INTERDISCIPLINARY BASELINE ECOSYSTEM ASSESSMENT SURVEYS TO INFORM ECOSYSTEM-BASED MANAGEMENT PLANNING IN TIMOR-LESTE:

FINAL REPORT

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Interdisciplinary Baseline Ecosystem Assessment Surveys to Inform Ecosystem-Based Management Planning in Timor-Leste: Final Report

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ACRONYMS

ARMS – autonomous reef monitoring structure
BOLD – Barcode of Life Database
$CaCO_3$ – calcium carbonate
CAU – calcification accretion unit
CCA – crustose coralline algae
CI – Conservation International
COI – cytochrome oxidase subunit 1
CPCe – Coral Point Count with Extensions (software)
CRCP – Coral Reef Conservation Program
CT6 – the six countries of the Coral Triangle
CTI-CFF – Coral Triangle Initiative on Coral Reefs, Fisheries, and Food Security
CTSP – Coral Triangle Support Partnership
DIC – dissolved inorganic carbon
EAFM – ecosystem approach to fisheries management
EAFM-LEAD – EAFM for leaders, executives, and decision-makers
ENVI – Environment for Visualizing Images (software)
GIS – geographic information system
HCl – hydrochloric acid bath
ISD – image support data
MAF – Ministry of Agriculture and Fisheries
MPA – marine protected area
NOAA – National Oceanic and Atmospheric Administration
NOAA-CREP – National Oceanic and Atmospheric Administration's Coral Reef Ecosystem Program
OISST – Optimal Interpolation Sea Surface Temperature
OTU – operational taxonomic unit
PCR – polymerase chain reaction
PIFSC – Pacific Islands Fisheries Science Center
PMEL – Pacific Marine Environmental Laboratory
PVC – plastic polyvinyl chloride
SPC – stationary point count
SST – sea surface temperature
STR – subsurface temperature recorder
TA – total alkalinity
USAID – United States Agency for International Development
USCTI – United States Coral Triangle Initiative
WESTPAC – Western Pacific region of United Nations Intergovernmental Oceanographic Commission

EXECUTIVE SUMMARY

Overview

This document is the final report on the activities performed by the United States National Oceanic and Atmospheric Administration (NOAA) from 2012 to 2016, through a partnership agreement with the United States Agency for International Development (USAID) Timor-Leste Mission, in support of the Government of Timor-Leste—particularly the Ministry of Agriculture and Fisheries (MAF). Based on consultative discussions among USAID, MAF, and NOAA, these activities provide essential baseline fisheries and marine resource information to inform ecosystem-based management of the nearshore waters of Timor-Leste. These efforts were funded primarily by the USAID Timor-Leste Mission, with significant in-kind contributions and support from NOAA, as part of the 5-year partnership between NOAA and USAID.

This document provides the basis for science-based management for fisheries conservation, which in turn can improve food security and strengthen climate change resilience for the benefit of the people of Timor-Leste. NOAA's Coral Reef Ecosystem Program (CREP) provides high-quality data and information products which inform ecosystem-based management decisions and conservation actions.

Collectively, the chapters on Satellite Mapping of Nearshore Habitats (Chapter 2), Coral Reef Ecosystem Assessments (Chapter 3), Establishing Ecological Baselines for Climate Change (Chapter 4), and Developing a Spatial Data Framework (Chapter 5) provide a baseline assessment of Timor-Leste's nearshore habitats and coral reef ecosystems for the areas surveyed. As the survey methods described and used herein are also implemented as part of the NOAA Pacific Reef Assessment and Monitoring Program (Pacific RAMP)—an ecosystem-scale interdisciplinary coral reef monitoring program—the data from Timor-Leste are directly comparable to and informed by data collected by NOAA-CREP throughout the U.S. Pacific Islands and Territories. Furthermore, the methods used for establishing ecological baselines for climate change in Timor-Leste (Chapter 4) are being adopted and implemented at 21 sites across eight member states of the Intergovernmental Oceanographic Commission within the Western Pacific (WESTPAC) region. These data provide a foundation for comparing the ecological baselines under current and future stresses associated with climate change in the Coral Triangle region.

Findings

The baseline data collected by NOAA-CREP through partnership with USAID show that the waters surrounding Timor-Leste support high fish diversity as well as areas of localized high coral cover. Yet, the seawater carbonate chemistry observed in the shallow water reef environments of Timor-Leste suggests an area of concern and warrants continued long-term monitoring to assess whether low reef accretion rates are indeed an early indication of the effects of ocean acidification reducing reef growth and survival in the region.

Satellite Mapping of Nearshore Habitats

- Bathymetry was successfully derived from the shoreline to approximately 15-m depths for Atauro Island, Oecusse, and most of the north shore of Timor-Leste with relatively few spatial gaps.
- Over 190 km^2 of shallow water habitats were classified into hard and soft substrate, mangrove, seagrass, intertidal, rock and lagoon habitats.

Coral Reef Ecosystem Assessments

- The average fish species richness for all sectors was extremely high in Timor-Leste (averaging 57 species per site) compared to any other Pacific region that NOAA-CREP surveys.
- Small-bodied fish biomass in Timor-Leste was similar to other remote, unpopulated areas in the Pacific islands, while medium- and large-bodied fish biomass (including species important as fishery targets) was comparable to values from other human-populated areas in the Pacific.
- Fish biomass was greatest in West Atauro comparable to other remote areas in the Pacific, suggesting that West Atauro fish assemblages are relatively unimpacted by human activities and/or this is an area of high productivity.
- The surgeonfish family had the highest biomass, accounting for 20% of the total fish biomass.
- With respect to benthic cover, hard coral cover averaged 15.6% among the eight survey districts. Hard and soft corals as well as crustose coralline algae were more dominant than turf and macroalgae in Atauro, Liquica, and Manatuto districts, favoring reef structure and integrity. In the remaining survey sectors, turf and macroalgae were more dominant than corals and crustose coralline algae.
- Live hard coral cover reached 40% within the recently designated Nino Konis Santana National Marine Park and 38% in the Belio Barrier Reef complex, reflecting some of the highest quality reefs in the country.
- A diverse number of crustaceans have been found in the biodiversity assessments conducted using autonomous reef monitoring structures (ARMS), including important fishery targets, such as shrimp, crab, and lobster, with the highest mean cryptobiota diversity at the Biaucou and Tutuala sites.

Ecological Baselines for Climate Change

- Net calcium carbonate accretion rates (used to track early responses to acidifying seawater conditions) were among the lowest recorded among NOAA-CREP's Pacific monitoring sites, and fell below predicted values based on water chemistry parameters.
- Recorded reef seawater temperatures from Oct 2012 to Oct 2014 exceeded the previously reported maximum for northern Timor-Leste from the NOAA Reynolds Optimal Interpolation Sea Surface Temperature (OISST) dataset.
- Timor-Leste's reefs have lower pH, aragonite saturation state, and net carbonate accretion values than many Pacific reefs monitored by NOAA-CREP. These low measurements suggest that

ocean acidification impacts are part of a suite of threats currently facing growth of Timor-Leste's reefs.

Recommendations and Best Practices

The Ministry of Agriculture and Fisheries (MAF) and other key stakeholders can use the data collected by NOAA-CREP as a starting point, or baseline, for long-term monitoring of the status and trends of the habitats, marine resources, and biodiversity of Timor-Leste with the objective of informing coastal management decisions and evaluating the effectiveness of the resulting actions for sustainably managing coastal fisheries and development for the long-term benefits of the people of Timor-Leste. These benefits include improving food security, sustaining marine-based livelihoods, and ensuring coastal protection. This report both highlights the special nature of the nearshore waters of Timor-Leste and demonstrates that habitats and marine resources, as well as threats, are heterogeneously distributed. As such, the information provided in the report provides a robust foundation for MAF or other coastal stakeholders to implement various types of marine spatial planning for responsible use of Timor-Leste's nearshore habitats and ecosystem resources. The successful delineation of nearshore habitats and bathymetry and their associated mapping products, in conjunction with the Coral Reef Ecosystem Assessments, will aid MAF in establishing spatially-explicit management approaches that can target specific habitat types or areas of high reef productivity (for example, high coral cover or abundant fish biomass). Continued monitoring and assessment of the coral reef communities, seawater chemistry, and reef processes using the NOAA-CREP methodologies described herein will build upon these baseline datasets and help MAF understand how the nearshore and coral reef ecosystems of Timor-Leste change through time under differing management and climate change scenarios.

1. INTRODUCTION

Overview

This is the final report on the activities performed by the United States National Oceanic and Atmospheric Administration (NOAA) from 2012 to 2016, through a partnership agreement with the United States Agency for International Development (USAID) Timor-Leste Mission to support the Government of Timor-Leste, particularly the Ministry of Agriculture and Fisheries (MAF). Based on consultative discussions among USAID, MAF, and NOAA, these activities provide essential baseline fisheries and marine resource information to inform marine ecosystem-based fisheries management in the nearshore waters of Timor-Leste. These efforts were funded primarily by the USAID Timor-Leste Mission, with significant in-kind contributions and support from NOAA, as part of the 5-year partnership between NOAA and USAID.

Background

The Coral Triangle has the highest marine biological diversity in the world. Coral reefs and fisheries in this region encompass the tropical waters of Malaysia, Indonesia, the Philippines, Papua New Guinea, the Solomon Islands, and Timor-Leste (Figure 1). One in three people in the Coral Triangle region depend upon coral reefs for subsistence and livelihood. With expanding populations and development, increased global food demands, and extensive poverty, the coral reefs and fisheries in this region are both highly valued and severely threatened by numerous stressors, including overfishing/gleaning, destructive fishing, land-based pollution, climate change, ocean acidification, and other effects from human activities and natural events. In these developing coastal and island nations, managing and conserving coral reef ecosystems for future generations links inextricably to provision of food, enhanced resilience to climate change, and capacity for alternative livelihoods.

The need to sustainably manage and protect coral reefs and their associated resources across the Coral Triangle was highlighted as a priority by President Yudhoyono of Indonesia in 2007. In 2009, the six countries of the Coral Triangle, including Timor-Leste, established a multi-national ocean governance partnership called the *Coral Triangle Initiative on Coral Reefs, Fisheries, and Food Security* (CTI-CFF) to work toward improved management of marine and coastal resources throughout the region. The six countries of the CTI-CFF adopted a Regional Plan of Action with five overarching goals:

1. Priority seascapes designated and effectively managed
2. Ecosystem approach to fisheries management (EAFM) and other marine resources fully applied
3. Marine protected areas (MPAs) established and effectively managed
4. Climate change adaptation measures achieved
5. Threatened species status improving

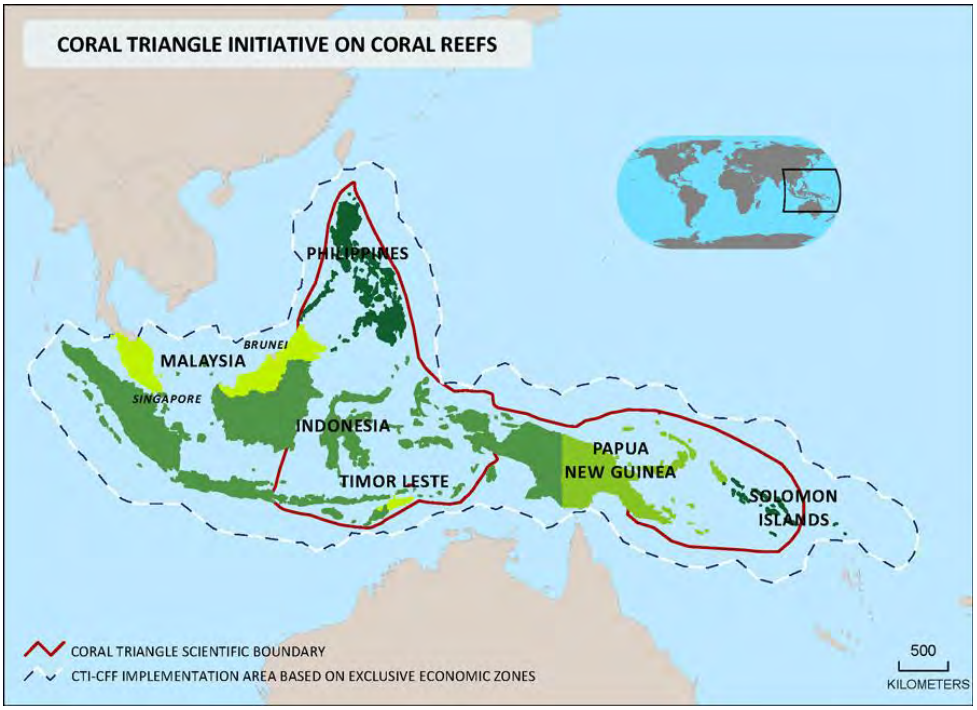


Figure 1. Map of the six countries of the Coral Triangle Initiative on Coral Reefs, Fisheries, and Food Security. Dashed line shows implementation area, based on Exclusive Economic Zones (Flanders Marine Institute 2016). Solid line shows scientific boundary of the Coral Triangle (Veron et al. 2009). Image courtesy of Coral Triangle Secretariat.

The United States committed substantial resources through the Department of State and the USAID Regional Development Mission for Asia (RDMA) and formed the United States Coral Triangle Initiative (USCTI) designed to assist the six countries achieve the ambitious and forward-thinking goals of the CTI-CFF. In executing USCTI, USAID established a Program Integrator for management and administration of the overall effort, a consortium of international non-governmental environmental organizations called the Coral Triangle Support Partnership (CTSP) consisting of the World Wildlife Fund, The Nature Conservancy, and Conservation International who can provide on-the-ground implementation support, and NOAA who provides world-class government-to-government technical expertise in NOAA's mission of science, service, and stewardship of the nation's coastal and ocean resources.

In 2011, Dr. Rusty Brainard of the NOAA Pacific Islands Fisheries Science Center's Coral Reef Ecosystem Program (NOAA-CREP) became NOAA's technical lead for the CTI-CFF Goal 2 which promotes an ecosystem approach to fisheries management (EAFM) across the six Coral Triangle countries. As a result, NOAA began working closely with the colleagues at USAID-RDMA, CTSP, the Program Integrator, and the primary fisheries agencies in each of the six countries. NOAA's objective was providing both technical assistance and capacity building toward the application of an EAFM and science supporting an EAFM leading to growth, conservation, and sustainability for food security, livelihoods, biodiversity, economic development, and threatened species.

Timor-Leste

As one of the six Coral Triangle countries working toward implementation of an EAFM, Timor-Leste's food security, human health and well-being, and facility for adapting to climate change depend in part upon its capacity for management and conservation of its coastal and nearshore marine resources. Based on initial successes with the USCTI regional efforts, environment officer Peter Cloutier of USAID Timor-Leste reached out to the NOAA CTI Program Manager Dr. Janna Shackeroff and Dr. Brainard in May 2011 to initiate the establishment of a bi-lateral partnership which would provide technical assistance in support of an EAFM and improved ocean stewardship for the people of Timor-Leste. In August 2011, the USAID Timor-Leste Mission Director, Rick Scott, hosted Drs. Shackeroff and Brainard through a series of consultative meetings with the Government of Timor-Leste's Ministry of Agriculture and Fisheries (MAF) in which they discussed and developed a draft partnership agreement and work plan to best enhance the capacity of the Government of Timor-Leste and local communities in management and conservation of nearshore fisheries and ecosystems along with the goods and services they provide to the Timorese people.

During those discussions, both MAF and USAID Timor-Leste requested that NOAA focus initially on filling significant information gaps regarding their coastal and marine ecosystems prior to moving toward training-focused activities aimed at building capacity in utilizing the information provided by NOAA. Both USAID Timor-Leste and MAF officials stated that MAF staff was overwhelmed by numerous, well-intended training activities that left many staff with insufficient time to perform their job functions. Accordingly, MAF prioritized their request to USAID Timor-Leste for NOAA's technical assistance primarily in obtaining baseline scientific data for the nearshore marine ecosystems around Timor-Leste as an essential first phase of the partnership, followed by capacity building in data collection and utilization in the later phases of the partnership. Specifically, they requested technical assistance from NOAA focused on addressing the following questions:

1. Where are Timor-Leste's nearshore marine resources?
2. What are Timor-Leste's nearshore resources and how do coastal people and communities rely upon these resources?
3. How are the coastal and fisheries resources changing over time?
4. What are the threats to the nearshore resources that are causing these changes?
5. What approaches are needed to help manage and conserve the nearshore resources towards ensuring food security, livelihoods, and adaptation to climate change over the long-term?

Though neither USAID nor NOAA could firmly commit to a long-term agreement, both NOAA and USAID Timor-Leste acknowledged that addressing and resolving any of these prioritized needs would require sustained engagement by NOAA. Shorter-term efforts would likely compromise success through inefficient use of USAID's resources and NOAA's institutional and personnel engagement.

As a result of those early discussions, numerous email exchanges, and conference calls over the following months, USAID Timor-Leste and NOAA developed and agreed upon a 5-year work plan whereby USAID Timor-Leste would provide funding support to NOAA (subject to Congressional appropriations and mission priorities) for technical assistance and capacity building in baseline assessments and monitoring of the nearshore marine ecosystems to help managers apply scientific information toward decision-making that supports coastal and fisheries management using an EAFM. The following activities were proposed, initially agreed upon, and most were implemented to address these five key questions over the next five years, though some modifications to the work plan did occur over time as USAID Timor-Leste's programmatic requirements shifted away from the marine sector.

1. Where are Timor-Leste's nearshore marine resources?

Activity: Satellite mapping of nearshore habitats

For effective management of their resources, managers must know where the different habitats and their resources are located. Since marine and fisheries resources are not uniformly distributed along coastlines, habitat maps which delineate coral reefs, seagrass beds, mangroves, and other habitats are foundational in establishing ecosystem baselines and informing coastal resource management decisions. Timor-Leste was missing two important pieces of data in its nearshore ecosystem maps: depth and key features of benthic habitats. NOAA-CREP acquired and processed high-resolution, WorldView-2 satellite imagery along much of the coastline of Timor-Leste to derive estimated depths and benthic features. The resulting maps can now be used as foundational layers which can support resource management decision-making (e.g., restricted fishing areas, marine spatial planning, coastal development and permitting, etc.), designing scientific survey efforts, and ecosystem modeling. Depth and habitat information are also useful in scoping and defining fisheries management units and developing EAFM plans well into the future.

See Chapter 2. *Satellite Mapping of Nearshore Habitats* for further details on this activity.

2. What are Timor-Leste's nearshore resources and how do coastal people and communities rely upon these resources?

Activity A: Coral reef ecosystem assessments

Knowing the status of nearshore fisheries and marine resources (including their location, quantity, and condition) is critical information for effectively managing coastal and nearshore ecosystems and protecting food security in a changing climate. NOAA conducted surveys of reef fish and their habitats along the entire north coast of Timor-Leste.

See Chapter 3. *Coral Reef Ecosystem Assessments* for further details on this activity.

Activity B: Building socioeconomic monitoring capacity and establishing a baseline assessment of Timorese reliance upon nearshore ecosystems and vulnerability to climate change

Due to changes in personnel (therefore expertise available) within NOAA's Coral Reef Conservation Program (CRCP) and a steep increase in costs associated with carrying out marine resource assessment activities along the south shore of Timor-Leste (a concern brought up with initial work planning), this activity was canceled and USAID agreed that associated funding should be transferred to the marine resource field assessments and spatial data framework.

3. How are resources changing over time? and 4. What are the threats to the nearshore resources?

Activity A: Establishing a baseline for climate change

Climate change and ocean acidification pose significant threats to nearshore marine resources, biodiversity, and the ecosystem goods and services they provide to coastal communities, such as food security, livelihoods, and coastal protection. The potential impacts of these threats are poorly understood. At the request of the Timor-Leste government's request for assistance, NOAA deployed a suite of relatively low-budget climate assessment instruments in shallow-water reef areas around Timor-Leste, using standardized methods established for use across the U.S. Pacific Islands and elsewhere in the Coral Triangle. These data establish a baseline for future monitoring activities of several climate change-related parameters in the nearshore ecosystem. These data also build capacity by improving understanding of the cascading impacts of climate change and ocean acidification on the nearshore ecosystems and resources.

See Chapter 4. *Establishing Ecological Baselines for Climate Change* for further details on this activity.

Activity B: Building biophysical and socioeconomic monitoring capacity

This activity, which was planned for the later phases of the partnership, was canceled by USAID Timor-Leste Mission in late 2013 as the capacity building components of the later phases were not included in their new 5-year strategic plan. A portion of the associated funding was transferred to assist with the marine resource field assessments and spatial data framework project.

5. What approaches (and/or tools) are needed to help manage and conserve the nearshore resources towards ensuring food security, livelihoods, and adaptation to climate change over the long term?

Activity A: Building management capacity by developing a spatial data framework

NOAA supported the government of Timor-Leste by providing guidance and technical assistance to MAF in the development of a spatial data framework for integrating the new basemaps and baseline datasets. This will help managers determine what resources need managing, where those resources are located, where baseline data have been collected, and the types of data collected all together in a visual format for planning and decision-making.

See Chapter 5. *Developing a Spatial Data Framework* for further details on this activity.

Activity B: Building capacity in ecosystem-based management of Timor-Leste's nearshore ecosystems and ecosystem services they provide

During the early phases of the effort, NOAA led a workshop with leaders from fisheries and other sectors in which the benefits of applying data layers to an EAFM for planning and implementation was introduced. In the final phase of the effort, NOAA transitioned to capacity building for conducting science pertinent to ecosystem-based management. This was done by working with local partners on the methods associated with the assessment efforts and further engaging communities during each in-country activity.

For the final year of the effort, the focus was on capacity building to institutionalize knowledge and on training capabilities in core areas applicable to nearshore marine ecosystem assessments that apply to management. However, NOAA was notified by USAID Timor-Leste that changes to the initial work plan needed to be made to phase out NOAA work in the country. In developing the work plan revisions, NOAA carefully incorporated the knowledge and experiences acquired over the first two years of working in Timor-Leste (i.e., reality checks). As agreed upon with USAID, the revised work plan was based on a local in-country partner's ability to assist with on-the-ground coordination and communication with Timor-Leste government agencies and key stakeholders.

In the revised work plan, the capacity building efforts planned primarily for the final phase of the project were canceled. While the formal capacity building efforts were eliminated, NOAA included workshops during the final phase on using the data and information in both the short-term and in the long-term which could, in turn, be applied toward more effective management of coastal and fisheries resources in the face of climate and ocean changes.

Final workshops were planned for 2015 and 2017 in an effort made by NOAA to deliver the data and spatial framework in a meaningful way, the most helpful to Timor-Leste given these changes. As a result, a Geographic Information System (GIS) workshop was held in 2015 with the AL-GIS team. At this point, NOAA introduced the spatial data framework that allows MAF to convert the raw data collected into a useable format for decision makers strengthening the relationship between the data managers and those tasked with management decisions. In 2017, a workshop is planned with USAID and MAF to deliver the final data and report and socialize the information with MAF partners and stakeholders.

See Appendix A. *Capacity Building and Community Engagement* for further details on these activities.

2. WHERE ARE THE NEARSHORE RESOURCES LOCATED?
SATELLITE MAPPING OF NEARSHORE HABITATS

What did we do, and why is this information important?

Bathymetry is the foundation for much ocean science and policy. In the same way that topographic maps represent the three-dimensional features of the terrain on land, bathymetric maps illustrate the terrain that lies underwater. Bathymetric data, which include information about the depths and shapes of underwater terrain, are essential for characterizing marine habitats and have a range of important management applications. Bathymetry is a key element of biological oceanography. The depth and characteristics of the seabed define the habitat for benthic (bottom-dwelling) organisms and are fundamental aspects of marine ecosystems. Nearshore bathymetric data are increasingly important as scientists learn more about the effects of tsunamis, cyclones, and climate change-driven sea level rise on coastal communities and economies.

