Cawich	WWF	Belice	shalini@wwfca.org
Marion Cayetano	Universidad de Galen	Belice	mcayetano@galenu.edu.bz
Ivis Chan	Belize Audubon Society	Belice	research@belizeaudubon.org
Emil Cherrington	CATHALAC	Panamá	Emil.cherrington@cathalac.org
Edgar Ek	Centro de información de tierra	Belice	edgar_ek@yahoo.com
Ramón Frutos	Departamento metereológico	Belice	rfrutos01@yahoo.com
José Herrero	USAID/MIRA – FUCSA	Honduras	jherrero@mirahonduras.org
Sergio Hoare	WCS	Belice	shoare@wcs.org
Joshua López	Ministerio de Recursos Naturales	Belice	jal20075@hotmail.com
Joep Luijten	WCMC (Consultor)	UK	joepluijten@yahoo.com
Miguel Martínez Tuna	WWF-Central América	Guatemala	mmartinez@wwfca.org
Melanie McField	Healthy Reefs Initiative	Belice	mcfield@btl.net,mmcfield@wwfca.org
Jan Meerman	Belize Tropical Studies	Belice	meerman@biological-diversity.info
Néstor Meneses	USAID/MIRA	Honduras	nestor.meneses@gmail.com
Nelson Muñoz	SERNA	Honduras	nmunoz@serna.gob.hn

Nombre	Organización	País	E-mail
Efraín Novelo	Embajada USA	Belice	NoveloER@state.gov
Juan Manuel Núñez	Centro Geo	México	jnunez@centrogeo.org.mx
Gerardo Rios	CONANP	México	grios@conanp.gob.mx
Carlos Rivas	SIDA	Honduras	carlos.rivas@sida.se
Julianne Robinson	TNC Belize	Belice	jrobinson@mail.usf.edu
José Rodríguez Rocha	INEGI	México	jose.rodriguez@inegi.gob.mx
Víctor Romero Benítez	INEGI	México	manuel.romero@inegi.gob.mx
Antonio Salaverria	Unidad de Pesca	Guatemala	antoniosalaverria@gmail.com
Linda Searle	Seasports Belize	Belice	info@seasportsbelize.com
Zachary Sugg	WRI	US	zsugg@wri.org
Armeid Thompson	ICRAN-MAR	Belice	athompson@icran.org,chicarule@yahoo.com
Victor Valencia	Universidad del Valle	Guatemala	vhva1976@yahoo.es
Eric van Praag	WCMC	Venezuela	evan@cantv.net
Jorge Enrique Vargas	MARN	Guatemala	enriquevargasm@marn.gov.gt
José Vásquez	WWF	Honduras	jvasquez@wwfca.org
Mary Vásquez	MBRS / SAM	Belice	queenconch@mbrs.org.bz
Mauricio Mejia	WWF	Belice	mmejia@wwfca.org
Ramadan Salazar	CONANP	México	litbios16mm@hotmail.com
Roy E. Polonio	TIDE	Belice	banjahni@yahoo.com
Mauro Salazar	WWF	Guatemala	msalazar@wwfca.org
Candy González	BELPO	Belice	belprbz@starband.net
Aldo Cansio (for Martín Alegria)	Departamento del Ambiente	Belice	envirodept@btl.net