Bathymetric data for shallow-water areas are critical for assessing the status of coral reef ecosystems located there, as the exchange of nutrients, sediments, and pollutants between the land and ocean must pass through these habitats. It is also an area susceptible to anthropogenic impacts, such as sedimentation, nutrient enrichment, and ship groundings. Perhaps most importantly for the people and coastal communities of Timor-Leste, these nearshore areas provide food and livelihoods (Figure 2). Therefore, these data can be useful in helping protect and manage these fragile resources that support high levels of biodiversity.

Figure 2. A panoramic view of local fishers reef gleaning at low tide on the north coast of Timor-Leste near Manatuto (*top*) and a close-up showing two of the fishers gleaning (*bottom*).

Bathymetric data can be acquired by many techniques, each with varying degrees of accuracy and resolution. Collecting bathymetric data for shallow-water habitats can be challenging—especially in remote locations—as many available options are logistically unfeasible or prohibitively expensive. For such locations, satellite-derived bathymetry, also referred to as estimated depths, has been shown to be an effective technique. NOAA-CREP has developed and refined methods for deriving depth from high-resolution WorldView-2 satellite imagery for shallow-water coral reef habitats (Ehses and Rooney 2015). Along with the satellite-derived depths, NOAA-CREP has also developed new methods of identifying different marine habitats (e.g., sand flats, seagrasses) by interpreting patterns in seafloor terrain from WorldView-2 satellite imagery for the shallow-water habitats.

NOAA-CREP has applied these two methods here to develop baseline maps for the nearshore habitats along the coastline of Timor-Leste.

Where and how did we do it?

Satellite Imagery Acquisition and Analysis

The region of interest for this mapping effort focused on coastal shallow-water habitats (Figure 3). NOAA-CREP contracted with DigitalGlobe (http://www.digitalglobe.com/) for the acquisition of high-resolution WorldView-2 satellite imagery for the coastline of Timor-Leste. The WorldView-2 imagery is composed of 8-multispectral imaging bands, including a coastal band that allows for greater penetration in clear waters, an important consideration in bathymetric mapping of nearshore habitats (DigitalGlobe 2010). The spatial resolution of the WorldView-2 imagery varies from 46–52 cm for panchromatic and from 184–210 cm for multispectral.

We evaluated both archived and newly collected image swaths with DigitalGlobe ensuring the highest quality images available for each of the regions were purchased. Images for the south shore were specifically acquired during the dry season in September and October, assuming the nearshore waters would be less turbid at that time, thereby improving the quality of those images. DigitalGlobe permitted us to decline images for the same area up to three times before making a final selection. Images with minimal cloud cover, water turbidity, and sun glint (the amount of light reflected from the ocean surface) and with a higher solar elevation angle (angle of the sun above the horizon) were selected. DigitalGlobe was unable to fulfill our quality requirements for all regions and therefore provided an excess set of images to peruse. A method referred to as “cloud patching” had to be applied to some areas, especially along the shore of Timor-Leste, using cloud-free portions of an image rather than the whole image for processing.

Altogether, 104 high-resolution unprocessed WorldView-2 satellite images, collected between January 2010 and August 2014, were acquired for Timor-Leste (Appendix B). Each image provided by DigitalGlobe was roughly clipped to the region of interest boundaries; areas outside the region of interest were masked out (Figure 3). Complete image coverage was achieved for the coastlines of Oecusse, Atauro Island, and the north and south shores of Timor-Leste. Overall challenges in acquiring WorldView-2 imagery of sufficient quality included cloud cover, sun angle and glint, waves and whitewater, and particularly, nearshore turbidity caused by run-off of terrestrial sediments during heavy rains.

After evaluating the quality of each image, 68 were deemed suitable for potentially deriving depths or for benthic habitat classification (Figure 3). The remaining images were either unsuitable due to high turbidity, cloud cover, etc., or they overlapped with higher quality images; therefore, further processing of these images was not required.

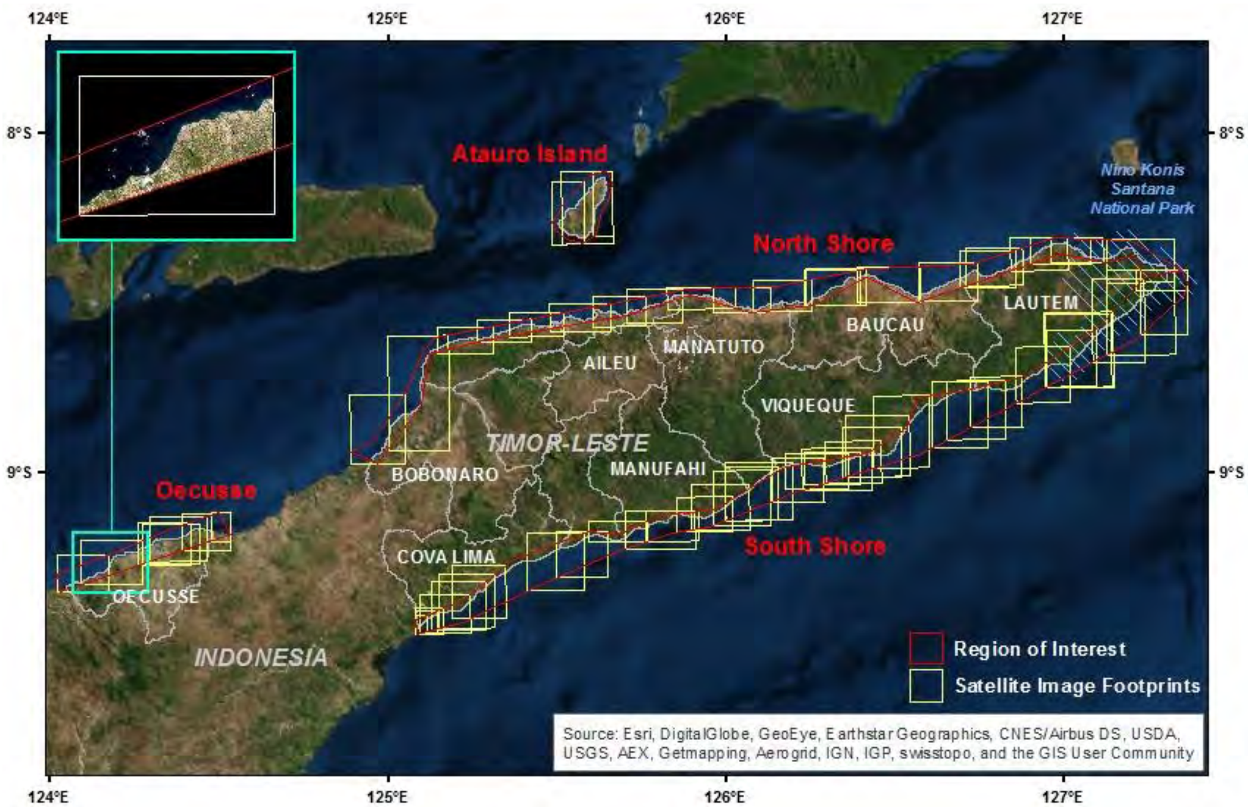


Figure 3. Map showing the region of interest outlined in red around Timor-Leste of which 68 WorldView-2 satellite images were acquired and georeferenced (yellow boxes). Inset shows an example of the extent for one satellite image that was clipped to the region of interest.

The typical geolocation accuracy of a standard WorldView-2 product is in the range of 4–5 m. Depth estimations are sensitive to high geographic accuracy because *in-situ* depth values (i.e., ground-truth data) correspond to specific coordinates. Therefore, our goal was improving the accuracy of the raw images' geographic location by associating them to a georeferenced basemap. At the time, the only known available large-scale basemap covering Timor-Leste was an ESRI ArcGIS online map (http://www.esri.com/data/basemaps). This was used to georeference the 68 raw satellite images.

Prior to extracting estimates of depth based on coastal, blue, green, and yellow bands in the georeferenced satellite image, radiometric corrections were applied using DigitalGlobe's established processing procedures. Depth soundings, collected during NOAA-CREP's field operations in Timor-Leste in October 2012 and June 2013, were then used to validate or ground truth the estimated depths derived from the satellite imagery (Figure 4). Next, benthic habitats were classified into one of 12 different habitat classes. Areas that could not be classified, primarily due to the depth limitations of satellite imagery, were labeled as unknown. See Appendix C for details on the processes to derive estimated depths and classify benthic features from WorldView-2 satellite imagery and available ground-truth data.

Figure 4. Depth soundings collected during NOAA-CREP surveys in 2012 (black) and 2013 (blue) used to validate the estimated depths derived from the satellite imagery.

What did we accomplish?

Bathymetry

We generated satellite-derived bathymetry in shallow waters, from the shoreline to approximately 15-m depths, for Atauro Island, Oecusse, and most of the north shore of Timor-Leste with relatively small gaps (Figure 5). These gaps mainly occur in areas of surf, breaking waves, and intensive glint. Insufficient depth soundings which would support effective groundtruthing and prolonged periods of high turbidity (i.e., low visibility) caused by extensive rain and sediment runoff prevented the calculation of reliable estimated depths for the entire south coast. In total, we derived estimated depths over a ~120.0 km^2 area surrounding Atauro Island (15.1 km^2), Oecusse (19.3 km^2), and the north shore of Timor-Leste (85.6 km^2; Table 1).

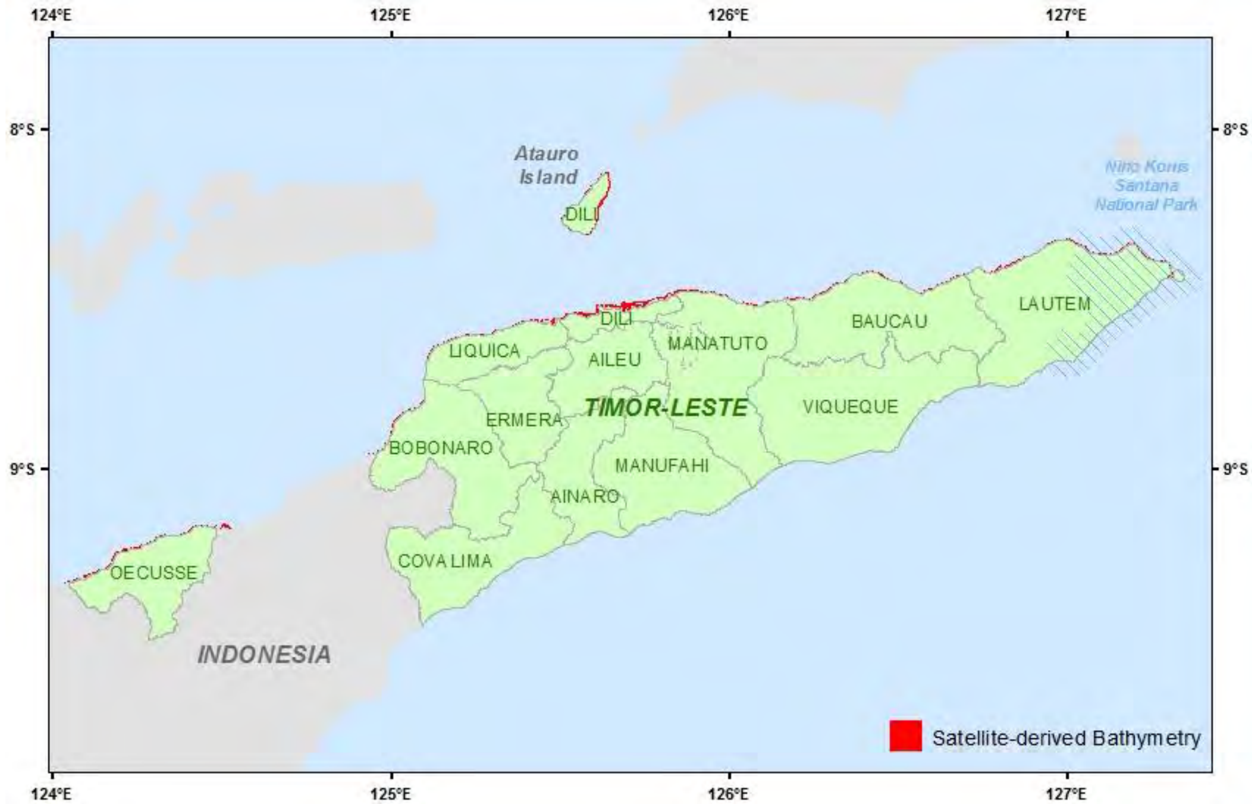


Figure 5. The extent of the satellite-derived bathymetry prepared for Timor-Leste is shown in red.

Table 1. Summary of the satellite-derived bathymetry and habitat classification efforts. 'Derived Bathymetry' and 'Benthic Habitat' is the area mapped by region (km^2). 'Unknown' is the area that could not be classified and is therefore excluded from the 'Benthic Habitat' area. The remaining columns in light green show the benthic habitat characterized for each region (km^2) that are included in the 'Benthic Habitat' area.

Region	Derived Bathymetry (km^2)	Benthic Habitat (km^2)	Hard Substrate (km^2)	Soft Substrate (km^2)	Seagrass (km^2)	Mangrove (km^2)	Macroalgae (km^2)	Intertidal (km^2)	Emergent Rocks (km^2)	Lagoon (km^2)	Unknown (km^2)
Atauro Island	15.1	13.1	7.1	3.6	2.4	0.1	–	–	–	–	7.7
Oecusse	19.3	12.6	3.8	6.8	2.0	< 0.1	–	–	–	–	16.8
North Shore	85.6	76.9	35.1	16.3	10.5	2.7	6.2	3.3	0.5	2.3	249.1
South Shore	–	32.7	14.3	15.3	3.0	0.1	–	–	–	–	120.0
Total	**120.0**	**135.3**	**60.3**	**41.9**	**17.9**	**2.9**	**6.2**	**3.3**	**0.5**	**2.3**	**393.6**

Benthic Habitat

Benthic habitat area by region is less than the satellite-derived bathymetry coverage in the three regions where both were derived; Atauro, Oecusse, and North Shore. This is due to the depth limitations of the satellite imagery and the lack of available validation data for the habitat classifications (Table 1). Like the estimated depth calculations, the quality of benthic habitat classifications is highly dependent on the quality of the images; good visibility is essential. Therefore, the largest gaps in the benthic habitat dataset are along the southern coast of Timor-Leste (Figure 6). Further, the lack of sufficient *in-situ* habitat data across the entire region was problematic. In lieu of having sufficient validation data, local knowledge and visual interpretations of the benthos were used to aid in the benthic habitat characterization. Despite these challenges, we can provide a partial benthic habitat dataset for the shallow (0–20 m) coastal seafloor around Timor-Leste. The resulting dataset summarized 12 characterized habitat classes into 8 habitat types, including: 1) hard substrate, 2) soft substrate, 3) seagrass, 4) mangrove, 5) macroalgae, 6) intertidal, 7) emergent rocks, and 8) lagoon. In total, benthic habitat data covering 135.3 km^2 of nearshore habitats in Timor-Leste (excluding unknown areas) were developed around Atauro Island (13.1 km^2), along the coast of Oecusse (12.6 km^2), and along the north and south shores (76.9 km^2 and 32.7 km^2, respectively; Table 1). We were not able to assess the quality of the benthic habitat classifications due to the lack of ground-truth data.

Figure 6. The extent of the benthic habitat dataset prepared for Timor-Leste is shown in blue.

Detailed Maps

A "Map Book" containing a collection of detailed bathymetry and benthic habitat maps for the entire coastline of Timor-Leste has been developed (Appendix D). The maps include additional information allowing for wider utilization, including the location of the NOAA-CREP baseline reef assessment and climate survey sites, satellite imagery for the land area, water features, district boundaries, and place names. High-resolution maps are also provided to better characterize each of the climate survey sites (Appendix E).

Poster Presentation

The process of this satellite mapping work for Timor-Leste was presented in a poster at the 13th International Coral Reef Symposium held in Honolulu, Hawaii in June 2016. See Appendix F for a reduced-size copy of the poster titled *WorldView-2 Satellite Mapping of the Nearshore Ecosystems around Timor-Leste: Goals, Challenges and Accomplishments*.

3. WHAT ARE THE NEARSHORE RESOURCES?
CORAL REEF ECOSYSTEM ASSESSMENTS[1]

What did we do, and why is this information important?

Nearshore and coral reef fishes provide sustenance and livelihoods for the people of the coastal communities of Timor-Leste. The condition of fish populations is related to overall reef health, which is influenced by interconnected oceanographic, climatic, and ecological processes, as well as the interactions of various human activities on land and in the ocean. Assessing and monitoring reef fish assemblages along with the benthic communities and ocean conditions is important in establishing a more complete baseline of the coral reef ecosystem and the fish community it supports. This baseline can then be used as a starting point for monitoring changes to the coral reef community over time and better understanding status and the long-term trends of fish and coral populations.

In 2013, NOAA-CREP conducted surveys, which generated baseline data on the composition and abundance of the reef fish and the associated benthic community cover (Figure 7). The baseline data gathered from the reef fish and benthic surveys in Timor-Leste can inform management in a variety of ways. For example, information on reef fish abundance and size-frequency distributions can inform decisions about the status of a fishery, such as whether the resources are being sustainably fished or potentially over-exploited. The integrated reef fish and benthic data can inform managers about the different patterns of habitat utilization by different species and guide the development of marine managed areas or other management measures aimed at protecting key species or habitats of interest. Benthic cover is the most widely used metric for assessing coral reef condition because it is relatively easy to acquire, and changes in cover often reflect environmental and/or human-induced disturbance regimes that influence the overall structure and function of the reef ecosystem (Jokiel et al., 2015; Rogers, et al., 1994).

Assessment of benthic habitat characteristics at the sites where fish surveys were conducted was done using two complementary methods. The first, rapid visual assessments, were made by divers who visually estimated the percent cover of major benthic categories (e.g., coral, macroalgae, sand, other). The second method consisted of divers who conducted a photo transect through the middle of survey transects. Analysis of photo-quadrat provides taxonomically finer-scale information on the benthic community composition, but requires time for processing the images post-survey. Because of this time lag, only the visually-estimated benthic data were reported in McCoy et al. (2015). Post processing of the photo-quadrat data has since been completed and those finer-scale data are reported here.

[1] Except where noted, the content in this chapter has been adapted from the Methods, Summary and Results & Discussion sections of McCoy et al. (2015).

Figure 7. A NOAA-CREP SCUBA diver conducting a reef fish survey in Timor-Leste.

Where, when and how did we do it?

Survey Design

The surveys used a common stratified random survey design, where sites were randomly selected from hard-bottom habitats within two depth strata (Ayotte, et al., 2015). Due to the large area of coastline and logistical/fiscal constraints, survey efforts were focused on eight sections of coastline (hereafter referred to as sectors) within 7 districts (Figure 8). Each sector was treated as an independent survey area, and was separated by at least 18 km of coastline from adjacent sectors, except for East and West Atauro, which were separated by 2 km. The target survey areas were hard-bottom habitats in either shallow (0–6 m) or mid-depth (6–18 m) range. For most NOAA-CREP reef fish assessments, survey allocation is determined by area of hard-bottom reef habitat within 3 depth ranges; shallow, mid, and deep (18–30 m). The deep area of reef habitat was not surveyed during the Timor-Leste surveys due to safety restrictions set by the NOAA Diving Program that require timely accessibility to a recompression chamber. Bathymetry and hard-bottom reef habitat maps were not available at the time of the mission planning (and have since been developed under the activity, *Satellite Mapping of Nearshore Habitats*), so sites were randomly selected within an estimated 30 m depth contour. Once the divers arrived at the randomly located survey sites, they assessed the benthos to determine whether habitat and visibility were suitable and moved to the selected depth range. See Appendix G for details on the methodology to survey reef fish and to estimate benthic cover.

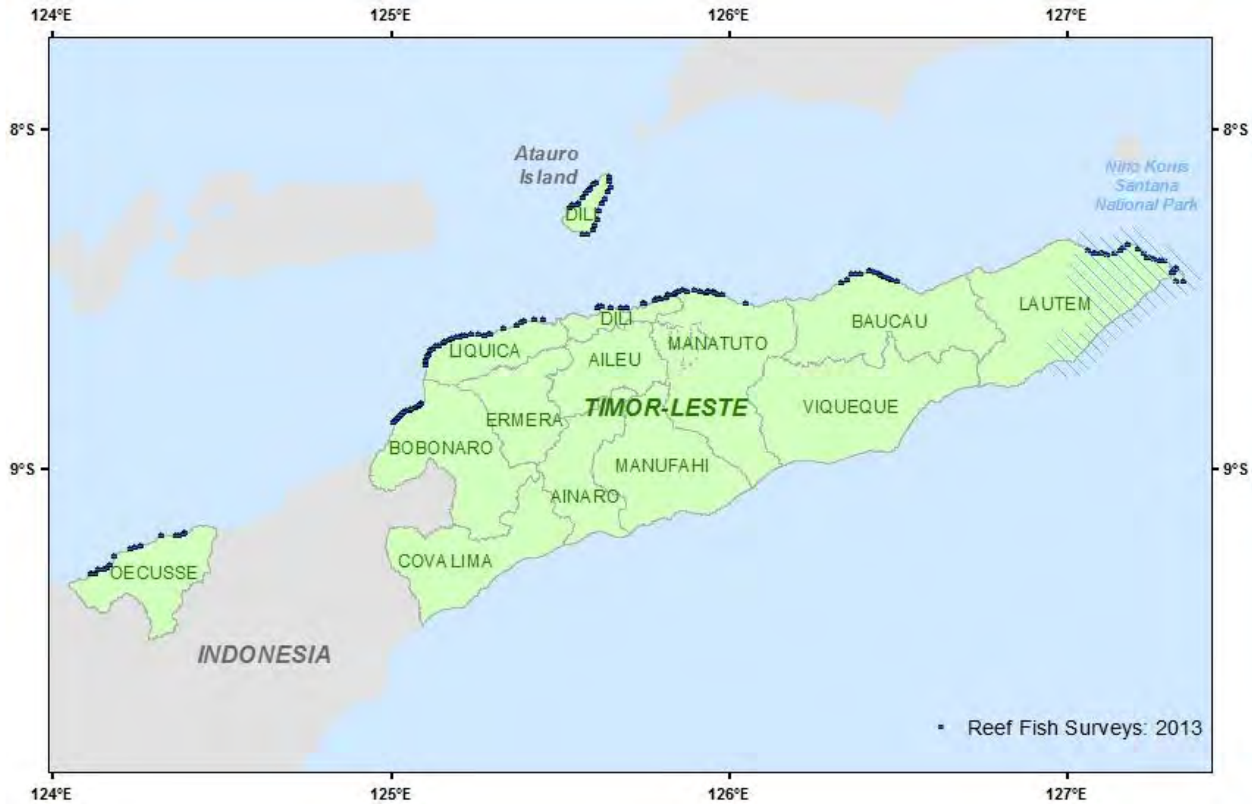


Figure 8. Map of locations where NOAA-CREP conducted reef fish surveys along the north coast of Timor-Leste and around Atauro Island in June 2013.

2013 Activities

In total, reef fish surveys were conducted at 150 sites along Timor-Leste's north shore from June 4–27, 2013 (Appendix H). Photographs of the benthos were collected and analyzed for benthic cover at 139 of those sites. See Appendix H for a list of the sites surveyed. Surveys were not conducted along the southern coastline due to weather and logistical/fiscal limitations.

What did we find?

Reef Fish Assemblages

Total Reef Fish Biomass

Total reef fish biomass at the 150 sites varied between 1.1 g m^{-2} and 283.9 g m^{-2}. There were many sites with relatively low-to-moderate biomass and only a few sites where total fish biomass was at the high end of the scale, compared with other locations surveyed by NOAA-CREP across the Pacific islands. The median value (the level at which half of the sites had lower biomass and half of the sites had higher biomass) was 31.5 g m^{-2} (Figure 9).