APÉNDICE 3. Participantes en la Sesión Técnica

Nombre	Organización	País	E-mail
Barbara Best	USAID	US	BBEST@USAID.GOV
Ramón Carcamo	Departamento de Pesquerías	Belice	ramalive@yahoo.com
Laura Carrillo	ECOSUR	México	lc_oceanografa@yahoo.com.mx
Marion Cayetano	Universidad de Galen	Belice	mcayetano@galenu.edu.bz
Ivis Chan	Belize Audubon Society	Belice	research@belizeaudubon.org
Emil Cherrington	CATHALAC	Panamá	Emil.cherrington@cathalac.org
Ramón Frutos	Departamento de Metereologia	Belice	rfrutos01@yahoo.com
Sergio Hoare	WCS	Belice	shoare@wcs.org
Joshua López	Ministerio de Recursos Naturales	Belice	jal20075@hotmail.com
Miguel Martínez Tuna	WWF-Central América	Guatemala	mmartinez@wwfca.org
Jan Meerman	Belize Tropical Studies	Belice	meerman@biological-diversity.info
Néstor Meneses	USAID/MIRA	Honduras	nestor.meneses@gmail.com
Juan Manuel Núñez	Centro Geo	México	jnunez@centrogeo.org.mx
Gerardo Rios	CONANP	México	grios@conanp.gob.mx
Julianne Robinson	TNC Belize	Belice	jrobinson@mail.usf.edu
Víctor Romero Benítez	INEGI	México	manuel.romero@inegi.gob.mx
Antonio Salaverria	Unidad de Pesca	Guatemala	antoniosalaverria@gmail.com
Víctor Valencia	Universidad del Valle	Guatemala	vhva1976@yahoo.es
Jorge Enrique Vargas	MARN	Guatemala	enriquevargasm@marn.gov.gt
José Vásquez	WWF	Honduras	jvasquez@wwfca.org
Mary Vásquez	MBRS / SAM	Belice	queenconch@mbrs.org.bz
Mauricio Mejia	WWF	Belice	mmejia@wwfca.org
Ramadan Salazar	CONANP	México	litbios16mm@hotmail.com
Roy E. Polonio	TIDE	Belice	banjahni@yahoo.com
Aldo Cansino	Departamento del Medio Ambiente	Belice	envirodept@btl.net

APÉNDICE 4. Hoja de Evaluación de la Sesión Técnica

EVALUACIÓN DEL TALLER
Proyecto ICRAN-MAR

Taller sobre Manejo de Cuencas, Modelaje de Escenarios de Cambio en la Cobertura Terrestre y Modelaje de Descarga Hídrica de Sedimentos y Nutrientes

San Ignacio, Belice, 15 – 18 de Marzo de 2006

Agradecemos su tiempo para responder algunas preguntas que nos permitirán mejorar aspectos del curso y evaluar su impacto. Utilice la siguiente escala de valores para responder a las preguntas:
[1 = muy pobre, no adecuado, no útil, 5 = muy bueno, muy buena capacidad, muy útil]

1. El curso
Marque con un círculo el valor de su respuesta

¿Qué tan útil resultó el taller para Ud.?	1	2	3	4	5
¿Fueron valiosas las presentaciones de la Sección de Políticas?	1	2	3	4	5
Las sesiones teóricas fueron:	1	2	3	4	5
Las sesiones prácticas fueron:	1	2	3	4	5
El nivel de los instructores fue:	1	2	3	4	5
La calidad del entrenamiento fue:	1	2	3	4	5
¿Fue el curso compatible con sus intereses, conocimiento previo y responsabilidades laborales?:	1	2	3	4	5
¿Qué tan útil fue el entrenamiento en CLUE-S?	1	2	3	4	5
¿Qué tan útil fue el entrenamiento en N-SPECT?	1	2	3	4	5
¿Qué tan útil fue el componente sobre ArcMAP y herramientas hídricas?	1	2	3	4	5

2. Resultados del entrenamiento en N-SPECT
¿Ud. se siente capaz de?:

Realizar una delimitación de cuencas	1	2	3	4	5
Calcular escorrentía (runoff) y acumulación de sedimentos	1	2	3	4	5
Calcular acumulación de contaminantes	1	2	3	4	5
Calcular local effects (erosión local)	1	2	3	4	5
Utilizar sus propios datos en el modelo N-SPECT	1	2	3	4	5