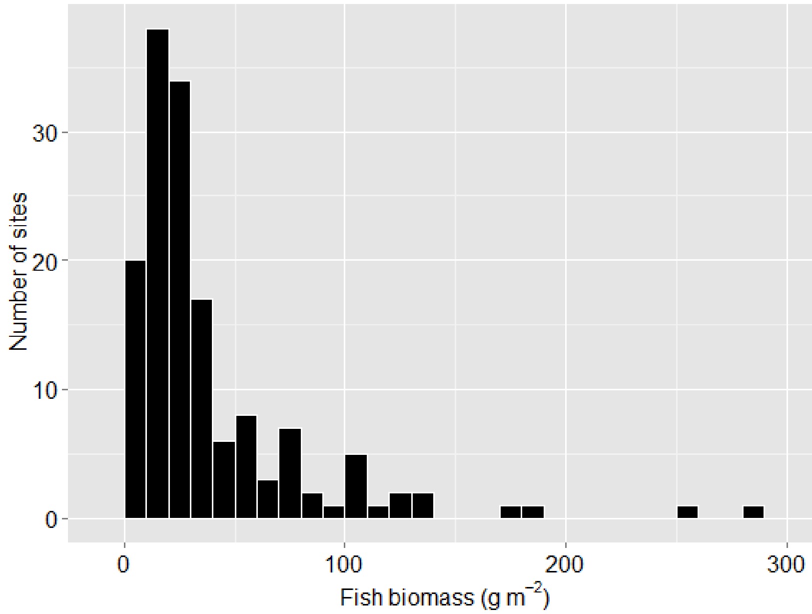


Figure 9. Distribution of total reef fish biomass observed per site.

Fish Biomass by Geographic Region and Trophic Group

Total reef fish biomass for Timor-Leste averaged 41.1 g m^{-2} (standard error [SE] 3.1), which is slightly higher than other populated areas in the Pacific (30.6 g m^{-2} [SE 2.1]), but more comparable to populated than remote areas (119.2 g m^{-2} [SE 11]; Figure 10).

Reef fish biomass by trophic group classifications include: 'primary consumers' are herbivores that eat marine plants and detritivores that eat detritus (largely comprised of surgeonfishes and parrotfishes); 'secondary consumers' are omnivores that eat marine plants and animals and invertivores that eat benthic invertebrate organisms (includes most wrasses, butterflyfishes, triggerfishes, and filefishes); 'planktivores' that eat drifting marine plants (phytoplankton) and animals (zooplankton) (includes several unicornfishes, damselfishes, fusiliers, and several soldierfishes); and 'piscivores' that eat other fish (includes most jacks, groupers, emperors, barracudas, sharks, moray eels, and lizardfishes).

Planktivores made up the majority of the overall fish biomass (50.3%), followed by primary consumers (22.3%), secondary consumers (18.8%), and lastly, piscivores (8.6%; Figure 10).

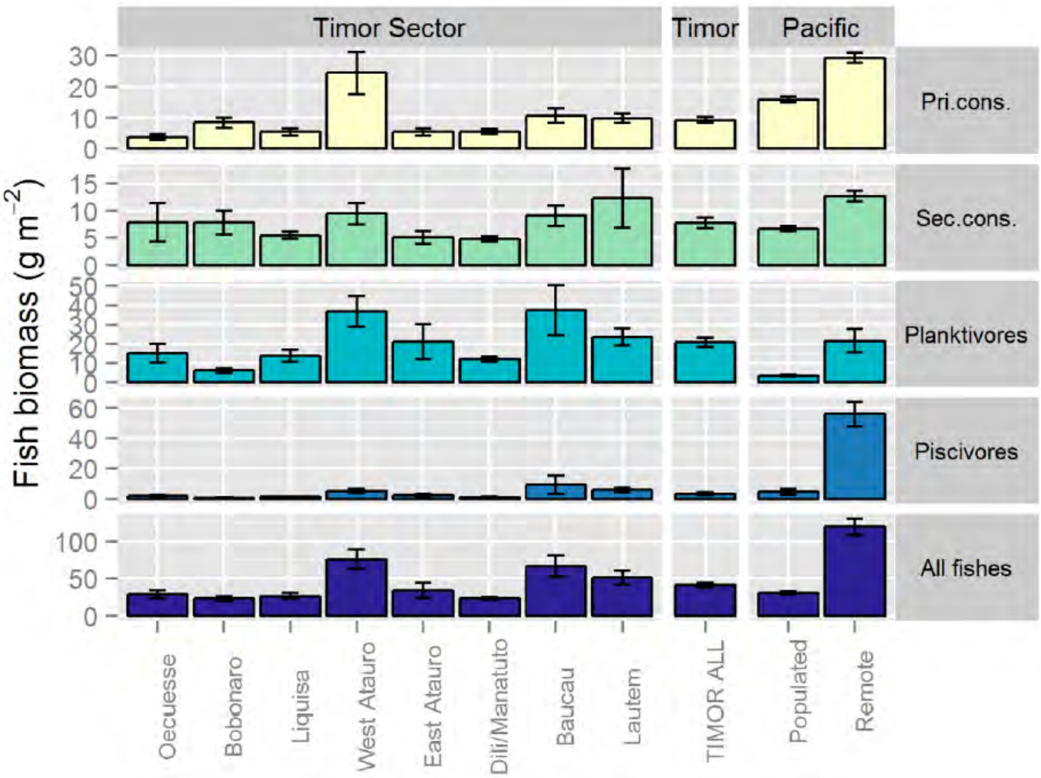


Figure 10. Average reef fish biomass by fish trophic group per Timor-Leste sector. Sectors are ordered from west to east. The average among all sectors is shown as TIMOR ALL. Populated average is pooled from 923 sites from highly human-populated Pacific islands, and remote average is pooled from 858 sites from sparsely-human populated Pacific islands. Note different scales on *y*-axes. Error bars show standard error (SE). See text for explanation on tropic classification groups.

The west side of Atauro Island had the highest average fish biomass (75.9 g m^{-2} [SE 12.90]), while Dili/Manatuto (23.4 g m^{-2} [SE 2.0]) and Bobonaro (23.0 g m^{-2} [SE 3.1]) sectors had the lowest (Figure 11). The high biomass in West Atauro may be related to the relatively high structural complexity of the reef, which was dominated by a steep wall.

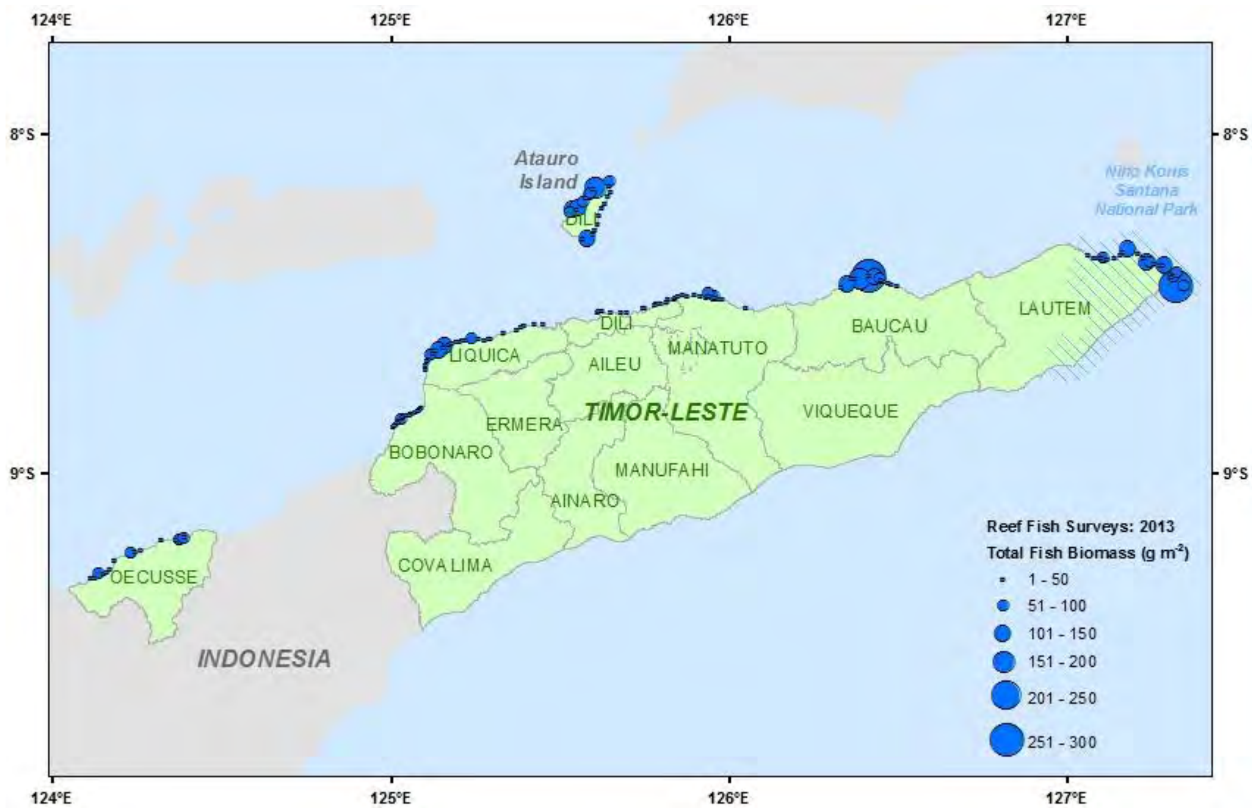


Figure 11. Total reef fish biomass per survey site.

Fish Biomass by Family

The surgeonfish family had the highest overall fish biomass (8.2 g m^{-2} [SE 1.1]) and made up 19.8% of the total fish biomass (Figure 12). Overall, the average biomass observations of snappers, breams, groupers, parrotfishes, and emperors (often important as fishery targets) were comparable to other populated areas in the Pacific, although average fish biomass in West Atauro was comparable to other remote areas in the Pacific for these families (Figure 12) suggesting that there is either high biological productivity at West Atauro or that fish assemblages are relatively unimpacted by human activities there.

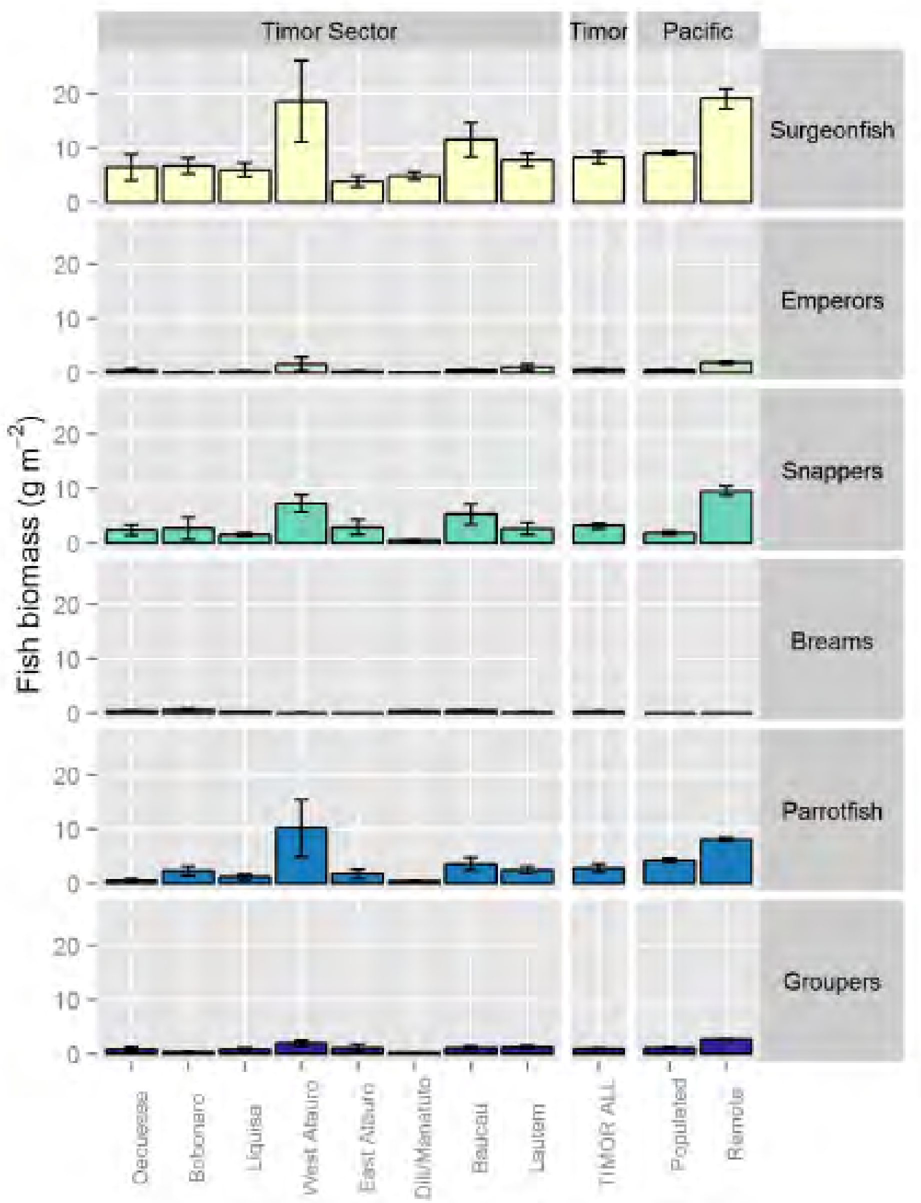


Figure 12. Average reef fish biomass (standard error) by family per sector. Sectors are ordered from west to east. Timor-Leste average among all sectors is shown as TIMOR ALL. Populated average is pooled from 923 sites from highly human-populated Pacific islands, and remote average is pooled from 858 sites from sparsely-human populated Pacific islands. Error bars show standard error (SE).

Fish Biomass by Size Class

Fish biomass was pooled into three size classes: small- (0–20 cm), medium- (>20–50 cm), and large-bodied reef fish (> 50 cm). Small-bodied reef fish made up the majority of the biomass overall, and in each sector (Figure 13). Overall, the biomass of small-bodied reef fish in Timor-Leste was comparable to the results of NOAA-CREP surveys at remote, unpopulated areas in the Pacific islands. Biomass estimates for medium- and large-bodied reef fishes were generally comparable to values from other human-populated areas in the Pacific islands surveyed by NOAA-CREP.

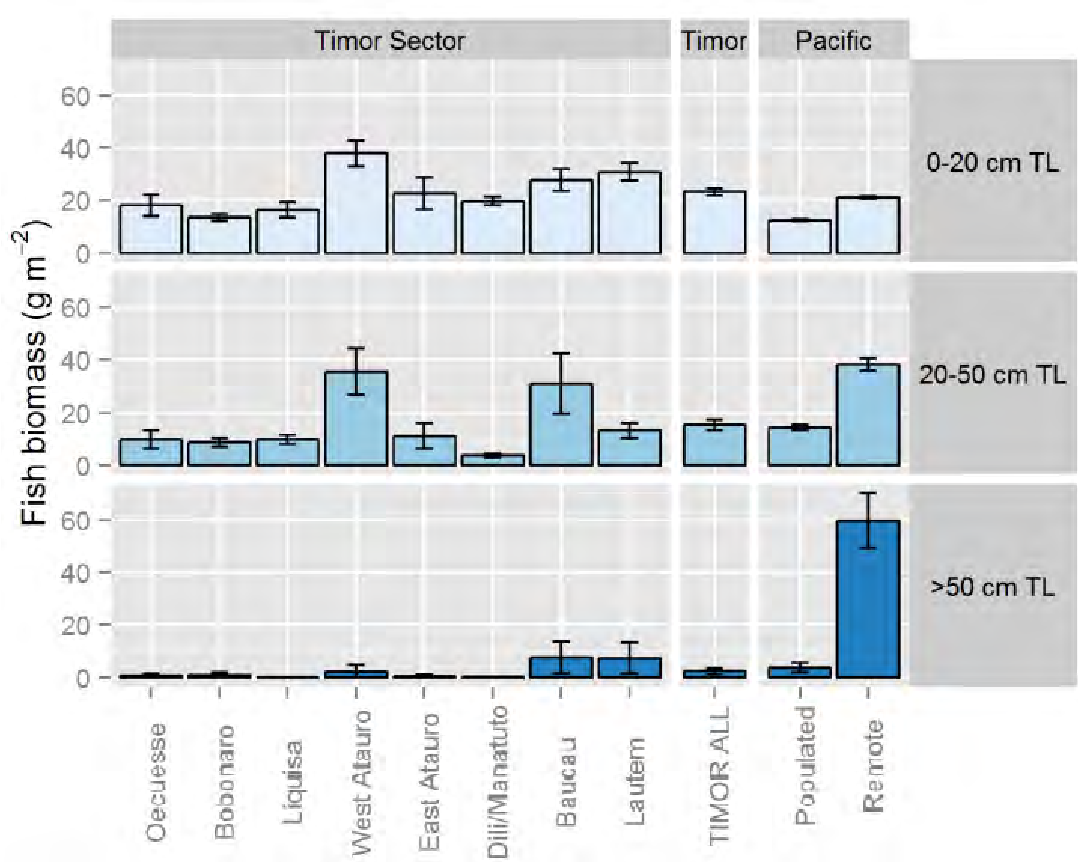


Figure 13. Mean reef fish biomass by size class per sector ordered from west to east along the north coast of Timor-Leste. Timor-Leste average among all sectors is shown as TIMOR ALL. Populated average is pooled from 923 sites from highly human-populated Pacific islands, and remote average is pooled from 858 sites from sparsely human-populated Pacific islands. Error bars show standard error (SE). TL: total length.

Fish Species Richness

Timor-Leste sites had extremely high species richness compared with other Pacific islands locations surveyed by NOAA-CREP. The average species richness among all sectors, 57 species per survey site, was higher than any other region that NOAA-CREP surveys (typically around 25 to 45; Figure 14).

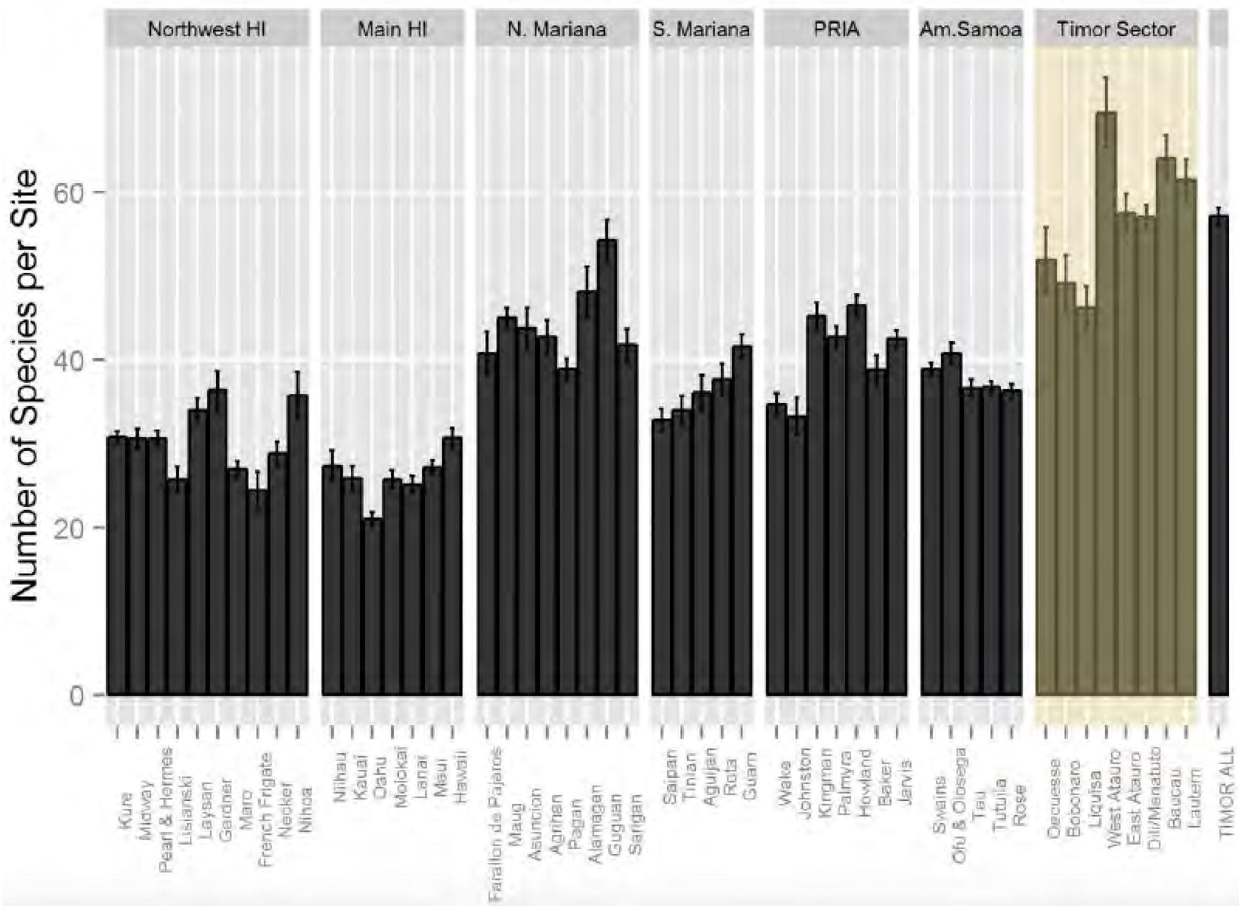


Figure 14. Average species richness per site by sector/island for all Pacific islands areas surveyed by NOAA-CREP.

In addition to the results provided here from McCoy et al. (2015), information about the top reef fish species by quantity (i.e., biomass) for each municipality (district) are provided in Table 2.

Table 2. Top 20 reef fish species by district based on mean biomass (g m^{-2}) from NOAA-CREP reef fish surveys in Timor-Leste, including the standard error (SE) of the mean.

OECUSSE		
RANK	SPECIES	MEAN BIOMASS g m^{-2} (SE)
1	*Plectorhinchus gibbosus*	3.5 (3.5)
2	*Acanthurus mata*	3.0 (2.0)
3	*Caesio teres*	2.5 (1.7)
4	*Chromis ternatensis*	1.4 (1.1)
5	Apogonidae*	0.9 (0.7)
6	*Ctenochaetus striatus*	0.8 (0.3)
7	*Acanthurus thompsoni*	0.8 (0.8)
8	*Macolor macularis*	0.5 (0.5)
9	*Lutjanus bohar*	0.5 (0.5)
10	*Acanthurus blochii*	0.4 (0.3)
11	*Pterocaesio tile*	0.4 (0.3)
12	*Pseudanthias huchtii*	0.4 (0.1)
13	*Pomacentrus melanochir*	0.4 (0.4)
14	*Balistapus undulatus*	0.3 (0.1)
15	*Lutjanus lutjanus*	0.3 (0.3)
16	*Lethrinus olivaceus*	0.3 (0.3)
17	*Lutjanus fulvus*	0.3 (0.1)
18	*Thalassoma lunare*	0.3 (0.0)
19	*Dascyllus trimaculatus*	0.3 (0.2)
20	*Dascyllus reticulatus*	0.3 (0.2)

BOBONARO		
RANK	SPECIES	MEAN BIOMASS g m^{-2} (SE)
1	*Lutjanus rivulatus*	1.6 (1.6)
2	*Ctenochaetus striatus*	1.4 (0.5)
3	*Acanthurus blochii*	1.0 (0.5)
4	*Naso hexacanthus*	0.9 (0.5)
5	*Chlorurus bleekeri*	0.8 (0.6)
6	*Diagramma melanacrum*	0.7 (0.7)
7	*Scarus rubroviolaceus*	0.7 (0.5)
8	*Naso thynnoides*	0.7 (0.7)
9	*Melichthys vidua*	0.6 (0.2)
10	*Acanthurus lineatus*	0.5 (0.3)
11	*Caesio teres*	0.5 (0.4)
12	*Acanthurus mata*	0.5 (0.3)
13	*Acanthurus pyroferus*	0.5 (0.1)
14	*Melichthys niger*	0.3 (0.1)
15	*Balistapus undulatus*	0.3 (0.0)
16	*Dascyllus trimaculatus*	0.3 (0.1)
17	*Pomacanthus semicirculatus*	0.3 (0.2)
18	*Macolor macularis*	0.2 (0.2)
19	*Acanthurus nigrofuscus*	0.2 (0.1)
20	*Chlorurus japanensis*	0.2 (0.2)

LIQUICA		
RANK	SPECIES	MEAN BIOMASS g m^{-2} (SE)
1	*Melichthys niger*	2.9 (1.8)
2	*Pterocaesio tile*	2.6 (1.2)
3	*Acanthurus mata*	1.8 (0.8)
4	*Caesio teres*	1.0 (0.9)
5	*Naso hexacanthus*	0.9 (0.6)
6	*Scarus rubroviolaceus*	0.8 (0.4)
7	*Melichthys vidua*	0.8 (0.2)
8	*Ctenochaetus binotatus*	0.6 (0.3)
9	*Ctenochaetus striatus*	0.5 (0.2)
10	*Acanthurus lineatus*	0.5 (0.2)
11	*Chaetodon kleinii*	0.4 (0.0)
12	*Cephalopholis argus*	0.4 (0.2)
13	*Lutjanus lutjanus*	0.4 (0.2)
14	*Naso brachycentron*	0.3 (0.3)
15	*Dascyllus reticulatus*	0.3 (0.1)
16	*Acanthurus nigrofuscus*	0.3 (0.1)
17	*Balistoides viridescens*	0.3 (0.3)
18	*Pseudanthias huchtii*	0.3 (0.1)
19	*Pomacanthus sexstriatus*	0.3 (0.3)
20	*Lutjanus rivulatus*	0.2 (0.2)

MANATUTO		
RANK	SPECIES	MEAN BIOMASS g m^{-2} (SE)
1	*Pseudanthias huchtii*	1.3 (0.7)
2	*Acanthochromis polyacanthus*	1.3 (0.3)
3	*Euthynnus affinis*	1.1 (1.1)
4	Ctenochaetus sp*	0.8 (0.6)
5	*Chromis weberi*	0.7 (0.3)
6	*Caesio teres*	0.6 (0.6)
7	*Ctenochaetus striatus*	0.6 (0.2)
8	*Dascyllus trimaculatus*	0.5 (0.2)
9	*Dascyllus reticulatus*	0.5 (0.2)
10	Acanthurus sp*	0.5 (0.4)
11	*Chaetodon kleinii*	0.5 (0.1)
12	*Cirrhilabrus solorensis*	0.5 (0.4)
13	*Pomacentrus amboinensis*	0.5 (0.2)
14	*Melichthys vidua*	0.5 (0.1)
15	*Zebrasoma scopas*	0.5 (0.2)
16	*Acanthurus pyroferus*	0.5 (0.1)
17	*Naso lituratus*	0.5 (0.3)
18	*Chromis ternatensis*	0.5 (0.2)
19	*Pseudanthias squamipinnis*	0.5 (0.2)
20	*Chromis viridis*	0.4 (0.3)

**indicates genus or family level of identification*

BAUCAU		
RANK	SPECIES	MEAN BIOMASS g m^{-2} (SE)
1	*Pterocaesio tile*	10.7 (8.6)
2	*Sphyraena qenie*	6.2 (6.2)
3	*Caesio teres*	4.2 (2.2)
4	*Acanthurus mata*	2.5 (1.2)
5	*Macolor macularis*	2.4 (1.0)
6	*Caesio lunaris*	2.4 (1.5)
7	*Naso lopezi*	1.8 (1.8)
8	*Chromis weberi*	1.2 (0.4)
9	*Lutjanus bohar*	1.2 (0.8)
10	Anthias sp*	0.9 (0.7)
11	*Lutjanus gibbus*	0.9 (0.5)
12	*Naso tonganus*	0.9 (0.8)
13	*Pseudanthias squamipinnis*	0.8 (0.3)
14	*Naso hexacanthus*	0.8 (0.8)
15	*Zebrasoma scopas*	0.7 (0.3)
16	*Chromis ternatensis*	0.7 (0.3)
17	*Pomacentrus coelestis*	0.7 (0.4)
18	*Ctenochaetus striatus*	0.7 (0.3)
19	*Acanthurus leucocheilus*	0.7 (0.5)
20	*Pseudanthias huchtii*	0.6 (0.3)

LAUTEM		
RANK	SPECIES	MEAN BIOMASS g m^{-2} (SE)
1	*Cheilinus undulatus*	5.0 (5.0)
2	*Caesio teres*	3.7 (1.9)
3	*Pterocaesio tile*	2.3 (1.8)
4	*Heteroconger hassi*	1.8 (1.3)
5	*Pseudanthias lori*	1.4 (1.4)
6	*Ctenochaetus striatus*	1.4 (0.4)
7	*Pseudanthias huchtii*	1.4 (0.6)
8	*Chromis ternatensis*	1.2 (0.5)
9	*Chromis margaritifer*	1.1 (0.5)
10	*Melichthys niger*	1.0 (0.5)
11	*Acanthurus lineatus*	0.9 (0.4)
12	*Macolor macularis*	0.9 (0.5)
13	*Scomberomorus commerson*	0.8 (0.8)
14	*Chromis weberi*	0.8 (0.2)
15	*Naso vlamingii*	0.8 (0.6)
16	*Chlorurus microrhinos*	0.8 (0.4)
17	*Balistapus undulatus*	0.7 (0.1)
18	*Acanthurus pyroferus*	0.7 (0.1)
19	*Naso thynnoides*	0.6 (0.6)
20	*Zebrasoma scopas*	0.6 (0.2)

DILI		
RANK	SPECIES	MEAN BIOMASS g m^{-2} (SE)
1	Apogonidae*	1.5 (1.3)
2	*Caesio teres*	0.8 (0.5)
3	*Naso hexacanthus*	0.8 (0.5)
4	*Ctenochaetus striatus*	0.8 (0.2)
5	*Acanthurus pyroferus*	0.7 (0.2)
6	*Chaetodon kleinii*	0.6 (0.1)
7	*Acanthochromis polyacanthus*	0.6 (0.3)
8	*Melichthys vidua*	0.6 (0.1)
9	*Melichthys niger*	0.5 (0.3)
10	*Pomacentridae*	0.5 (0.2)
11	*Zebrasoma scopas*	0.5 (0.1)
12	*Balistapus undulatus*	0.4 (0.2)
13	*Gymnothorax javanicus*	0.4 (0.4)
14	*Acanthurus nigrofuscus*	0.4 (0.2)
15	*Neoglyphidodon melas*	0.4 (0.1)
16	Cirrhilabrus sp*	0.4 (0.1)
17	*Ctenochaetus binotatus*	0.4 (0.1)
18	*Neoglyphidodon nigroris*	0.3 (0.2)
19	*Amblyglyphidodon leucogaster*	0.3 (0.2)
20	*Scolopsis bilineatus*	0.3 (0.0)

ATAURO		
RANK	SPECIES	MEAN BIOMASS g m^{-2} (SE)
1	*Pterocaesio tile*	2.6 (1.5)
2	*Caesio teres*	2.3 (1.4)
3	*Scarus rubroviolaceus*	2.1 (1.3)
4	*Naso unicornis*	2.1 (2.1)
5	*Naso hexacanthus*	2.1 (1.0)
6	*Caesio lunaris*	2.0 (1.4)
7	*Melichthys niger*	1.9 (0.7)
8	*Chromis ternatensis*	1.7 (1.0)
9	*Macolor macularis*	1.7 (0.6)
10	*Ctenochaetus striatus*	1.5 (0.5)
11	*Melichthys vidua*	1.2 (0.3)
12	*Chromis analis*	1.1 (1.0)
13	*Lutjanus gibbus*	1.1 (0.6)
14	*Odonus niger*	1.0 (0.9)
15	*Lutjanus bohar*	1.0 (0.3)
16	*Pseudanthias huchtii*	1.0 (0.4)
17	*Chlorurus sordidus*	0.9 (0.4)
18	*Naso vlamingii*	0.8 (0.6)
19	*Thalassoma amblycephalum*	0.8 (0.3)
20	*Lepidozygus tapeinosoma*	0.7 (0.4)

**indicates genus or family level of identification*

Benthic Community Composition

Benthic Cover

Coral communities were assessed along a diverse range of physical, biological, and anthropogenic influences including an extensive portion of the shallow to mid-depth (0–18 m) marine hard-bottom habitats along the north coast of Timor-Leste, including Atauro Island (Figure 16). Hard (scleractinian) coral cover ranged from 0.0 to 42.3% across sites, with an average of 15.6% (SE 0.8). Notably, Lautem and Atauro exhibited the highest mean coral cover at 20.3% (SE 2.1) and 20.5% (SE 2.0), respectively. Baucau and Liquica had the lowest at 10.4% (SE 1.8) and 10.7% (SE 1.6), respectively (Figure 17 and Table 3).

These observations corroborate Erdmann and Mohan (2013) who indicated that some of the highest quality reefs in Timor-Leste in terms of coral cover and diversity are found in the Nino Konis Santana National Park in Lautem and in reefscapes off the island of Atauro harbor (Figure 15).

Figure 15. Site VIL-10 located on the Belio Barrier Reef complex off east Atauro Island is an example of a high-quality reef in Timor-Leste, rich in diversity and with abundant coral cover.

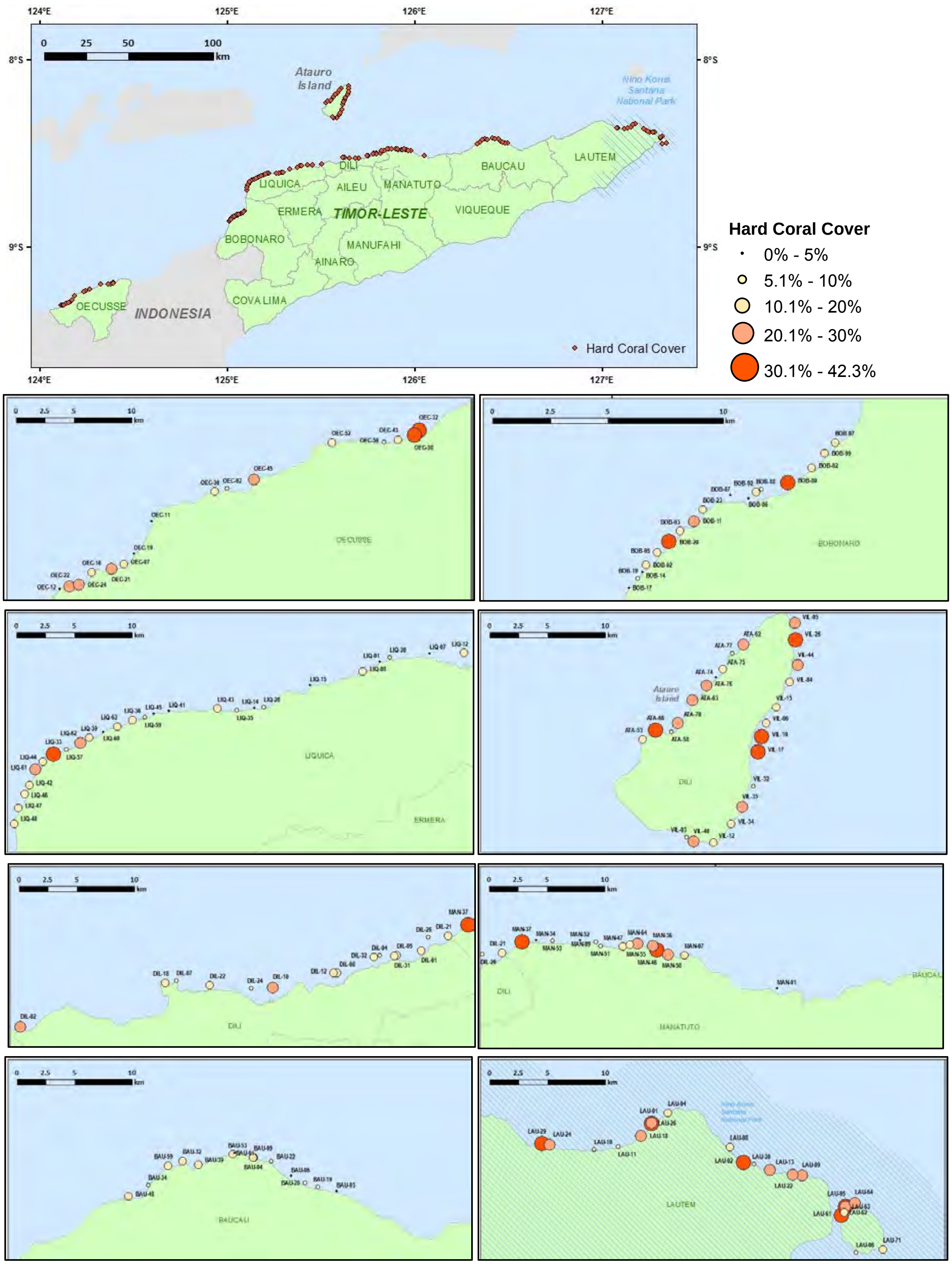


Figure 16. Map of locations where NOAA-CREP collected benthic images along the north coast of Timor-Leste and around Atauro Island in June 2013 that were analyzed for benthic cover (*top*). The panels show hard coral cover (%) per site for each district surveyed (*from left to right, Oecusse, Bobonaro, Liquica, Atauro, Dili, Manatuto, Baucau, and Lautem).* Data were derived from analysis of benthic images.

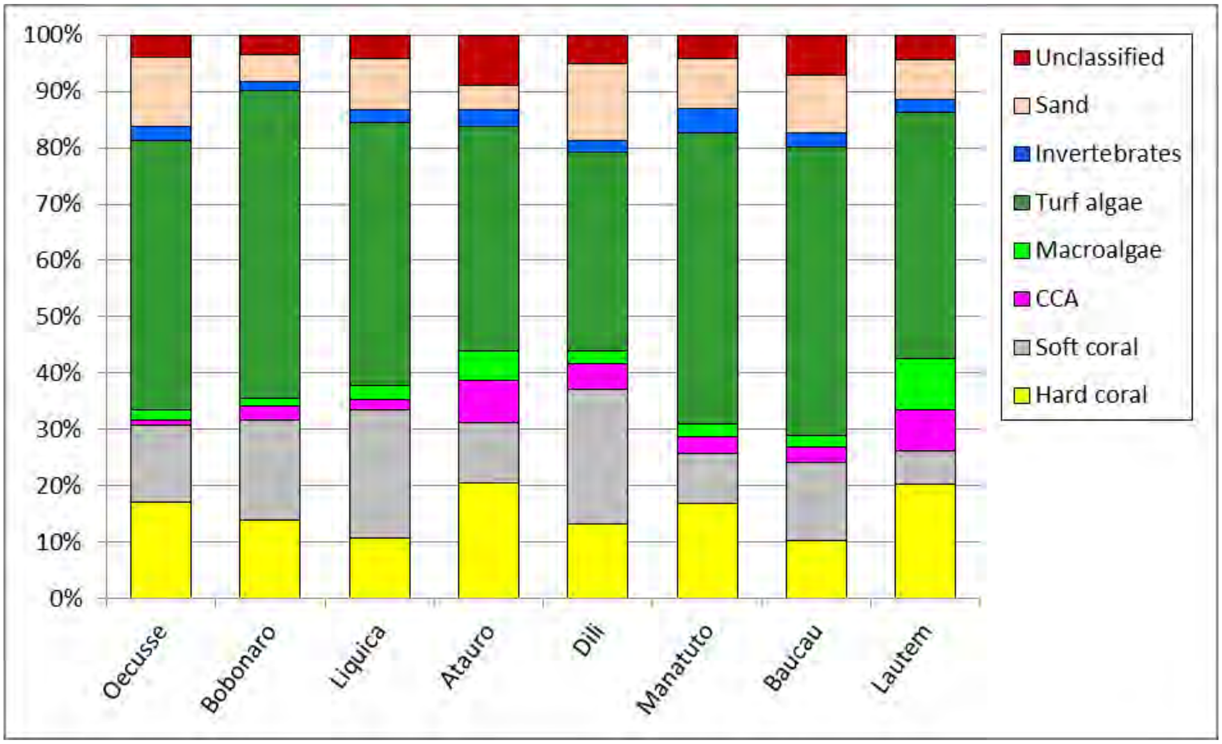


Figure 17. Spatial comparison of average benthic cover (%) for 8 districts along north coast of Timor-Leste, based on the analysis of benthic images collected at hard-bottom sites during surveys conducted by NOAA-CREP in 2013. District mean benthic compositions are spatially displayed from west to east. CCA: Crustose coralline algae.

Table 3. Average percent cover (standard error) of the reef benthos and benthic substrate ratio (hard and soft coral and CCA/turf and macroalgae) by district. Districts are sorted spatially from west to east. CCA: Crustose coralline algae.

District	Sites (#)	Hard coral % (SE)	Soft coral % (SE)	CCA % (SE)	Macroalgae % (SE)	Turf algae % (SE)	Sand % (SE)	Benthic Substrate Ratio
Oecusse	16	17.2 (3.0)	13.7 (3.9)	0.7 (0.3)	1.8 (0.5)	47.9 (4.6)	12.2 (2.5)	**0.9**
Bobonaro	16	14.0 (2.5)	17.8 (3.8)	2.4 (0.7)	1.5 (0.7)	54.5 (4.3)	4.7 (1.8)	**0.8**
Liquica	26	10.7 (1.6)	22.9 (3.6)	1.8 (0.7)	2.4 (0.6)	46.7 (4.7)	9.0 (1.6)	**1.4**
Atauro	22	20.5 (2.0)	10.7 (1.9)	7.7 (1.4)	5.2 (0.9)	39.8 (4.0)	4.4 (1.7)	**1.2**
Dili	14	13.2 (1.3)	24.0 (3.5)	4.6 (0.8)	2.1 (0.6)	35.4 (4.8)	13.6 (2.7)	**1.5**
Manatuto	13	17.0 (3.6)	8.9 (2.1)	2.9 (1.0)	2.2 (1.0)	51.8 (4.6)	8.7 (3.6)	**0.7**
Baucau	13	10.4 (1.8)	13.8 (4.4)	2.8 (0.7)	1.9 (0.6)	51.3 (5.0)	10.3 (3.9)	**0.7**
Lautem	19	20.3 (2.1)	6.0 (1.3)	7.2 (1.4)	9.2 (3.4)	43.7 (4.3)	7.1 (2.1)	**0.8**

Soft corals were another important reef benthic community component, ranging from 0.0 to 55.7% across sites, with an overall average of 14.9% (SE 1.2). The highest soft coral cover was observed in Dili (24.0% [SE 3.0]) followed closely by Liquica (22.9% [SE 3.6]), and while Lautem harbored one of the highest levels of coral cover, it exhibited the lowest levels of soft coral cover at 6.0% (SE 1.3; Figure 17 and Table 3). Macroalgae cover was highly variable among sites, ranging between 0.0 and 60.9%. However, the overall average percent cover among all districts was only 3.5% (SE 0.6). Lautem exhibited the highest levels of macroalgal cover at 9.2% (SE 3.4)—with sites LAU-63 and LAU-29 having significantly higher macroalgal cover compared with all other sites surveyed (60.9% and 34.1%, respectively). Bobonaro had the lowest macroalgal cover at 1.5% (SE 0.7). Turf algae dominated the benthic cover, averaging 46% among all districts. Finally, crustose coralline algae (CCA) cover was relatively low across all districts, but was twice as abundant in the eastern district of Lautem and Atauro Island compared to the other districts (7.2% [SE 1.4] and 7.7% [SE 1.4], respectively). In summary, turf algae, hard corals, and soft corals made up the majority of the benthos, representing >70% of the average benthic cover.

Benthic Substrate Ratio

Benthic substrate ratio, defined as the ratio of the sum of coral (hard and soft) and CCA divided by the sum of turf and fleshy macroalgae, is often used as a metric of reef condition (Houk et al. 2010). High benthic substrate ratios indicate reefs dominated by reef-building corals and calcium carbonate accreting CCA, whereas low benthic substrate ratios indicate reefs dominated by algal forms that do not contribute to reef structural growth (Figure 18). A ratio of 1 indicates a substrate equally covered by reef-building organisms (corals and CCA) and algae (turf and fleshy macroalgae). Dili, Liquica, and Atauro exhibited average benthic substrate ratios higher than 1, and the remaining districts had benthic substrate ratios less than 1 (Table 3).

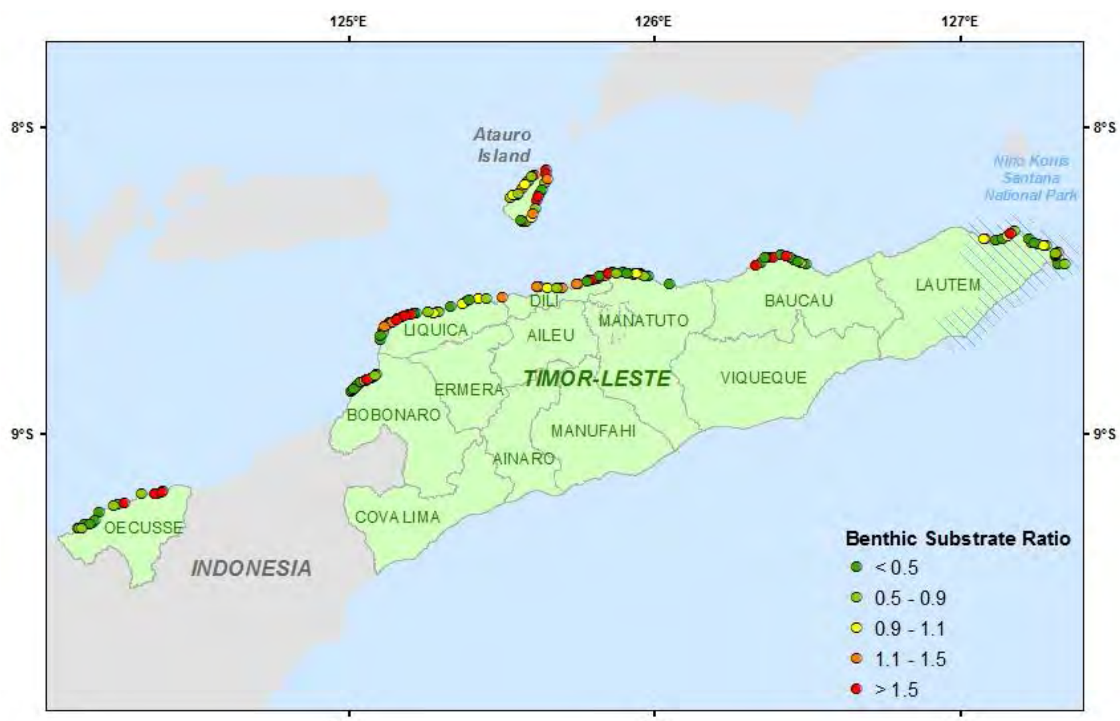


Figure 18. Benthic substrate ratio per site. Sites in green have low substrate ratios (algal dominated), sites in red have high ratios (coral dominated), and sites in yellow are generally balanced between reef builders (corals and CCA) and algae.