3. Resultados del entrenamiento en CLUE-S
¿Ud. se siente capaz de?:

Entender los distintos datos y parámetros de entrada	1	2	3	4	5
Preparar los datos de entrada para CLUE-S	1	2	3	4	5
Visualizar los resultados de CLUE-S en un SIG	1	2	3	4	5
Preparar y comparar sus propios escenarios para CLUE-S (land demand, area restriction files)	1	2	3	4	5
Trabajar con los datos de su país contenidos en el CD	1	2	3	4	5
Calcular nuevos coeficientes de regresión utilizando					

software de estadísticas y el manual de CLUE-S	1	2	3	4	5

4. Desarrollo del curso
Evalúe el curso de acuerdo a los siguientes criterios

Habilidad de transmitir conocimiento de formar clara	1	2	3	4	5
Habilidad de generar interés en los temas	1	2	3	4	5
Capacidad de transmitir conocimiento sobre el modelo CLUE-S a otros especialistas	1	2	3	4	5
Capacidad de transmitir conocimiento sobre el modelo N-SPECT a otros especialistas	1	2	3	4	5

5. Recursos del curso
Ofrezca su opinión sobre los siguientes recursos

El salón de entrenamiento:	1	2	3	4	5
Los computadores:	1	2	3	4	5
El material audiovisual:	1	2	3	4	5
El material impreso:	1	2	3	4	5
El CD de entrenamiento:	1	2	3	4	5
La traducción simultánea (sesión de políticas)	1	2	3	4	5
La traducción en la sesión técnica	1	2	3	4	5

6. Agenda
Agradecemos sus comentarios sobre la agenda del curso. ¿Le pareció correcta? ¿Se cubrieron los temas con el tiempo adecuado? ¿Hay temas que se debieron dar mas a fondo o mas rápido? ¿Qué aspectos de la agenda se pueden mejorar?

(Ver resumen de respuestas en el Apéndice 5)

7. Por favor especifique como los temas ofrecidos en el curso le apoyarán en su trabajo

(Ver resumen de respuestas en el Apéndice 5)

8. ¿Piensa que usará estos modelos en el futuro? Por favor especifique su respuesta para CLUE-S y N-SPECT y el tipo de aplicaciones donde los usaría?

(Ver resumen de respuestas en el Apéndice 5)

9. ¿Cómo visualiza que los resultados de los modelos serán presentados y explicados a tomadores de decisiones y autoridades? Favor explicar:

(Ver resumen de respuestas en el Apéndice 5)

10. . Comentarios generales:

(Ver resumen de respuestas en el Apéndice 5)

APÉNDICE 5. Resumen de los Resultados de la Evaluación Técnica.

Pregunta 6: Agradecemos sus comentarios sobre la agenda del curso. ¿Le pareció correcta? ¿Se cubrieron los temas con el tiempo adecuado? ¿Hay temas que se debieron dar mas a fondo o mas rápido? ¿Qué aspectos de la agenda se pueden mejorar?

Resumen de respuestas:
Las respuestas obtenidas sugieren que sería de utilidad:

- Proporcionar más información sobre el desarrollo de los escenarios y sobre la generación de los parámetros de modelación
- Tener tiempo adicional (vg. taller más largo) para cubrir algunos de los tópicos en forma más detallada.
- Explicar mejor el origen de los datos de ingreso para los modelos y cómo fue desarrollado
- Proveer más tiempo para completar los ejercicios
- Dar más tiempo para explicar el modelo CLUE-S
- Conducir el taller en un solo idioma, o utilizando traducción simultaneas. Demasiado tiempo se perdió debido a la necesidad de traducir al español.