4. WHAT ARE THE THREATS TO THE NEARSHORE RESOURCES? *ESTABLISHING ECOLOGICAL BASELINES FOR CLIMATE CHANGE*

What did we do and how did we do it?

Interdisciplinary physical, chemical, and ecological observations were collected at Climate Monitoring Sites around Timor-Leste to establish baseline measurements for tracking ecological responses to climate change and ocean acidification projected over the coming decades. Ten Climate Monitoring Sites (Figure 23) were selected in consultation with local resource management agencies as areas of special management interest, such as potential Marine Managed Areas or Marine Protected Areas. At each of these sites, temperature, carbonate chemistry (i.e., ocean acidification), biodiversity, and calcium carbonate accretion rates were measured, providing a foundation to understand present-day spatial patterns and a baseline for monitoring and detecting long-term responses to climate change.

The spatial information on the parameters provided here can assist in the development of climate change vulnerability assessments to further inform coastal resource managers and policy makers as they develop climate adaptation plans for the coastal communities of Timor-Leste. Furthermore, these data will be integrated into a broader regional effort focused on establishing baselines and monitoring the ecological impacts of ocean acidification on coral reefs by the Intergovernmental Oceanographic Commission for the Western Pacific region (WESTPAC). In 2015, eight WESTPAC nations (Phillipines, Indonesia, Malaysia, Vietnam, China, Banglesh, Cambodia, and Thailand) committed to the implementation of 21 Climate Monitoring Sites using adopted methodologies that were executed in Timor-Leste. Thus, the Timor-Leste Climate Monitoring Sites, in conjunction with the ~50 Climate Monitoring Sites already established by NOAA-CREP's Pacific Reef Assessment and Monitoring Program, plus the 21 sites established by WESTPAC nations, will foster important comparative analyses across gradients of biodiversity, human impacts, and oceanographic/environmental conditions for better understanding the impacts of climate change.

Climate Monitoring Sites were set up as ~10 m x 5 m rectangular grids on hard-bottom coral reef habitat at depths of 11–15 m. Within each grid, instruments monitoring seawater temperature (subsurface temperature recorder [STR]), reef calcification rate (Calcification Accretion Units [CAUs]), and cryptic marine invertebrate biodiversity (Autonomous Reef Monitoring Structures [ARMS]) were installed and remained affixed to the reef for a period of two years (Figure 19). Approximtely 30 photographs of the seafloor (benthic photoquads) were taken at each Climate Monitoring Site to characterize the benthic community, and seawater samples were collected at the ocean surface and at the reef substrate to evaluate patterns in the carbonate chemisty.

The specific field and analytical methodologies used for collection and processing of information for each metric (seawater temperature from STRs, reef calcification rate from CAUs, marine invertebrate biodiversity from ARMS, carbonate chemistry from seawater samples, and benthic cover from photographs of the seafloor) are described in Appendix I.

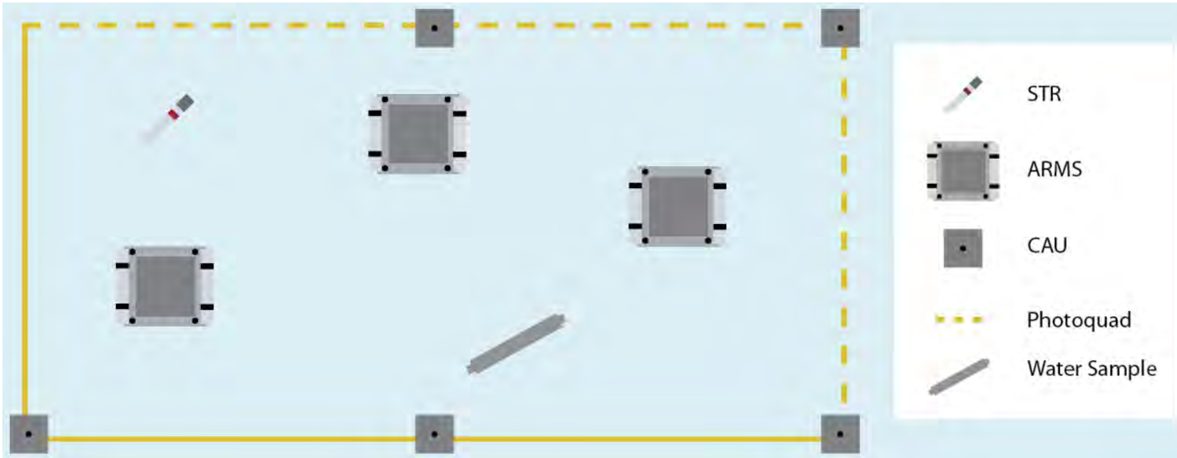


Figure 19. Example schematic of a Climate Monitoring Site in Timor-Leste (~10 m x 5 m). While the quantity of each instrument and sample was typical for all 10 sites, the specific spatial arrangement of the instruments and photoquads varied from site to site.

Why is this information important?

Temperature (STRs)

Changes in water temperature affect marine life in many ways. Temperature determines which organisms will thrive and which will diminish in numbers and size. It regulates the physiology of all marine organisms, affecting not only survival, but growth and reproduction, with each organism having optimal ranges and thermal tolerances. For example, seawater temperature increases of only 1°C above the normal annual maximum at any location can cause thermal stress and coral bleaching. Once thought to be a localized phenomenon affecting selected reefs, coral bleaching is now documented across the globe and considered a major threat to most coral reef ecosystems (Hughes et al. 2017). Since temperature is a key factor determining the distribution and abundance of corals and other marine life, it will be important for managers and policy makers to understand how the coral reef and associated coastal ecosystems of Timor-Leste will respond to projected temperature increases as the oceans continue to warm as a result of global climate change. It will also be important to establish long-term observations of the actual water temperatures at the coral reefs in Timor-Leste as a complement to global climate model projections. Hence, STRs were deployed on the reef substrate at each of the 10 Climate Monitoring Sites establishing baseline conditions and initiating time series records (Figure 20).

Figure 20. Newly deployed subsurface temperature recorder (STR) attached to the seafloor at one of the climate sites in Timor-Leste (*left*). STR about to be recovered approximately two years later (*right*).

Seawater Chemistry (Ocean Acidification)

Ocean acidification is caused by the ongoing decrease in the pH of the oceans caused by the uptake of excess carbon dioxide (CO_2) from the atmosphere. Roughly 30% of the CO_2 from human activities released into the atmosphere is absorbed by the oceans. Prior to the industrial revolution that began in the 18th century, most seawater had a pH of around 8.25, but this has since declined by about 0.13 pH units to ~8.12. This represents an increase of almost 35% in H^+ ion concentration in the world's oceans. These changes in seawater carbonate chemistry make it more difficult for marine calcifying organisms, such as reef-building corals, crustose coralline algae, and calcareous plankton, to form their calcium carbonate skeletons and shells and resulting habitat forming coral reefs. These calcium carbonate structures also become vulnerable to chemical dissolution as ocean acidification continues. Ongoing acidification of the oceans does not only threaten coral reefs, but entire marine food webs.

From the baseline surveys of the seawater carbonate chemistry conducted by NOAA-CREP for the nearshore waters around Timor-Leste, conditions are reported both as pH and saturation state. Increasing CO_2 levels and the resulting lower pH of seawater decreases the saturation state of calcium carbonate. This decrease in saturation state is one of the main factors leading to decreased calcification rates for many marine organisms, as the inorganic precipitation of calcium carbonate is directly proportional to its saturation state. Aragonite saturation state indicates how concentrated the water is for the particular form of calcium carbonate, aragonite, from which corals make their skeletons. The pH of the water strongly impacts the aragonite saturation state. When aragonite saturation state is high (i.e., 3.5–4.0), corals and other creatures can build their shells or skeletons relatively easily. However, if the aragonite saturation state declines, corals and other reef-builders have a much harder time building their calcium carbonate shells (i.e., reefs) and may even see their shells and the coral reef framework dissolve.

Figure 21. A NOAA-CREP SCUBA diver collecting a water sample at the reef using a Niskin bottle (*left*). NOAA-CREP field personnel transferring a water sample from a Niskin bottle to a glass bottle for later dissolved inorganic carbon and total alkalinity analysis (*right*).

Around Timor-Leste, seawater samples were collected and analyzed for two parameters, dissolved inorganic carbon (DIC) and total alkalinity (TA), which were then used to calculate the various carbonate system parameters, including pH and aragonite saturation state Ω_{arag}. The carbonate system is influenced by seawater salinity, temperature, and pressure; these data must be collected concurrently with the water samples for accurate measurement of the concentrations of DIC and TA in the laboratory (Figure 21). All carbonate system collection and measurement methodologies follow the protocol accepted by the greater scientific community and outlined in Dickson et al. (2007).

Calcification Accretion Units (CAUs)

One of the principal concerns surrounding ocean acidification is whether coral reefs will be able to continue to persist as pH and Ω_{arag} continue declining with increasing atmospheric CO_2. Many simplified laboratory experiments have found that most corals and crustose coralline algae (CCA) are not able to calcify their calcium carbonate skeletons under ocean acidification conditions. To complement these laboratory experiments, calcification accretion units (CAUs) were developed as a tool for monitoring changes in net reef accretion rates in nature while concurrently monitoring seawater carbonate chemistry. Deployed on the seafloor for periods of 2–3 years, CAUs allow for recruitment and colonization of CCA and hard corals. CCA play a pivotal role in supporting actively calcifying reefs, yet are extremely susceptible to changes in seawater pH. By measuring the net weight of calcium carbonate produced on the CAUs over time, the reef carbonate accretion rate can be calculated for that time period. Monitoring net accretion over successive deployments allows for the detection of changes in calcification rates over time.

Autonomous Reef Monitoring Structures (ARMS)

Another key question regarding the effects of ocean acidification is how changing carbonate chemistry will impact the biodiversity of coral reefs. Of the five mass extinction events—defined to periods in which the biodiversity declined by more than 50%—that have occurred over the Earth's history, at least a few coincided with ocean acidification events (Honisch et al. 2012). It is predicted that ocean acidification, together with temperature stress, will lead to severely reduced diversity, structural complexity, and resilience on coral reefs (Bellard et al. 2012; Kroeker et al., 2013).

Autonomous reef monitoring structures (ARMS) were developed as long-term sampling devices for assessing spatial patterns and monitoring long-term trends in the biodiversity of the small and functionally important group of organisms known as the cryptobiota. Cryptobiota live predominantly within the complex architecture of the reef matrix. They are important sources of food for many reef fish and are fundamental to nutrient cycling and the ability of reefs to thrive in nutrient poor environments. Despite their ecological importance, their diversity and composition has been poorly understood in part due to their sheer richness and the difficulty in extracting them from the reef to assess their diversity. However, with the development of ARMS, progress in DNA barcoding and DNA metabarcoding techniques (see Appendix J for overview), and declining costs in high-throughput DNA sequencing, examinations into cryptobiota diversity and composition across space and time are now a reality (Leray and Knowlton 2015).

To date, there have been over 800 ARMS deployed worldwide to examine cryptobiota communities across not only coral reefs, but temperate coastal habitats, oyster reefs, and deep-sea benthos (Figure 22). Although some of the computational bioinformatic processing techniques continue to be refined and polished, sequences are being archived until the computational methods are streamlined and available for more in-depth analyses into the biodiversity and the community composition of the cryptobiota. The ARMS deployed across Timor-Leste will not only establish baseline assessments of the spatial patterns of the cryptobiota along the north coast of Timor-Leste, but will also contribute toward greater insight into regional and global biodiversity patterns and trends.

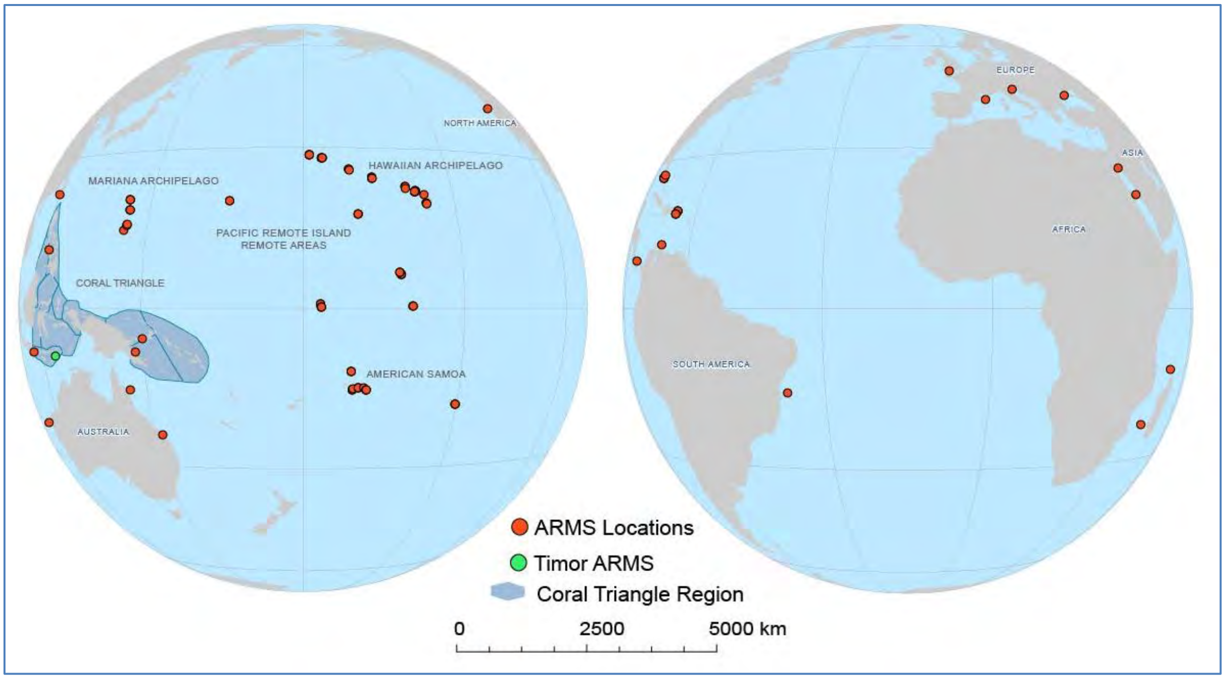


Figure 22. The global array of ARMS that have been deployed and recovered.

Benthic Cover

Benthic photoquads were analyzed to estimate the benthic community composition at each Climate Monitoring Site and provide site-specific context to the *in-situ* (stationary) climate survey data. Using the benthic cover data obtained from the broad-scale spatial surveys in the *Coral Reef Ecosystem Assessments* Chapter to contextualize the Climate Monitoring Sites would be inappropriate due to the natural variability of benthic organisms that exists across sites. Randomized surveys are essential for characterizing overall resources in a region while standardized stationary sites help contextualize the finer biophysical relationships when assessing, for example, the ecological impacts of climate change on coral reefs on a global scale. Thus, integrating a regional benthic cover value to examine biophysical relationships at a particular site would lead to false interpretations of the data. Similarly, using a site-specific benthic cover value to contextualize a region would lead to inaccurate conclusions of existing resources.

The benthic cover data derived from the climate sites are presented in the same manner as the photoquadrat data obtained from the broad spatial-scale surveys described in the preceding *Coral Reef Ecosystem Assessments* Chapter.

Operational logistics

2012 Activities

Climate sites were established at 10 coastal locations around Timor-Leste in October 2012, in the districts of Bobonaro, Dili, Manatuto, Baucau, Lautem, and Manufahi, as recommended by MAF partners and other stakeholders in Timor-Leste (Figure 23, Appendix E). Sites were initially enumerated in sequence as TIM-01, TIM-02, etc., and were later renamed to match the site naming convention established during the reef fish surveys in June 2013 (Table 4).

At the request of Timor-Leste agencies and stakeholders during consultations in 2012, two Climate Monitoring sites (LAU-07 and MAF-01) were initially established along the south shore (Figure 23). However, those sites were eliminated due to poor accessibility causing significant logistical and fiscal constraints, poor SCUBA conditions from heavy rainfall and siltation, and safety concerns (Figure 24).

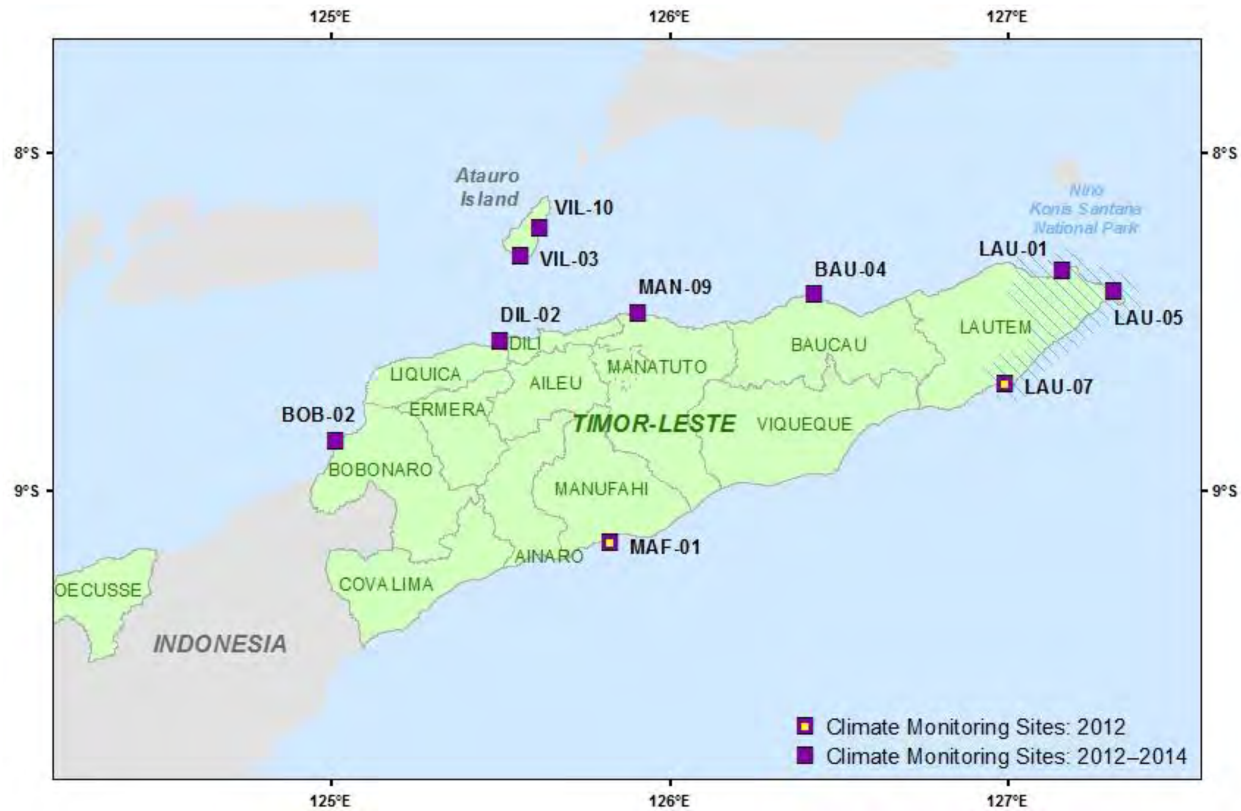


Figure 23. Map showing the location of the 10 Climate Monitoring sites established in October 2012, and the 2 sites that were not revisited after the first year.

Table 4. List of Climate Monitoring sites established in 2012 and the original site names for each prior to renaming in 2013. Highlighted in grey are the two sites along the south shore that were not resurveyed by NOAA-CREP after 2012.

DISTRICT	ORIGINAL SITE ID	NEW SITE ID	LATITUDE (S)	LONGITUDE (E)	DEPTH (ft)	DEPTH (m)
Bobonaro	TIM-02	BOB-02	-8.85329	125.01327	46	14.0
Dili	TIM-01	DIL-02	-8.55465	125.49913	43	13.1
Atauro (Vila MPA)	TIM-03	VIL-03	-8.30332	125.55847	47	14.3
Atauro (Vila MPA)	TIM-10	VIL-10	-8.22441	125.61684	43	13.1
Manufahi	TIM-06	MAF-01	-9.15203	125.82206	48	14.6
Manatuto	TIM-09	MAN-09	-8.47513	125.90675	48	14.6
Baucau	TIM-04	BAU-04	-8.4196	126.42707	45	13.7
Lautem	TIM-07	LAU-07	-8.68429	126.98978	36	11.0
Lautem	TIM-08	LAU-01	-8.34638	127.161	48	14.6
Lautem	TIM-05	LAU-05	-8.4108	127.31222	48	14.6

Figure 24. At site MAF-01 near Betano in Manufahi district—the southernmost site established in Timor-Leste during the 2012 mission—the waters were markedly murky with visibility less than 3 meters.

2013 Activities

Eight of the ten Climate Monitoring sites were revisited during the *Coral Reef Assessment* surveys in June 2013, and carbonate chemistry water samples were collected to improve the quality of the baseline assessment. Water samples were also randomly collected at six additional [non-climate] sites chosen using the stratified-random selection method (Figure 25). Efforts were made to collect a distribution of samples across the north coast of Timor-Leste and around Atauro Island.

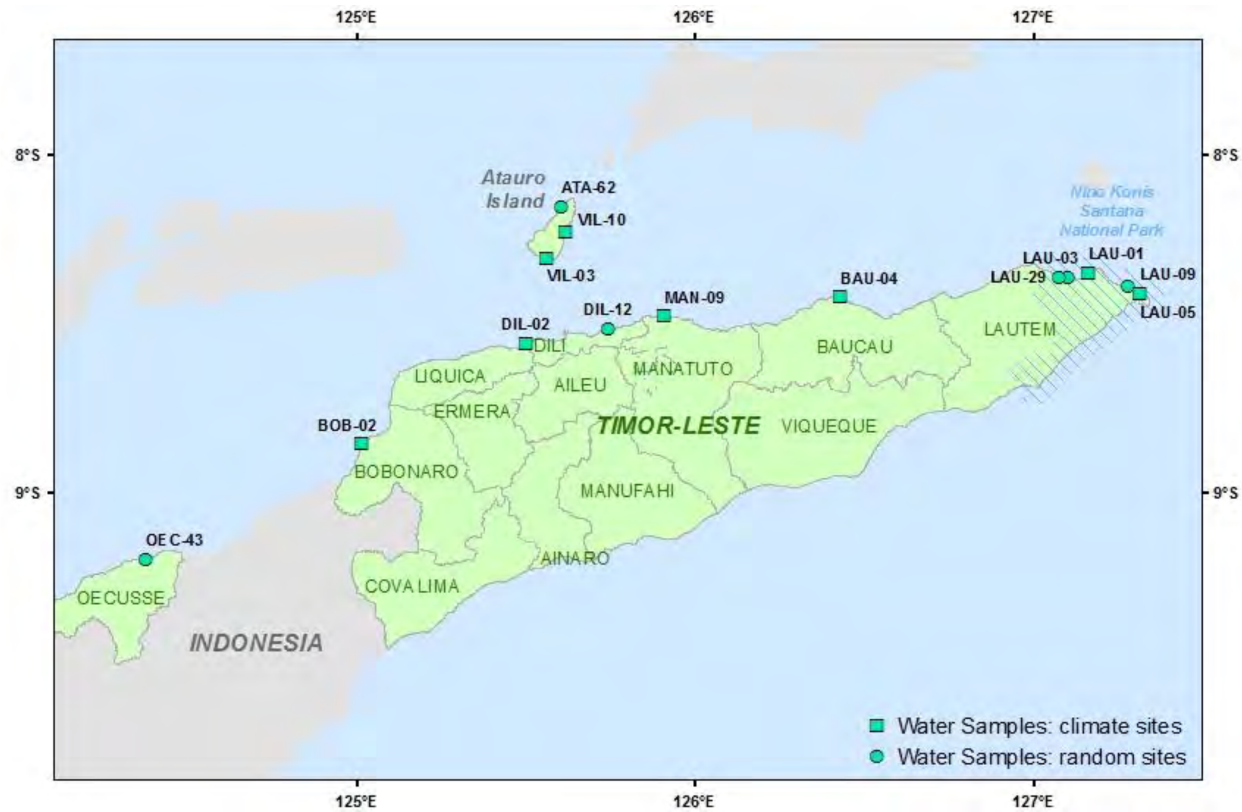


Figure 25. Map showing the location of the sites where water samples were collected in 2013.

2014 Activities

The same eight climate sites sampled in 2013 were revisited again by the NOAA-CREP team in October 2014 to recover the instruments (STRs, CAUs, and ARMS) and collect water samples and perform benthic photoquadrat surveys.

See Table 5 for the complete list of activities conducted at the Climate Monitoring sites during each of the three NOAA-CREP missions in Timor-Leste. Some of the instrumentation could not be located during the recovery mission in 2014, most likely due to weather events dislodging the instrumentation from the seafloor.

Table 5. The activities conducted at the Climate Monitoring sites during the October 2012, June 2013, and September/October 2014 NOAA-CREP missions in Timor-Leste.

DATE	STRs	CAUs	ARMS	WATER SAMPLES	BENTHIC IMAGES
Oct 2012	Deployed (17)	Deployed (50)	Deployed (32)		Collected (332)
Jun 2013				Collected (24)	
Sept-Oct 2014	Recovered (14)	Recovered (34)	Recovered (25)	Collected (16)	Collected and analyzed for Benthic Cover (232)

What did we find?

Temperature (STRs)

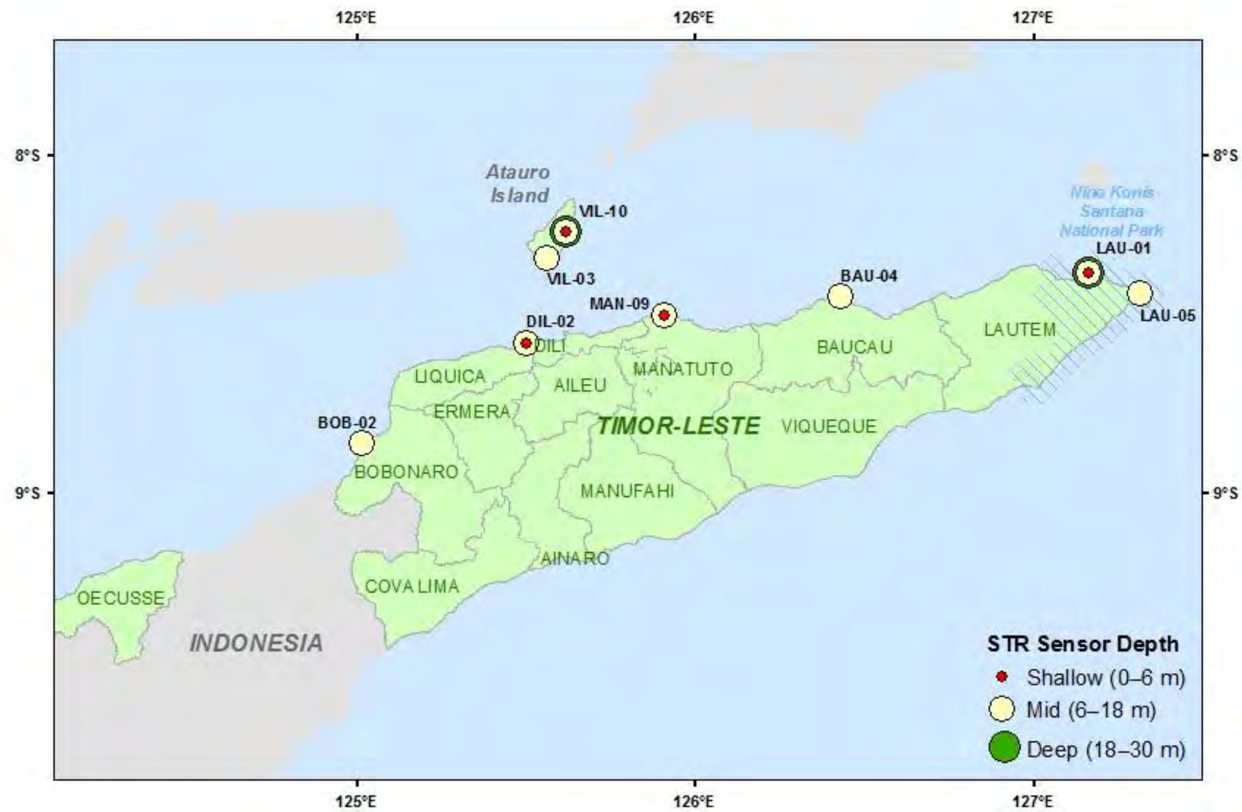
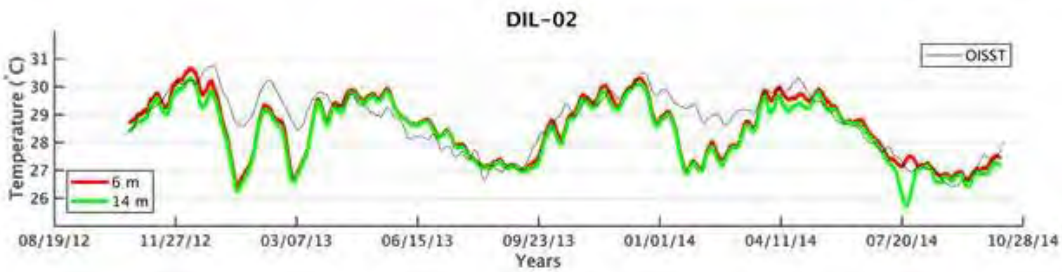


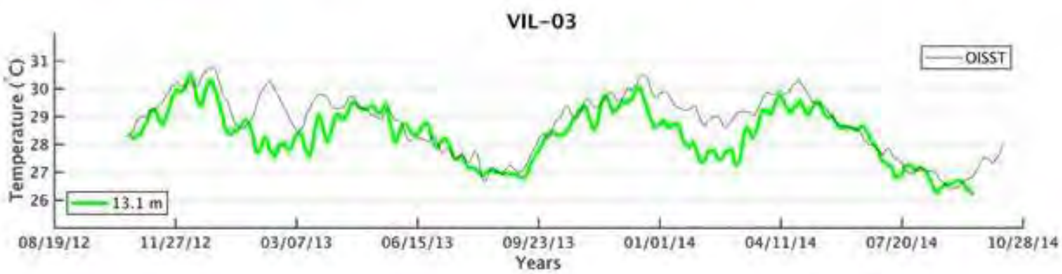
Figure 26. Positions (circles) and depths (colors) of subsurface temperature recorders (STR) successfully recovered from Timor-Leste in 2014. Sites with multiple STRs (e.g., LAU-01) represent STR depth transects (i.e., a shallow-, mid-, and deep-depth STR deployed at one site). No data was collected from the mid-depth STR recovered at LAU-01.

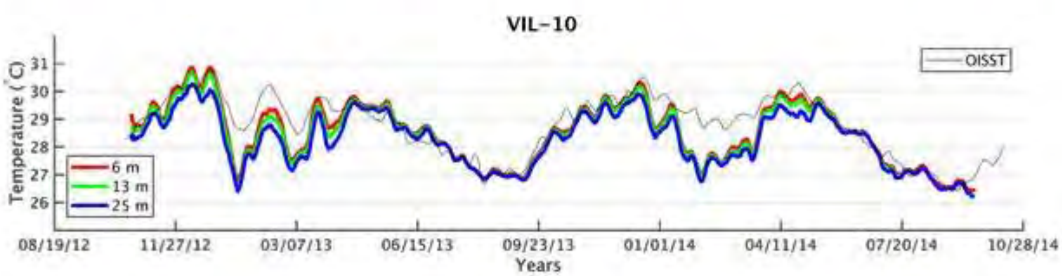
Subsurface temperature data were successfully recorded from 13 locations/depths at 8 sites around Timor-Leste from October 2012 to October 2014. Temperature data show regionally coherent patterns of heating and cooling over the recording period, with the hottest periods occurring in November and December of each year (Figure 27). Similarities between BOB-02 and VIL-03 with respect to the rest of the sites, some consistent variability among sites, and temporal variability especially between December and February of each year are also evident.

The daily NOAA Reynolds Optimal Interpolation Sea Surface Temperature (OISST) data for the same time period as the STRs suggest the mean sea surface temperature values range between 25.86°C and 30.89°C for the north coast of Timor-Leste (Reynolds et al., 2002). However, the *in-situ* (non-smoothed) temperature data in both years include values that exceed the 30.89°C threshold at all locations and depths (Table 6). This indicates that STRs are better at detecting extreme changes in temperature than the OISST product for this region.


BOB-02
Temperature (°C)
31
30
29
28
27
26
OISST
15 m
08/19/12
11/27/12
03/07/13
06/15/13
09/23/13
01/01/14
04/11/14
07/20/14
10/28/14
Years


DIL-02
Temperature (°C)
31
30
29
28
27
26
OISST
6 m
14 m
08/19/12
11/27/12
03/07/13
06/15/13
09/23/13
01/01/14
04/11/14
07/20/14
10/28/14
Years


VIL-03
Temperature (°C)
31
30
29
28
27
26
OISST
13.1 m
08/19/12
11/27/12
03/07/13
06/15/13
09/23/13
01/01/14
04/11/14
07/20/14
10/28/14
Years


VIL-10
Temperature (°C)
31
30
29
28
27
26
OISST
6 m
13 m
25 m
08/19/12
11/27/12
03/07/13
06/15/13
09/23/13
01/01/14
04/11/14
07/20/14
10/28/14
Years


MAN-09
Temperature (°C)
31
30
29
28
27
26
OISST
5 m
15 m
08/19/12
11/27/12
03/07/13
06/15/13
09/23/13
01/01/14
04/11/14
07/20/14
10/28/14
Years

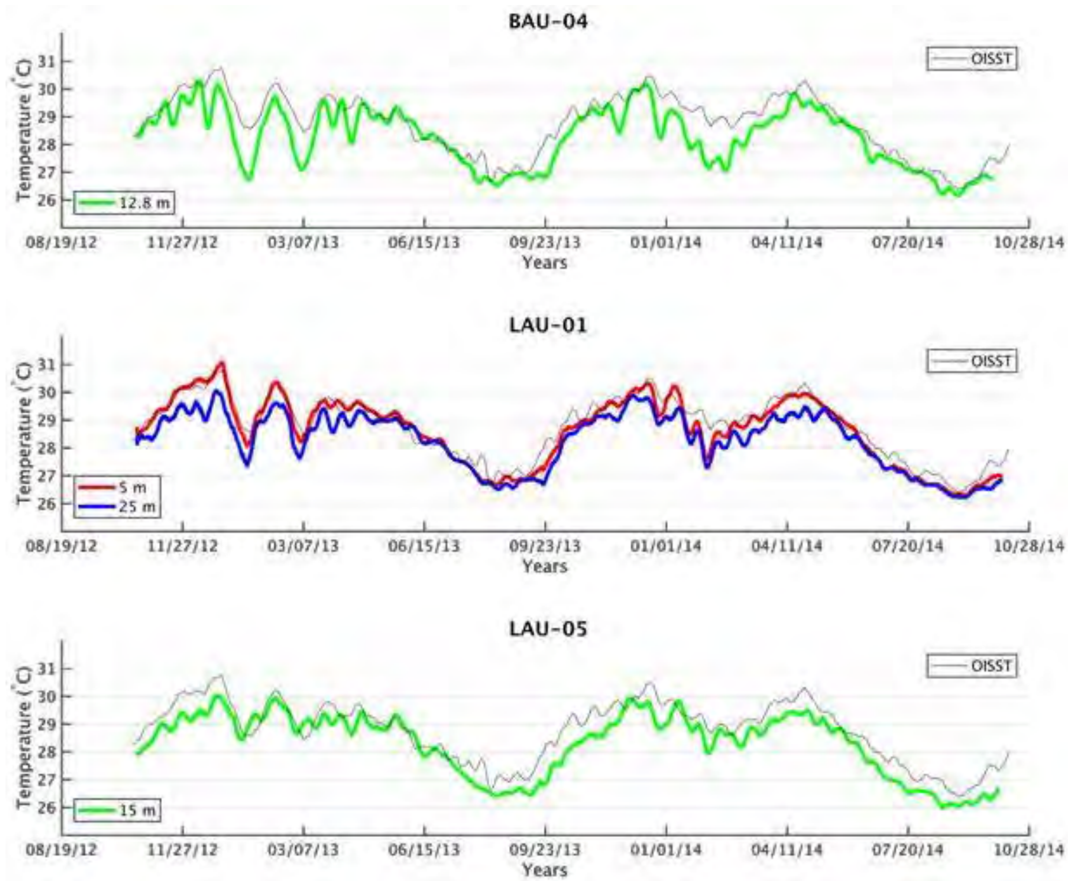


Figure 27. Subsurface temperature time series for multiple depths at each of the eight sites around Timor-Leste from 2012 to 2014. Red, green and blue lines correspond to "smoothed" temperature data from shallow (5–6 m), mid (12–15 m), and deep (25 m) water, respectively, and the grey lines correspond to the smoothed version of the OISST data for the northern region of Timor-Leste.

Table 6. Daily (before smoothing) minimum and maximum temperature values from STRs recovered from multiple depths at eight sites around Timor-Leste from 2012 to 2014, and for the Reynolds Optimal Interpolation Sea Surface Temperature (OISST) data for comparison (grey record). No specific depth is associated with the OISST data as it is an interpolated data product generated from the available satellite, ship and buoy observations for the region.

SITE ID	DEPTH (m)	MINIMUM TEMPERATURE (°C)	MAXIMUM TEMPERATURE (°C)
BOB-02	14.9	21.3087	30.9220
DIL-02	6.1	23.1373	31.8510
DIL-02	14.0	21.4766	31.5859
VIL-03	13.1	22.3787	31.3195
VIL-10	6.1	25.5837	31.8411
VIL-10	13.1	25.2706	31.3198
VIL-10	25.0	23.2996	31.1499
MAN-09	4.9	24.6026	31.6964
MAN-09	14.6	25.2706	31.3198
BAU-04	12.8	23.7113	31.2986
LAU-01	4.6	25.6580	32.2218
LAU-01	25.3	23.8373	31.3182
LAU-05	14.6	23.5564	31.1985
OISST	—	*25.8610*	*30.8914*

Seawater Chemistry

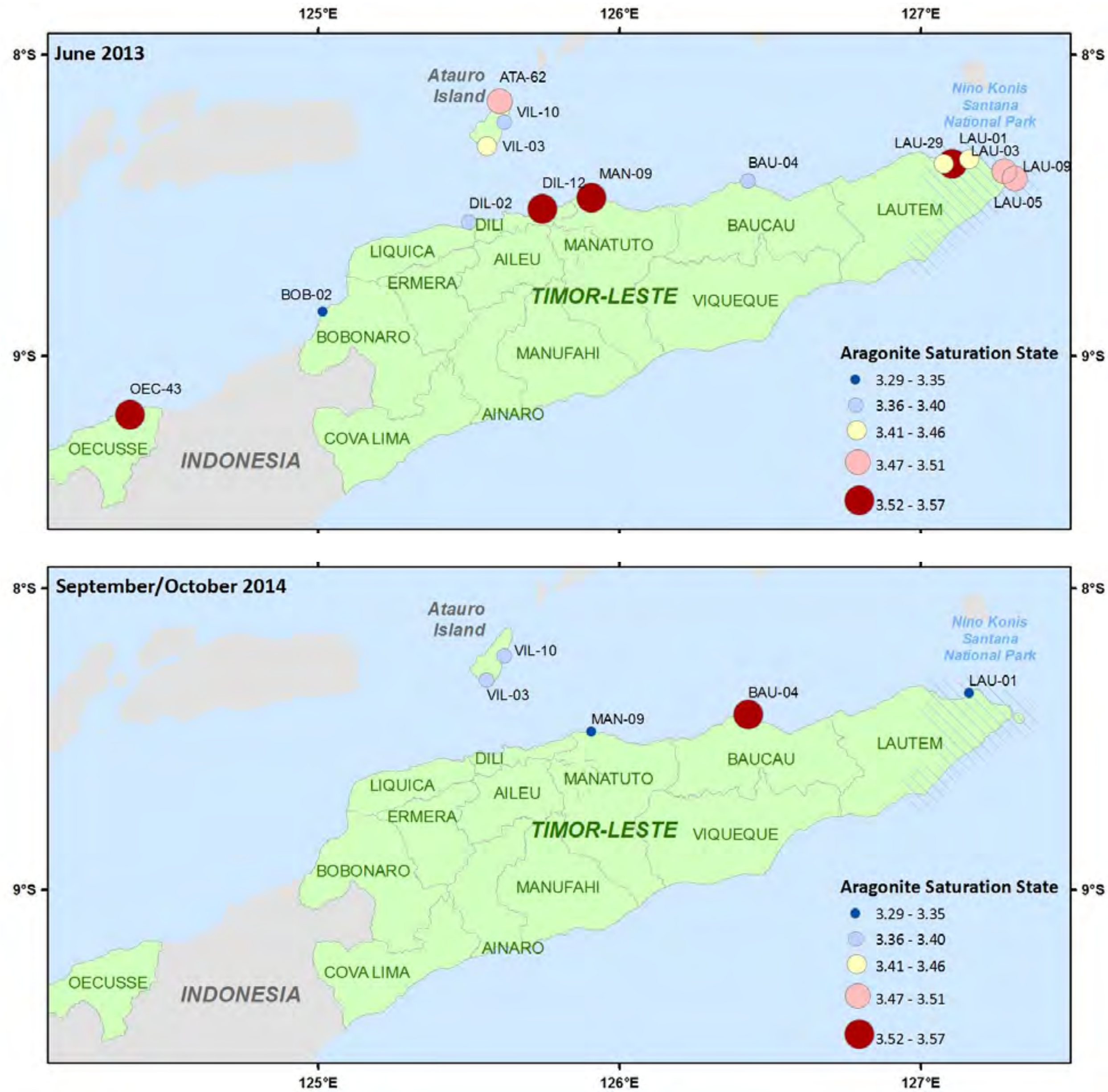


Figure 28. Aragonite saturation state of seawater at benthic sites (samples taken at the reef) around Timor-Leste in June 2013 (*top*) and September/October 2014 (*bottom*). Warmer colors indicate higher values, which are more favorable for calcification processes.

There is substantial spatial and temporal variability in measured carbonate parameters from the benthic sites around Timor-Leste in June 2013 (Figure 28 top panel) and September-October 2014 (Figure 28 bottom panel). Site BAU-04 had the most favorable seawater conditions for calcification, with an aragonite saturation state of ~3.5 in September-October 2014, but not in June 2013. Site MAN-09 had the least favorable conditions for calcification, with an aragonite saturation state of ~3.3 in 2014, but not in 2013. For most sites sampled, both aragonite saturation state and pH were higher in June 2013 than in September-October 2014, likely due to seasonal differences in weather and precipitation patterns (Figure 29). Offshore waters generally had higher aragonite saturation states and pH than surface waters at the reef, which tended to have higher aragonite saturation states and pH than reef waters, suggesting the various biogeochemical processes occurring on the reef were changing the carbonate chemistry. Typically, coral reefs take up carbon during daytime photosynthesis and export carbon during nighttime respiration; therefore, the observations support this expectation.

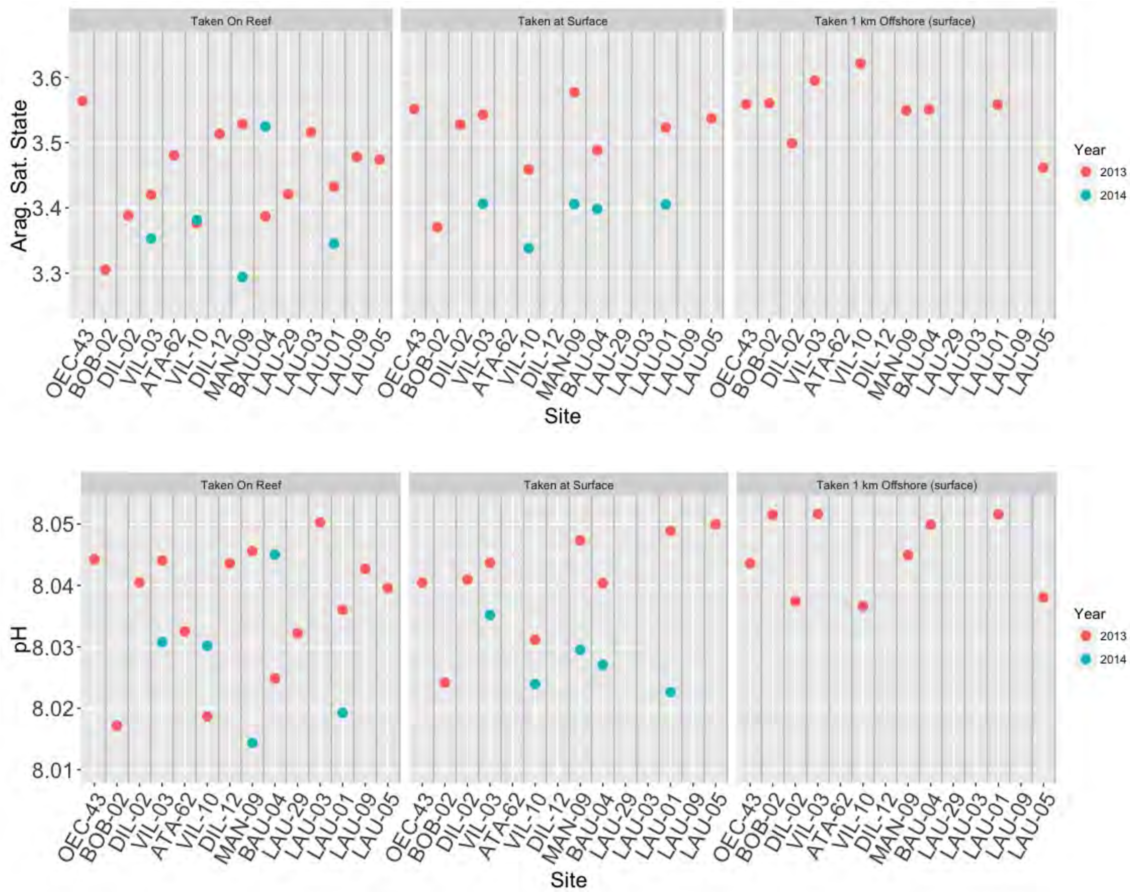


Figure 29. Site-by-site carbonate chemistry measurements from water samples collected in June 2013 and September-October 2014 along the north coast of Timor-Leste: aragonite saturation state at the reef (*top left*), surface (*top middle*), and 1 km offshore from the site at the surface (*top right*); pH at the reef (*bottom left*), surface (*bottom middle*), and 1 km offshore from the site at the surface (*bottom right*).

Overall, these baseline observations indicate that the seawater carbonate chemistry along the north coast of Timor-Leste had relatively low aragonite saturation states, as demonstrated by the median distributions compared to similar observations made by NOAA-CREP at coral reef sites across the Pacific (Figure 30 left panel). The median pH for Timor-Leste is nearer the mean of pH observations at coral reefs across the Pacific (Figure 30 right panel).