Pregunta 7. Por favor especifique como los temas ofrecidos en el curso le apoyarán en su trabajo
Resumen de respuestas:

- Apoya el mandato de algunas agencias de monitorear las cuencas
- Ofrece herramientas útiles para la toma de decisiones
- Es útil para evaluar el ciclo hidrológico y los patrones de sedimentación
- Complementa el trabajo de una agencia, donde imágenes satélite están siendo utilizadas para modelar recursos hidrológicos
- Apoya la necesidad de algunas agencias de identificar y medir las amenazas a sitios de anidación de tortugas y sitios de alimentación

Pregunta 8. Piensa que usará estos modelos en el futuro? Por favor especifique su respuesta para CLUE-S y NSPECT y el tipo de aplicaciones donde los usaría?
Resumen de respuestas:

- CLUE-S será muy útil para modelar la cobertura de vegetación en áreas naturales protegidas de México
- N-SPECT no será útil para la península de Yucatán, a menos que el flujo de agua subterránea se incorpore en el modelo
- Un participante manifestó querer probar ambos modelos en un área con gran degradación ambiental y evaluar los resultados
- El proyecto USAID MIRA utilizará el N-SPECT como parte de su componente de cuencas
- Algunas agencias utilizarán los modelos para simular el impacto de eventos climáticos mayores.
- N-SPECT será útil para la comunidad científica y los tomadores de decisiones en general que necesiten mejor información sobre sedimentación y patrones de contaminación.
- N-SPECT puede ser útil para estimar las necesidades, estatus y tendencias de la salud comunitaria en el Sur de Belice
- Los modelos serán más útiles si los grupos de datos nacionales pueden ser incorporados y probados
- Algunas agencias compararán los resultados de N-SPECT con los resultados de modelos existentes

- Algunas agencias comentaron que se necesita entrenamiento adicional en el uso de CLUE-S debido a su complejidad
- CLUE-S será de utilidad para planeamiento territorial en el contexto de las convenciones de las Naciones Unidas tales como UNCCD y UNFCCC
- El grupo de modelos es util para explicar las conexiones entre cobertura boscosa y la salud del océano

Pregunta 9. ¿Cómo visualiza que los resultados de los modelos serán presentados y explicados a tomadores de decisiones y autoridades? Favor explicar.
Resumen de respuestas:

- ICRAN-MAR debería entrenar más especialistas en el uso de los modelos, quienes a su vez informarán a los tomadores de decisiones locales acerca de los beneficios de los modelos
- Los países deberían correr los modelos utilizando grupos de datos nacionales y locales para producir mayor impacto cuando se presente a los tomadores de decisiones
- Al presentar los resultados, se debería hacer énfasis en el impacto económico de las decisiones de manejo mal enfocadas, que favorecen mayor contaminación y sedimentación, y los impactos de los cambios de cobertura sobre el sector turismo.
- Atención especial se debe dar cuando se explique la "naturaleza relativa" de los resultados, para que los tomadores de decisiones no consideren los resultados del modelo como predicciones de valor absoluto
- Es necesario preparar material de entrenamiento para diferentes tipos de seminarios enfocados a usuarios con diferentes necesidades.

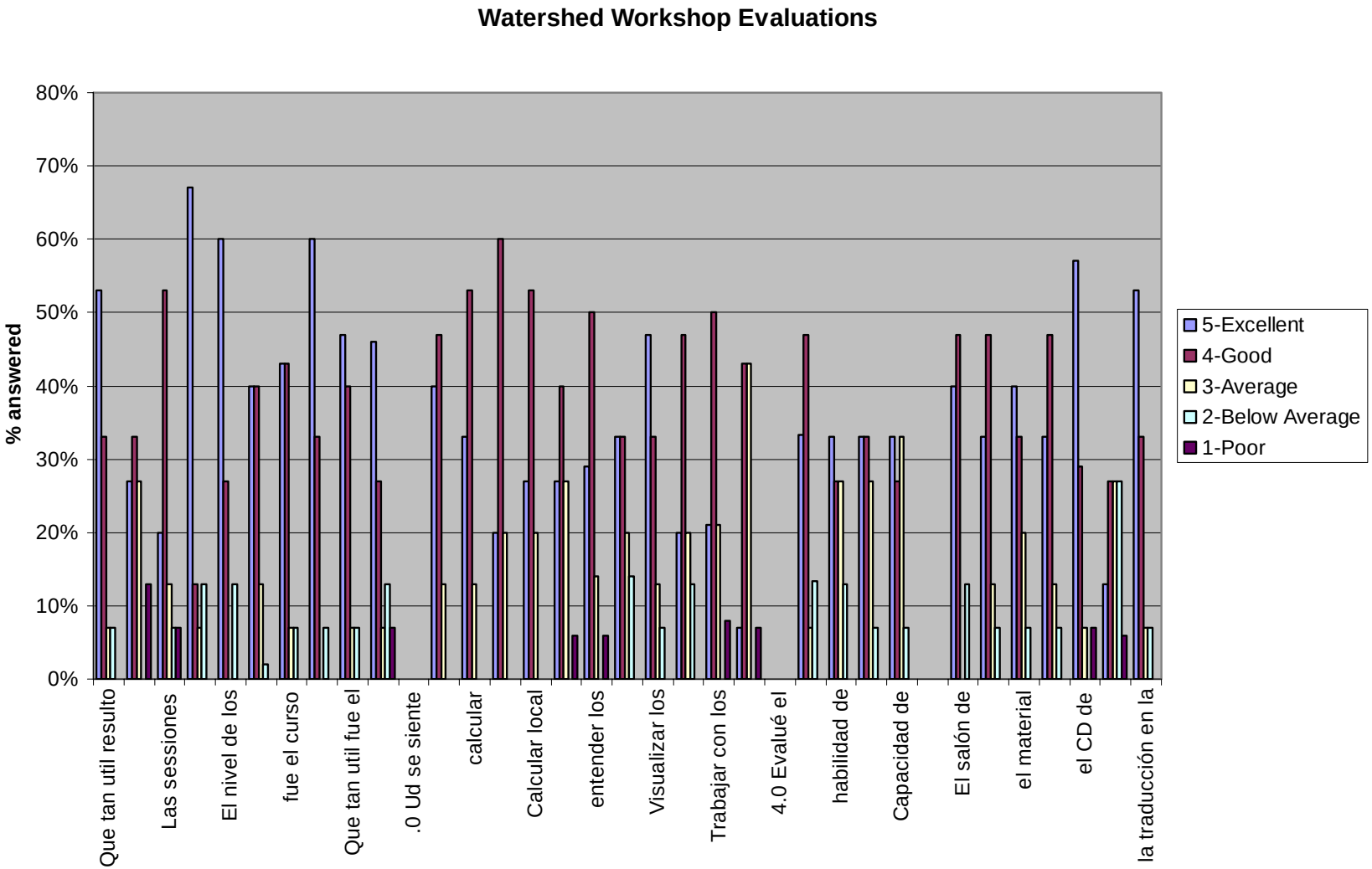
Pregunta 10. Comentarios generales
Resumen de respuestas:

- Es necesario incorporar variables socio-económicas en los modelos
- Es necesario traducir al español todo el material de entrenamiento y apoyo
- Es necesario conducir actividades de seguimiento
- Es necesario establecer una red de monitoreo del MAR que permita la calibración y mejoramiento de los modelos y para comparar los diferentes resultados y escenarios

Muchas de las respuestas comentaron sobre la gran utilidad del taller y agradecieron a los organizadores por su realización.

EVALUACION DEL TALLER ICRAN MAR:5- excelente; 4-bueno; 3-promedio; 2- debajo del promedio y 1-malo