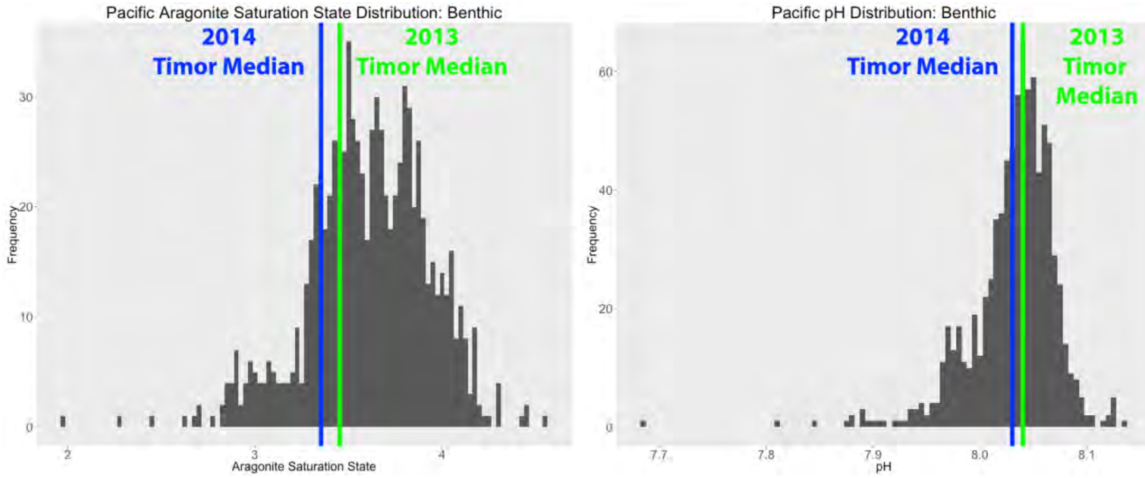


Figure 30. Pacific-wide distribution of aragonite saturation state (*left*) and pH (*right*), showing relative position of Timor-Leste benthic water samples in June 2013 (green line) and September-October 2014 (blue line).

Many factors can contribute to these results, including regional ocean acidification, active respiration on reefs, or even active drawdown of calcifying material (i.e., carbonate) from rapidly calcifying reefs.

Calcification Accretion Units (CAUs)

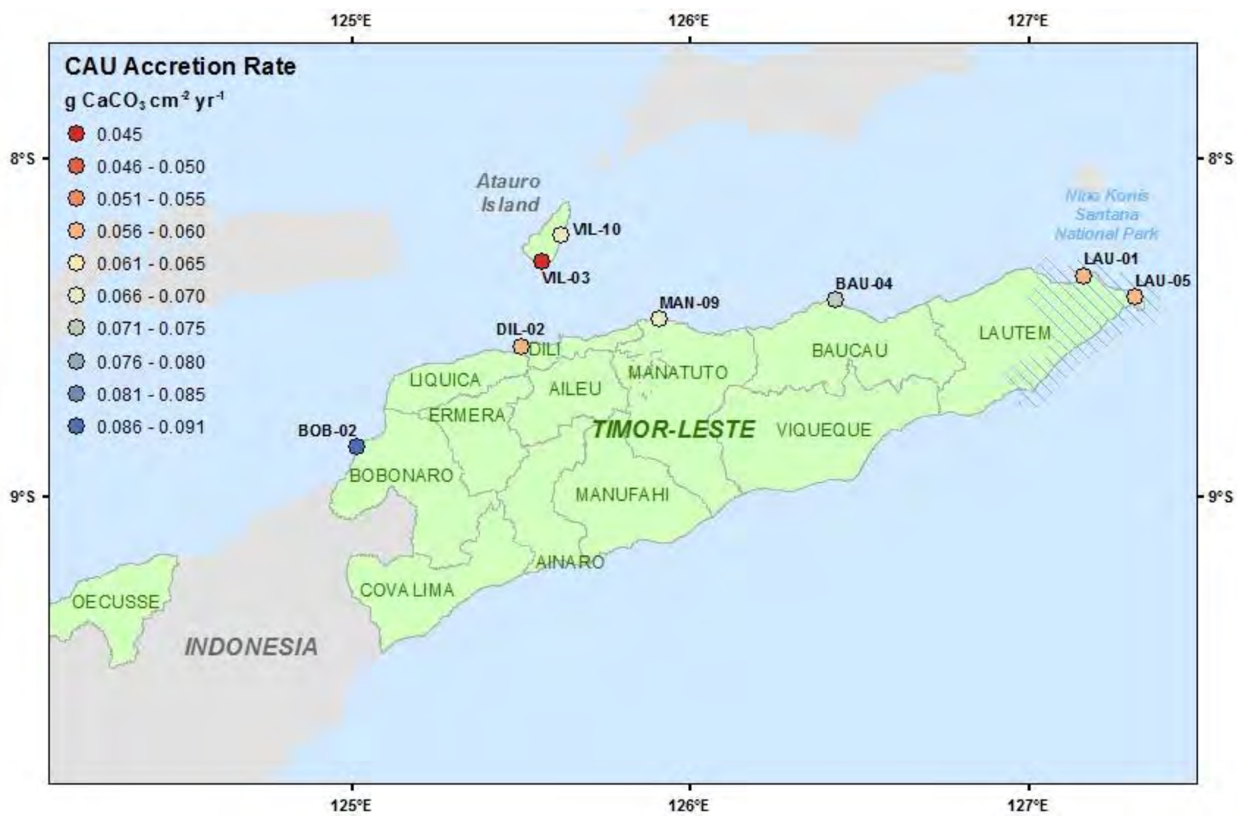


Figure 31. Spatial variation in net reef carbonate accretion rates (g $CaCO_3$ cm^{-2} yr^{-1}) at Climate Monitoring Sites along the north coast of Timor-Leste measured using calcification accretion units (CAUs) deployed from October 2012 to September-October 2014.

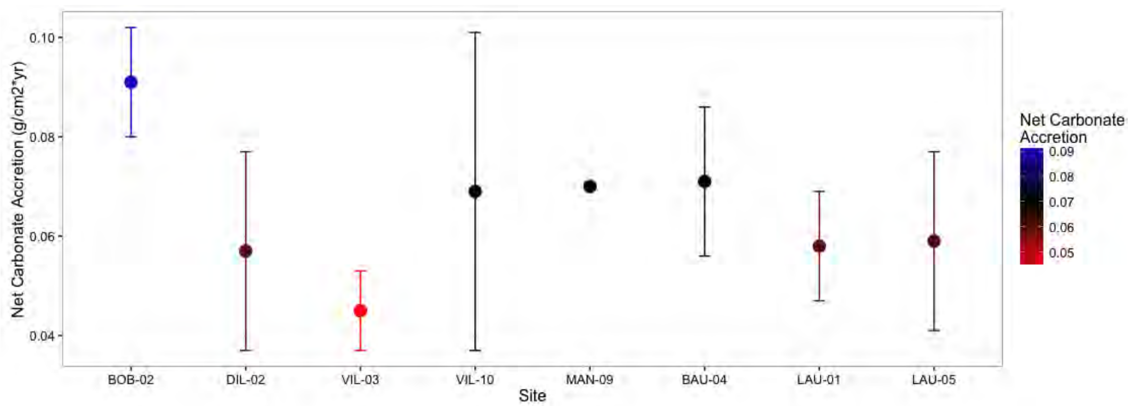


Figure 32. Net carbonate accretion (g $CaCO_3$ cm^{-2} yr^{-1}) by survey site showing the variability within each site.

CAUs were used to measure actual net accretion of calcium carbonate, the mineral that forms the skeleton of coral reefs, at Climate Monitoring Sites along the north coast of Timor-Leste from October 2012 to September-October 2014. The majority of carbonate accreted to a CAU plate comes from crustose coralline algae, not corals. These "pink pavement" algae species are sensitive to acidification and can act as "canaries in a coal mine" for tracking early responses to ocean acidification conditions. As with the data described for the seawater carbonate chemistry, there was variation from site to site in net carbonate accretion from the CAU units (Figure 31, Figure 32), but relative to the wider Pacific, carbonate accretion rates occupy a narrow range at the low end of Pacific-wide variation (Figure 33).

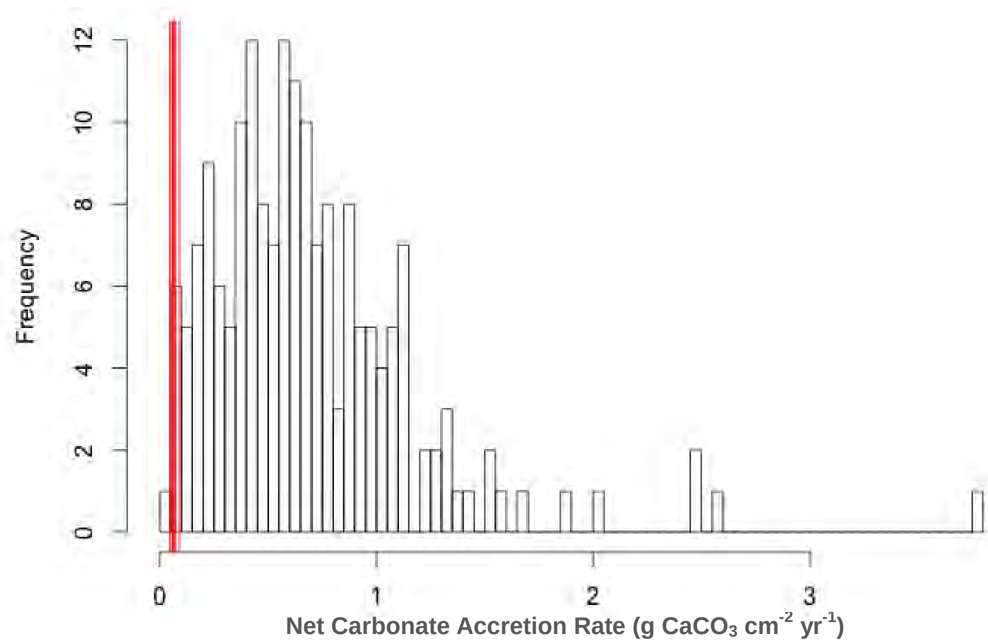


Figure 33. Net carbonate accretion rates of Timor-Leste compared with NOAA-CREP's other monitoring sites across the Pacific. Timor-Leste values are shown in red.

CAU net carbonate accretion rates ranged from 0.045 to 0.091 g $CaCO_3$ cm^{-2} yr^{-1}, which are some of the lowest measures we have recorded in our Pacific-wide monitoring efforts during the same time period. This is primarily driven by the seawater carbonate chemistry conditions (Figure 34) not providing the environment for calcifying organisms to flourish. Additionally, Timor-Leste's competing benthic communities contest calcifying organisms' success. Figure 35 clearly reveals how dominant other non-calcifying species can be on CAU recruitment and overall reef community composition. This example of a non-calcified dominated CAU is not unique to Timor-Leste and reflects the difficulty calcifying organisms have with recruitment and growth, where benthic calcifiers compete for space against faster growing species and with seawater carbonate chemistry conditions that do not promote high accretion rates.

The rate of reef accretion is affected by a complex mix of factors, which include the direct seawater chemistry, how quickly the water is refreshed by flow over the reef, and the complex physiology of the reef community. For better accretion rate prediction, considering this diverse suite of drivers, we developed a statistical model of CAU accretion rates that incorporates chemistry (as aragonite saturation state), water flow (as wave energy), and local productivity (as chlorophyll-a concentration) across all our Pacific-wide sampling efforts (Figure 34). If we compare the CAU accretion rates measured in Timor-Leste to those that our model predicted, the measured (observed) values obtained from the field sampling are close to our predictions. However, measurements of accretion on the reefs of Timor-Leste (0.045–0.091 g $CaCO_3$ cm^{-2} yr^{-1}) were lower than predicted (Figure 34), suggesting that other physical, chemical, and biological influences are further drawing down net accretion on these reefs. In short, low CAU accretion rates in this area were predicted, but the measured rates were even lower than expected.

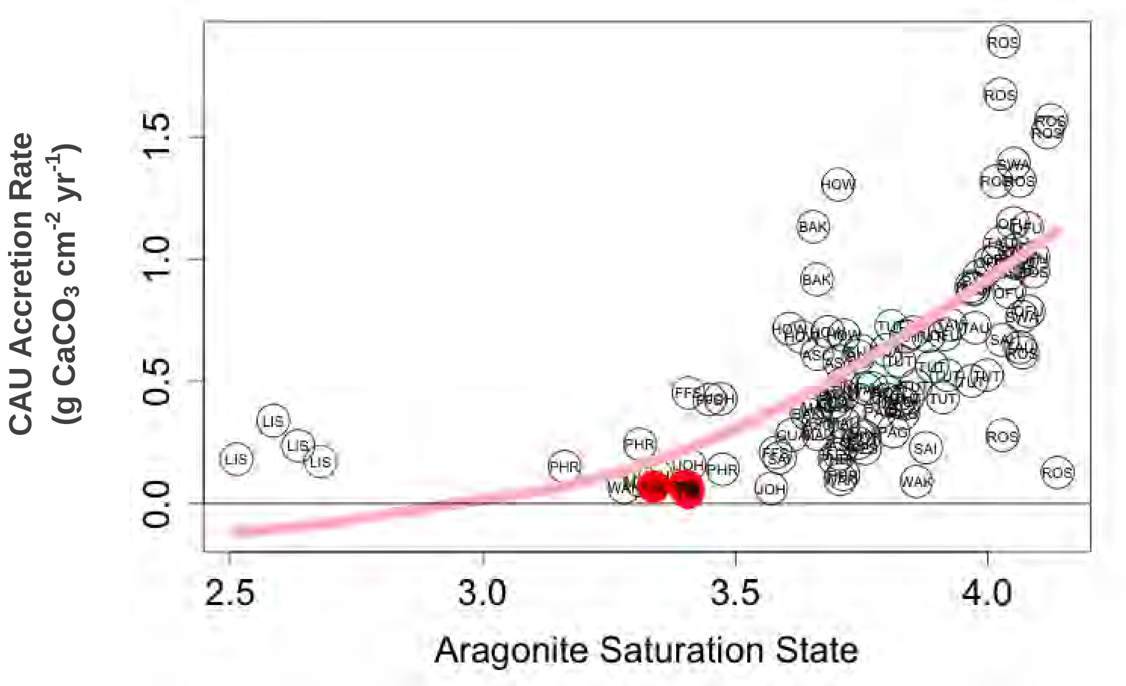


Figure 34. Relationship of carbonate accretion rates from CAUs to aragonite saturation state from seawater sampling. Observed values from Timor-Leste sampling are shown in red circles. All other circles represent observed values from sampling across the Pacific. The modeled dependency of CAU accretion rates on a site's aragonite saturation state is shown as the pink line.

Taken together with the relative seawater chemistry data, the CAU results suggest that the reefs of Timor-Leste are situated at the low end of both aragonite saturation state (or pH) and carbonate accretion when compared with other locations across the Western Pacific. While they continue to grow with a positive reef net accretion (above 0.0 g $CaCO_3$ cm^{-2} yr^{-1} suggests growth), the low accretion rates suggest that ocean acidification impacts should be carefully considered as part of a suite of threats currently facing the coral reefs of Timor-Leste and the associated ecosystem services they provide to coastal communities.

Figure 35. A CAU unit recovered from BAU-04 and dominated by an unidentified non-calcifying organism.

Autonomous Reef Monitoring Structures (ARMS)

Morphospecies collections

A total of 3,535 cryptofaunal organisms larger than 2 mm were collected from 25 ARMS units. On average, over 140 organisms per unit were found, comparable to other locations around the Pacific that ranged on average from 75 to 387 organisms per ARMS unit (Figure 36).

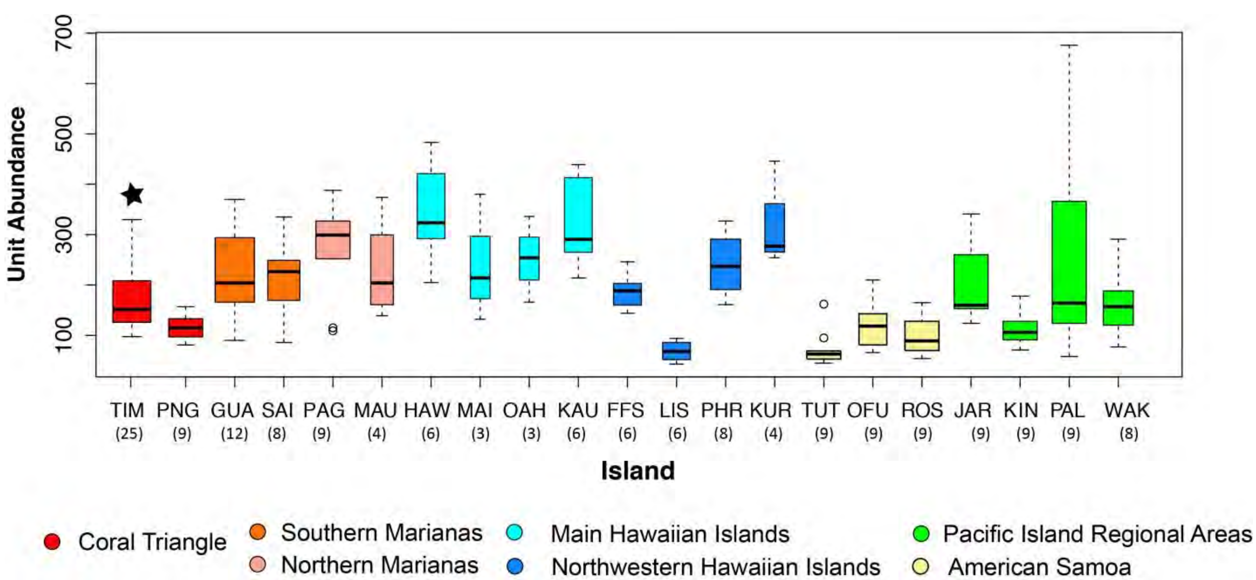


Figure 36. Mean abundance and standard deviation of >2 mm cryptofauna averaged by ARMS unit at different islands across the Indo-Pacific. Islands are color coded by geographic region and the number of ARMS units recovered at each island is in parentheses. Island codes are as follows: TIM (Timor-Leste), PNG (Papua New

Guinea), GUA (Guam), SAI (Saipan), PAG (Pagan), MAU (Maug), HAW (Hawaii), MAI (Maui), OAH (Oahu), KAU (Kauai), FFS (French Frigate Shoals), LIS (Lisianski), PHR (Pearl and Hermes), KUR (Kure), TUT (Tutuila), OFU (Ofu), ROS (Rose), JAR (Jarvis), KIN (Kingman), PAL (Palmyra), and WAK (Wake).

Sites BOB-02, LAU-05, and MAN-09 had the greatest averaged abundance of >2 mm organisms per ARMS unit (Figure 37).

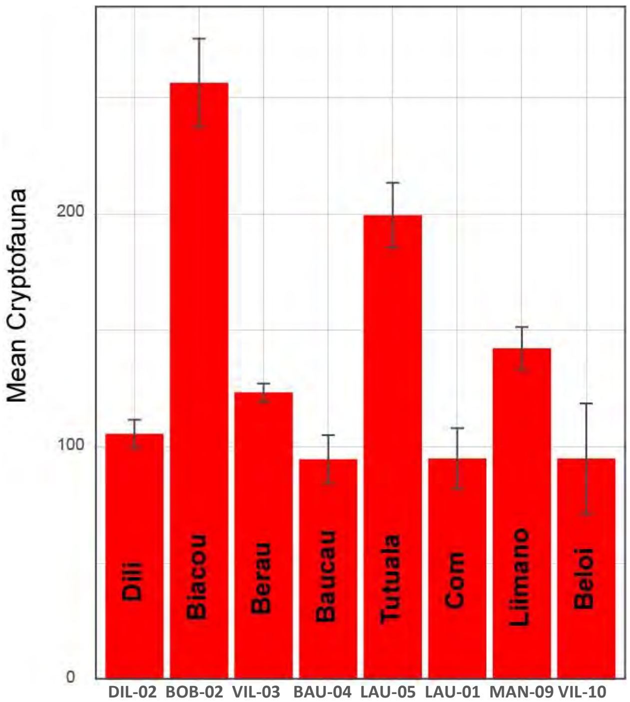


Figure 37. Mean abundance and standard deviation of >2 mm cryptofauna average by ARMS unit at each Climate Monitoring site along the north coast of Timor-Leste deployed from October 2012 to September-October 2014.

Of the >2 mm motile cryptofauna, a total of nine animal phyla were found on the ARMS units (Figure 38). The three most abundant phyla were Arthropoda (crabs and shrimps), Mollusca (sea slugs, bivalves, and marine snails), and Echinodermata (sea stars, sea urchins, and sea cucumbers). Abundance of these three phyla varied among the different sites (Figure 39).

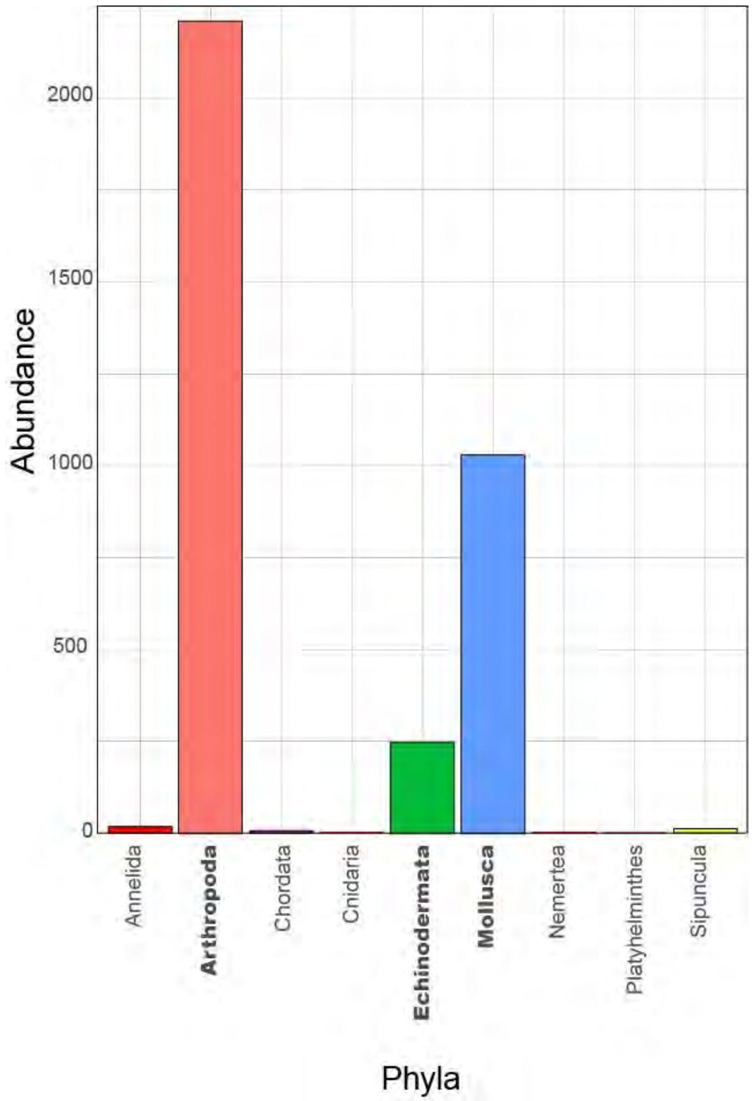


Figure 38. Overall abundance of each phyla from all ARMS units deployed along the north coast of Timor-Leste from October 2012 to September-October 2014.