ICRAN MAR WATERSHED WORKSHOP EVALUATIONS					
	5-Excellent	4-Good	3-Average	2-Below Average	1-Poor
Que tan util resulto el taller para ud	53%	33%	7%	7%	
Fueron valiosas las presentaciones de la seccion de politicas	27%	33%	27%		13%
Las sessiones teoricas fueron	20%	53%	13%	7%	7%
Las sesiones practicas fueron	67%	13%	7%	13%	
El nivel de los instructores fue	60%	27%		13%	
La calidad del entrenamiento fue	40%	40%	13%	2%	
fue el curso compatible con sus intereses, conocimiento previo y responsabilidades laborales	43%	43%	7%	7%	
que tan útil fue el entrenamiento en CLUE-S	60%	33%		7%	
Que tan util fue el entrenamiento en N-SPECT	47%	40%	7%	7%	
que tan util fue el componente sobre Arc Map y herramientas hidricas	46%	27%	7%	13%	7%
.0 Ud se siente capaz de					
Realizar una delimitacion de cuencas	40%	47%	13%		
calcular escorrentía (runoff) y acumulación de sedimentos	33%	53%	13%		
calcular acumulación de contaminantes	20%	60%	20%		
Calcular local effects (erosion local):	27%	53%	20%		
Utilizar sus propios datos en el modelo N-SPECT	27%	40%	27%		6%
entender los distintos datos y parámetros de entrada	29%	50%	14%		6%
preparar los datos de entrada para CLUE-S	33%	33%	20%	14%	
Visualizar los resultados de CLUE-S en un SIG	47%	33%	13%	7%	
. Preparar y comprar sus propios escenarios para CLUE-S (land demand, area restriction files):	20%	47%	20%	13%	
Trabajar con los datos de su país contenidos en el CD	21%	50%	21%		8%
Calcular nuevos coeficientes de regresión utilizando software de estadísticas y el manula de CLUE-S	7%	43%	43%		7%
4.0 Evalué el curso de acuerdo a los siguientes criterios					
habilidad de transmitir conocimiento de formar clara	33.30%	47%	7%	13.30%	
habilidad de generar interese en los temas	33%	27%	27%	13%	
capacidad de transmitir conocimientos sobre el modelo CLUE-S a otros especialistas:	33%	33%	27%	7%	
Capacidad de transmitir conocimiento sobre el modelo N SPECT o otros especialistas	33%	27%	33%	7%	
0 Ofrezca su opinión sobre los siguientes recursos					
El salón de entrenamiento	40%	47%		13%	
los computadores	33%	47%	13%	7%	
el material audiovisual	40%	33%	20%	7%	
el material impreso	33%	47%	13%	7%	
el CD de entrenamiento	57%	29%	7%		7%
La traducción simultanea	13%	27%	27%	27%	6%
la traducción en la sesión técnica	53%	33%	7%	7%	


Watershed Workshop Evaluations
% answered
80%
70%
60%
50%
40%
30%
20%
10%
0%
Que tan util resulto
Las sessiones
El nivel de los
fue el curso
Que tan util fue el
.0 Ud se siente
calcular
Calcular local
entender los
Visualizar los
Trabajar con los
4.0 Evalué el
habilidad de
Capacidad de
El salón de
el material
el CD de
la traducción en la
5-Excellent
4-Good
3-Average
2-Below Average
1-Poor

APÉNDICE 6. Cuestionario Técnico de Seguimiento

EVALUACIÓN DE OPORTUNIDADES PARA CAPACITACIÓN Y SEGUIMIENTO

Proyecto ICRAN-MAR

Taller sobre Manejo de Cuencas, Modelaje de Escenarios de Cambio en la Cobertura Terrestre y Modelaje de Descarga Hídrica de Sedimentos y Nutrientes
San Ignacio, Belice, 15 – 18 de Marzo de 2006

Nombre:

Institución:

Teléfono:

Email:

Agradecemos su tiempo para responder algunas preguntas que nos permitirán planificar potenciales actividades de capacitación posteriores al taller

1. **¿Qué tipo de entrenamiento adicional y complementario considera que se podría ofrecer a Ud. y su institución relacionado con los temas cubiertos en el taller?**

(Ver resumen de respuestas en el Apéndice 7)

2. **Por favor indique que instituciones de su país considera que podrían beneficiarse de una capacitación similar a la ofrecida durante el taller actual (indique para cada una nombre de persona contacto y lista especialistas que deben asistir).**

(Ver resumen de respuestas en el Apéndice 7)

3. **Por favor describa los beneficios que tendría una capacitación adicional para su institución y para otras instituciones de su país.**

(Ver resumen de respuestas en el Apéndice 7)

4. **¿Qué temas ofrecidos durante el taller considera de mayor interés para su institución (u otras instituciones de su país) para una futura capacitación? Por favor describa.**

(Ver resumen de respuestas en el Apéndice 7)

5. **¿Cuenta su institución con un laboratorio SIG adecuado para ofrecer capacitación similar a la ofrecida en el taller? En caso contrario, por favor indique si conoce de otra institución que podría ofrecer un laboratorio adecuado para el entrenamiento.**

(Ver resumen de respuestas en el Apéndice 7)

6. **¿Qué entrenamiento adicional es requerido para garantizar que los resultados de los modelos apoyen acciones concretas?**

(Ver resumen de respuestas en el Apéndice 7)

APÉNDICE 7. Resumen de los Resultados del Cuestionario de seguimiento

La siguiente tabla presenta un resumen de las respuestas a las siguientes preguntas:

Pregunta 1. ¿Qué tipo de entrenamiento adicional y complementario considera que se podría ofrecer a Ud. y su institución relacionada con los temas cubiertos en el taller?
Y
Pregunta 6. ¿Qué entrenamiento adicional es requerido para garantizar que los resultados de los modelos apoyen acciones concretas?

Respuestas	De
En México	
Apoyo recolección de datos en campo para mejorar los modelos	UNIPESCA
Organizar un seminario para tomadores de decisiones y explicar los beneficios de los modelos	UNIPESCA Centro GEO
Desarrollo de escenarios	CONANP
Explicar mejor el uso de ciertos parámetros y detalles del modelo que no fueron cubiertos durante el entrenamiento	CONANP
Entrenamiento básico en SIG para no especialistas para que se puedan beneficiar de los modelos	CONANP
Entrenamiento más detallado en el uso de los modelos utilizando grupos de datos locales para desarrollar parámetros apropiados para la región del MAR	ECOSUR INEGI
Entrenamiento en la generación del grupos de datos de insumo para el modelo	ECOSUR INEGI
En Honduras	
Entrenamiento para desarrollar mejores fuentes de datos como insumo para los modelos, tales como las grillas de precipitación o mapas de cobertura	USAID MIRA
En Belice	
Entrenamiento para establecer una metodología para validar N-SPECT utilizando datos reales de cuencas del MAR seleccionadas	Hydrology and Meteorology Service (HMS)
Asistir en el establecimiento de una red nacional que monitoree la erosión y sedimentación en los canales de ríos	Hydrology and Meteorology Service
Probar los modelos incorporando datos locales. Idealmente, hacer que los países valides estos datos previamente	TNC Belize
Guías para recolectar datos para la calibración del modelo	TIDE Belize
Apoyar el establecimiento de una red regional de especialistas en las herramientas de modelación	TIDE Belize
Obtener financiación para apoyo adicional de seguimiento	TIDE Belize
Entrenamiento en ArcGIS 9 y manejo básico de datos SIG para mejorar el ingreso de los datos al modelo	WCS Belize HMS
En Guatemala	
Valoración económica de los diferentes escenarios del modelo	Univ. Valle
Organizar un seminario que presente cómo los resultados de los modelos pueden utilizarse para solucionar problemas reales	Univ. Valle
Apoyar la formulación de políticas basándose en los resultados del modelo	MARN
Desarrollo de indicadores para asistir en las pruebas del modelo	MARN
Concepto y contexto general del desarrollo de los escenarios	MARN

Resumen de respuestas a la Pregunta 2. Por favor indique que instituciones de su país considera que podrían beneficiarse de una capacitación similar a la ofrecida durante el taller actual (indique para cada una nombre de persona contacto y lista especialistas que deben asistir)

- **México**. Universidades (relacionadas con agronomía y el ambiente), unidad de manejo de desastres del gobierno. CONANP CONANP, CONAFOR, Amigos de Sian Koan, CINVESTAN (Mérida), PRONATURA, UQROO, EPOMEX, Instituto Nacional de Ecología, Comisión Nacional de Agua, CONABIO, SEMARNAT, INEGI, Secretaría de Marina
- **Honduras**. Dirección de Recursos Hídricos, COHDEFOR.
- **Belice**. Sector privado (vg. floricultores), SATTIM, YATCHE, TASTE, TIDE, Belize Agricultural Health Authority, Agricultural Department, Department of Oil and Mining, Belize University, Program for Belize.
- **Guatemala**. Instituto de Hidrología, Vulcanología y Meteorología (INSIVUMEH), Secretaría General de Planificación (SEGEPLAN), Instituto de Estadística (INE), Instituto Geográfico Nacional, Ministerio de Agricultura (MAGA), Instituto Nacional de Bosques (INAB), Consejo Nacional de Áreas Protegidas, Ministerio del Ambiente (MARN)

Resumen de respuestas a la Pregunta 3. Por favor describa los beneficios que tendría una capacitación adicional para su institución y para otras instituciones de su país.

México

- Difusión de los resultados a un público más amplio
- Cambio actitud por parte de los tomadores de decisiones. Sensibilización hacia temas como el manejo del agua
- Mejor capacidad en SIG para técnicos y planificadores
- Nuevos usuarios mejorarán los resultados del modelo y ayudarán a mejorar los datos de insumo
- Desarrollo de legislación utilizando datos científicos
- Centro GEO podría considerar entrenar entrenadores en los modelos para difundir estas tecnologías en México

Belice

- Mejor planeación de desarrollo
- Identificar áreas con amenazas por escorrentía
- Establecimiento de medidas de mitigación a desastres naturales

Guatemala

- Estimulo para usar nuevas tecnologías y metodologías a nivel nacional
-

Resumen de respuestas a la Pregunta 4. ¿Qué temas ofrecidos durante el taller considera de mayor interés para su institución (u otras instituciones de su país) para una futura capacitación? Por favor describa.

México

- Contaminación
- Deforestación
- CLUE-S (4 respuestas) e IMAGE (1 respuesta)
- N-SPECT para análisis de cuencas (3 respuestas)
-

Honduras

- N-SPECT

Belice

- CLUE-S (2 respuestas)
- Desarrollo de mejores políticas de uso del suelo
- Calidad del agua y monitoreo de sedimentación
- Desarrollo de escenarios

Guatemala

- N-SPECT

Resumen de respuestas a la Pregunta 5. ¿Cuenta su institución con un laboratorio SIG adecuado para ofrecer capacitación similar a la ofrecida en el taller? En caso contrario, por favor indique si conoce de otra institución que podría ofrecer un laboratorio adecuado para el entrenamiento

México: Consejo Nacional de Áreas Protegidas, MAGA. Ministerio de Agricultura, ECOSUR, INEGI, Centro GEO.
Honduras: Zamorano.
Belice: TNC Belice, Land Information Center.
Guatemala: Universidad del Valle.

APENDICE 8. Vínculos Útiles

Introducción y presentaciones clave:

- http://www.icranmar.org
- http://www.healthyreefs.org/

Modelamiento de la cobertura terrestre y escenarios:

- http://www.ifsmodel.org/
- http://www.mnp.nl/image/
- http://www.cluemodel.nl/
- http://www.unep.org/geo
- http://www.scenariosforsustainability.org

Modelamiento hidrológico-circulación:

- http://reefsatrisk.wri.org

Vínculos para la distribución de datos SIG

- Sistema de Datos sobre los recursos en Biodiversidad y Medio Ambiente de Belice: http://www.biodiversity.bz
- Centro de intercambio de información de Belice: http://www.chm.org.bz
- Servicio de visualización y monitoreo para Mesoamérica - SERVIR: http://servir.nsstc.nasa.gov
- Página de N-SPECT: http://www.csc.noaa.gov/crs/cwq/nspect.html

Grupo de discusión

- http://groups.google.com/group/mar-watersheds