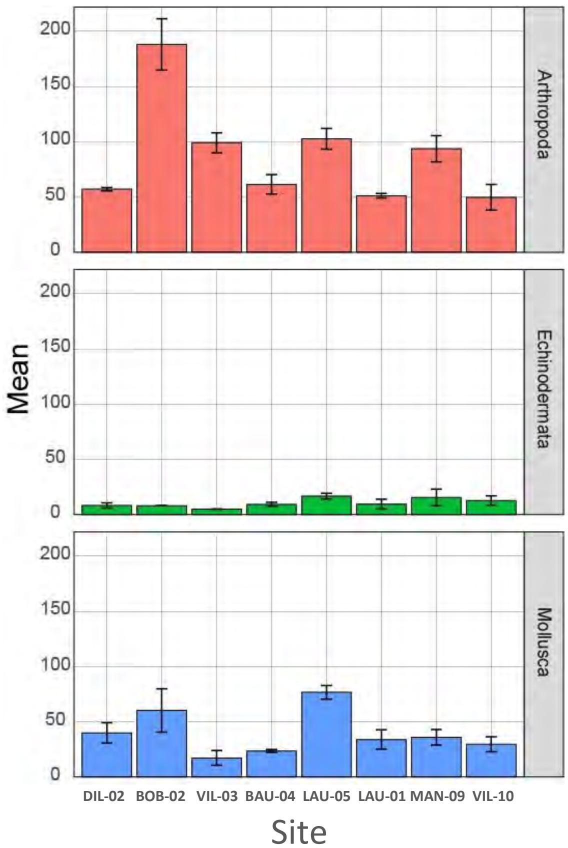


Figure 39. Mean abundance and standard deviation of the top three most abundant phyla collected on the ARMS units by site deployed along the north coast of Timor-Leste over the period October 2012 to September-October 2014.

Eight groups of crustaceans (arthropods) were found on the ARMS units: coral guard crabs (2%), crabs (20%), hermit crabs (16%), porcelain crabs (16%), sea spiders (<1%), shrimps (36%), squat lobsters (9%), and stomatopods (<1%). The abundance of these groups varied considerably among the sites surveyed (Figure 40).

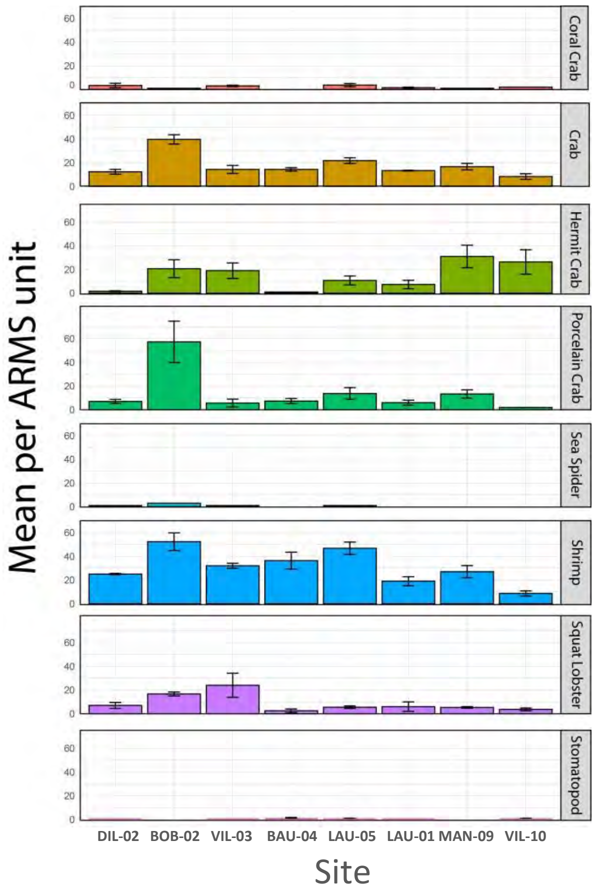


Figure 40. Mean abundance and standard deviation of crustacean groups from ARMS units by site deployed along the north coast of Timor-Leste over the period October 2012 to September-October 2014.

Five groups of echinoderms were encountered on the ARMS units: brittle stars (73%), crinoids (8%), sea stars (3%), sea cucumbers (12%), and sea urchins (4%). Brittle stars were dominant at all sites, while the remaining groups of echinoderms were in relatively low abundances or absent among sites (Figure 41).

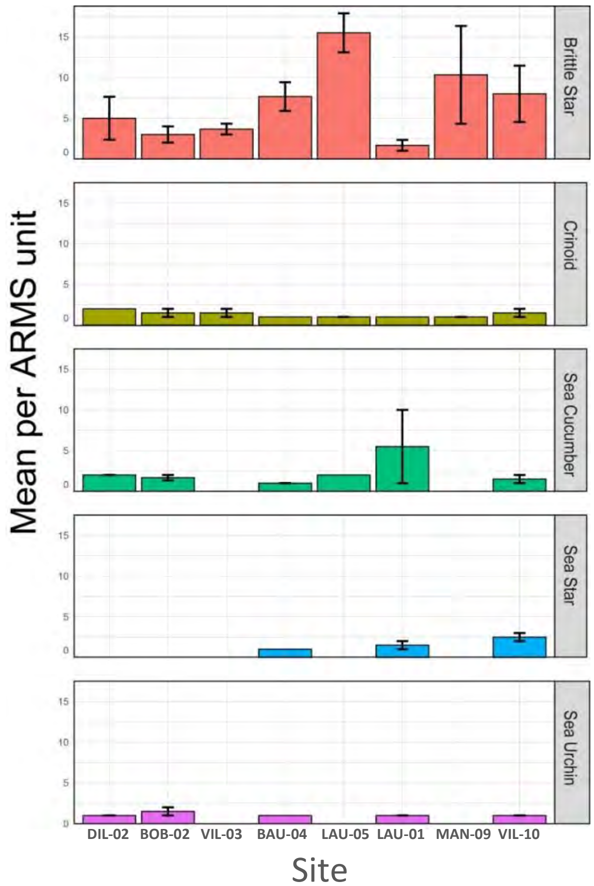


Figure 41. Mean abundance and standard deviation of echinoderm groups from ARMS units by site by site deployed along the north coast of Timor-Leste over the period October 2012 to September-October 2014.

There were five broad groups of Mollusca found on the ARMS: sea snails, sea slugs, bivalves, chitons, and octopuses. However, 91% of all Mollusca were gastropod sea snails.

Brachyuran Crab DNA Barcoding Results

A total 494 crabs were recovered from 25 ARMS units, 269 of which were DNA barcoded. Of the 269 crabs, 74 unique Operational Taxonomic Units (OTU) were found. Twenty-six OTUs were identified to species and 27 OTUs were new barcodes added to the database. Further taxonomic evaluation of these 27 new brachyuran OTUs is needed to determine if they are new species or simply known species that have not been barcoded.

There were 26 brachyuran families in total recorded from the recovered ARMS with 90% of the crabs from the following five families: Epialtidae, Pilumnidae, Portunidae, Trapezidae, and Xanthidae. Site BOB-02 had the greatest number of crabs from Epialtidae and Pilumnidae, site BAU-04 had the greatest number of Portunids and site LAU-05 had the greatest number of Trapezid and Xanthid crabs (Figure 42). Crab OTU richness was greatest at BOB-2 with 33 OTUs, followed by LAU-05 and MAN-09 with 28 and 23 OTUs, respectively. On average, there were approximately 7 crab species per ARMS unit. Other locations around the Indo-Pacific average from 2 to 16 crab species per ARMS unit.

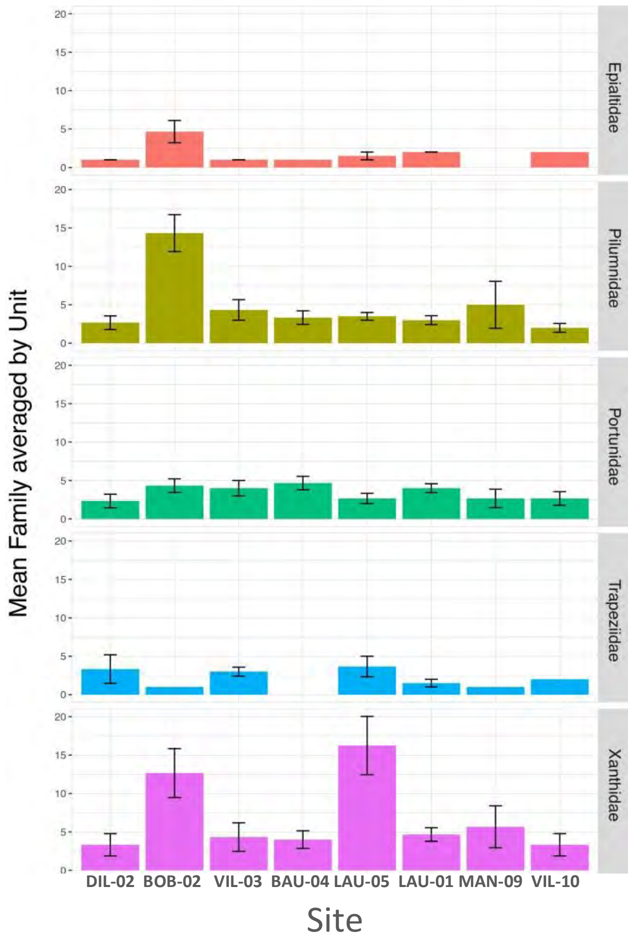


Figure 42. Mean abundance and standard deviation of brachyuran family groups from ARMS units by site deployed along the north coast of Timor-Leste over the period October 2012 to September-October 2014.

Genetic Metabarcoding Results

A total of 69 sample fractions of a possible 75 were metabarcoded from 25 ARMS units (3 sample fractions per unit; 100 µm, 500 µm, and sessile). From the 69 fractions that underwent successful next-generation molecular sequencing, over 14 million DNA sequences were obtained (Table 7).

Table 7. Number of sequences from each ARMS unit based on fraction size from next generation sequencing on the MiSeq Illumina platform. Greyed out cells represent the fractions that did not work during laboratory processing for DNA.

Site	Unit	Sequences		
		100 µm	500 µm	Sessile
DIL-02	A	161,071	118,039	215,629
DIL-02	B	173,868	212,808	192,152
DIL-02	C	183,409	196,812	208,357
BOB-02	A	126,555	199,896	249,989
BOB-02	B	348,560	215,181	
BOB-02	C	360,750	270,215	295,369
VIL-03	A	194,088	128,256	277,175
VIL-03	B	210,063	199,596	299,628
VIL-03	C	169,428	200,455	291,123
BAU-04	A	158,602	138,030	325,468
BAU-04	B		188,659	156,413
BAU-04	C	193,537	194,753	161,217
LAU-05	A	198,232	168,504	161,300
LAU-05	B		185,351	165,765
LAU-05	C	149,721	155,700	122,200
LAU-01	A	149,278	144,327	419,195
LAU-01	B	159,933	196,052	105,749
LAU-01	C	193,169		120,827
MAN-09	A	149,733	197,936	165,077
MAN-09	B	204,562	162,231	125,001
MAN-09	C		170,240	160,383
VIL-10	A	162,373		146,737
VIL-10	B	200,904	189,215	144,519
VIL-10	C	210,793	199,210	155,461
Total		**5,508,276**	**4,031,466**	**4,664,734**

Approximately 211,000 of the 14 million sequences were clustered into 311 OTUs that matched existing DNA barcodes within the Barcode of Life Data Systems (BOLD) database (http://www.boldsystems.org/). However, this is only 1.5% of all the sequences, indicating that much of the cryptofauna found on the ARMS units in Timor-Leste has not been DNA barcoded or identified. Once singletons were removed, 108 OTUs were identified to Species, 20 to Genus, and 2 to Family (Appendix K). Fifteen were not marine organisms but were birds, mammals, or insects. This indicates that samples were slightly contaminated during the land-based processing. This can happen from not wearing gloves, insects crawling into the samples during field processing, and eDNA (environmental DNA) from unfiltered salt water used during processing. Together, these contaminated sequences only represented 6% of the total OTU identified sequences.

The greatest number of species identified within taxa groups were fishes (24 species), followed by sponges (19), marine snails (15), and copepods (12; Table 8). The taxa groups with the most number of sequences were sponges (50,774), shrimps (50,361), fishes (38,425), and hard corals (20,185), indicating potentially higher biomass within the samples. Based solely on identified OTUs, BAU-04 had the greatest OTU richness with 77 OTUs followed by LAU-05 and BOB-02 with 72 and 70 OTUs, respectively. The site with the lowest OTU richness was DIL-02 with 58 OTUs.

Table 8. Number of species and pooled sequences summed within taxa groups from pooled metabarcoding data across all sites along the north coast of Timor-Leste over the period October 2012 to September-October 2014.

Taxa Group	Species (#)	Pooled Sequences (#)
Amphipods	2	76
Barnacle	1	48
Bivalves	3	19,138
Brittle Stars	5	10,592
Copepods	12	2,250
Crabs	10	2,620
Dinoflagellate	1	360
Fishes	24	38,425
Hard Corals	6	20,185
Marine Snails	15	1,666
Marine Worms	2	782
Octopus	1	28
Porcelain Crab	1	21
Red Algae	1	14
Sea Hare	1	425
Shrimps	6	50,361
Soft Coral	1	130
Spider	1	10
Sponges	19	50,774
Squat Lobster	1	28
Tunicates	2	272
Urchin	1	36

Three notable OTUs were detected from the Timor-Leste sequences. All sites contained the OTU sequence identified as the dinoflagellate, *Azadinium spinosum*, which is known to produce toxins with shellfish poisoning (Salas et al. 2011). The tunicate, *Symplegma rubra*, originally known from the western Atlantic, was detected at five sites (DIL-02, BOB-02, VIL-03, LAU-01, and VIL-10), and the sponge, *Geodia phlegraei*, originally known from the North Atlantic, was found at BAU-04, LAU-05, and MAN-09.

Benthic Cover

Coral cover was moderate and varied among Climate Monitoring Sites (Figure 43). The greatest levels of coral cover were reported at sites LAU-01 (40.1%), where branching corals were common, and VIL-10 (38.1%) that was characterized by a variety of massive, encrusting, and branching corals (Appendix E). Notably, site LAU-01 is located within the recently designated Nino Konis Santana National Park which, according to Erdmann and Mohan (2013), contains some of the highest biodiversity of all the reefs in the country and plays an important role in the regional Marine Protected Area Network. Site VIL-10 located on the Belio Barrier Reef complex off east Atauro Island is also found in a high-quality reef area that ranked amongst the highest in conservation value (Erdmann and Mohan 2013). Interestingly, these findings also correspond with the coral cover results by district presented in the benthic community composition section of the *Coral Reef Ecosystem Assessment* Chapter in which Atauro and Lautem had the overall highest hard coral percentages.

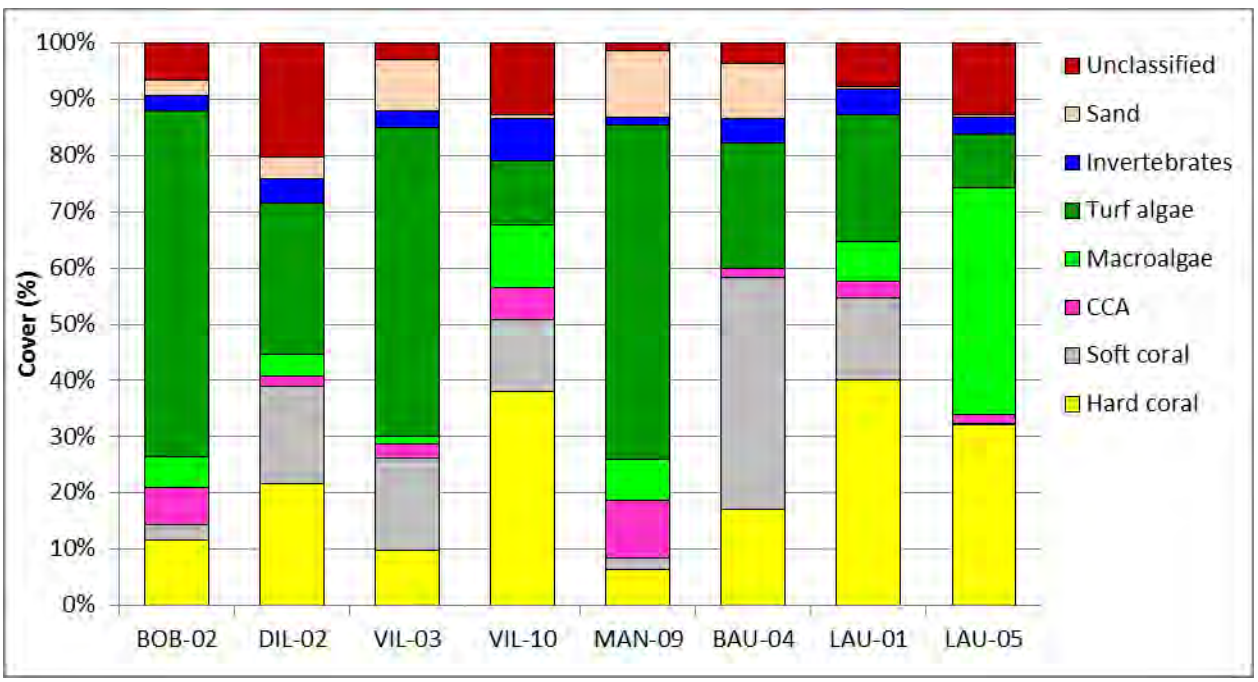


Figure 43. Benthic cover (%) based on analyses of benthic photoquadrat images collected at hard-bottom sites around Timor-Leste in September-October 2014. Sites are spatially arranged from west to east. CCA: Crustose coralline algae.

Table 9. Benthic cover (%) and benthic substrate ratio by site from photoquadrat surveys conducted at the Climate Monitoring sites in September-October 2014. Survey sites are spatially arranged from west to east. CCA: Crustose coralline algae.

Site ID	Hard coral (%)	Soft coral (%)	CCA (%)	Macroalgae (%)	Turf algae (%)	Sand (%)	Benthic Substrate Ratio
BOB-02	11.6	2.7	6.6	5.5	61.7	2.7	**0.3**
DIL-02	21.6	17.5	1.7	4.0	26.7	4.0	**1.3**
VIL-03	9.7	16.5	2.5	1.4	55.0	9.3	**0.5**
VIL-10	38.1	12.8	5.7	11.1	11.4	0.7	**2.5**
MAN-09	6.4	2.0	10.4	7.1	59.6	11.9	**0.3**
BAU-04	17.0	41.3	1.7	0.0	22.3	9.7	**2.7**
LAU-01	40.1	14.6	3.0	7.1	22.5	0.3	**2.0**
LAU-05	32.1	0.4	1.5	40.5	9.6	0.4	**0.7**

The lowest coral cover was observed at site MAN-09 (6.4%) and site VIL-03 (9.7%). Interestingly, site MAN-09 also displayed the highest levels of CCA (10.4%) and sediment (11.9%) and one of the highest levels of turf algae (59.6%), much of which grew on coral rubble. Sites BOB-02 and VIL-03 also had high levels of turf algae, 61.7% and 55%, respectively. Sites BAU-04 and LAU-05 also exhibited higher levels of sediment, 9.7% and 9.3%, respectively.

Soft corals were a noteworthy component of the benthic fauna, particularly at site BAU-04 where they accounted for over 40% of the benthic cover (Table 9). In contrast, soft corals were notably uncommon at site LAU-05 where they accounted only for 0.4% of the benthos; conversely, this site also contained the highest levels of macroalgae (40.5%), largely made up of *Halimeda*, another important component of the calcifying benthos.

The benthic substrate ratio (computed from mean percent cover values) was >1 at half the sites. The benthic substrate ratio was highest (≥2.0) at sites BAU-04, VIL-10, and LAU-01, which contained the highest levels of coral percent cover (hard and soft corals combined). The lowest substrate ratio (0.3) at sites BOB-02 and MAN-09 reflects the lower cover of hard and soft corals at these two sites despite having the highest levels of CCA (Table 9). Unlike the coral cover results, these single site metrics did not relate consistently with the district level ratios in which they reside.

5. DEVELOPING A SPATIAL DATA FRAMEWORK

The data compiled in this report have been organized into a spatial data framework to ease the delivery of the data collected and created by NOAA-CREP to our partners at the Timor-Leste Ministry of Agriculture and Fisheries (MAF). In lieu of specific capacity building activities, this spatial data framework is designed specifically for anticipated users and increases its relevance in resource management. This spatial data framework should therefore accompany the data structure provided to MAF at the workshop led by NOAA-CREP in June 2017.

Timor-Leste Project Portal

The framework is hosted on NOAA's Coral Reef Information Service (CoRIS)website, in a 'project portal' established specifically for this project with Timor-Leste (https://www.coris.noaa.gov/activities/projects/timor-leste/). The portal includes 3 tabs: 1) Project Overview, 2) Report Download, and 3) Data Download.

Project Overview

The Project Overview page includes a brief summary of the USAID-NOAA partnership in Timor-Leste, with the option to download this complete report in Adobe Acrobat (PDF) format.

Report Download

The Report Download page provides the contents of this report by chapter, also in PDF format, allowing a user to view or download only the chapters and/or appendices of interest. The appendices are organized by the corresponding chapter rather than in sequential order as they appear in this report.

Data Download

The Data Download page includes all datasets that have been collected or created by NOAA-CREP for Timor-Leste as part of this project, and the data are organized by the corresponding data chapters (Chapters 2–4). See the *Data Structure* section below for a detailed list and description of the datasets provided.

Data Documentation and Archival

Each dataset has been fully described in the NOAA Fisheries 'InPort' Enterprise Data Management Program, an online metadata (data documentation) catalog and repository (https://inport.nmfs.noaa.gov/inport). Additionally, to preserve the data in perpetuity, the data are archived and accessible online at the NOAA National Centers for Environmental Information. The data archive for each dataset is linked to the corresponding metadata record in the InPort catalog. Links for accessing the documentation in InPort and the data in the archive are included with each dataset in the project portal.

Data Structure

The data and information provided in the Timor-Leste project portal are organized similarly to the data structure delivered to MAF during the June 2017 workshop (Table 10).

Table 10. The folder structure of the data and information provided to MAF.

Folder name and hierarchy	Folder description
\TIMOR-LESTE\	The root folder of the entire data structure.
\Report\ \Full report\ \Report contents\	Contains the full report and the report contents in Adobe Acrobat format (PDF). The contents in these folders correspond to the contents available in the Project Overview and Report Download pages of the Timor-Leste project portal.
\Data\ \Satellite Mapping\ \Ecosystem Assessments\ \Climate Change Baselines\	Contains all datasets collected or created by NOAA-CREP and organized by the data chapters from the report. This corresponds to the Data Download page of the Timor-Leste project portal. See Table 11 for specific details.

Table 11 shows a list and description of the datasets available within the data structure, including the associated file formats and links to metadata for each dataset. A detailed description of the satellite mapping datasets is given in the *Satellite Mapping Data* section below, as these datasets have a complex data structure compared with the Ecosystem Assessment and Climate Change Baseline datasets.

Table 11. A list of the datasets available in the data structure and the Timor-Leste project portal. The folders are listed by chapter sequence from the report rather than in alphabetical order as found in the data structure. *The raw and georeferenced satellite imagery is not available on the Timor-Leste Project Portal because the DigitalGlobe license agreement prohibits public distribution of the source imagery (i.e., posting the imagery online is not allowed).

Folder name and hierarchy	Folder description
\Satellite Mapping	Contains the satellite mapping datasets described in Chapter 2.
\Image Catalog\	Inventory of WorldView-2 satellite images purchased, as well as the image footprints and boundaries, and the regions of interest used to define the geographic areas to acquire the satellite images (Figure 3). Format: .GDB and .SHP Metadata: https://inport.nmfs.noaa.gov/inport/item/46151
\Ground Truth\	Ground-truth data collected by NOAA-CREP used to validate the depths derived from the WorldView-2 imagery (Figure 4). Format: .SHP Metadata: https://inport.nmfs.noaa.gov/inport/item/25307
\Raw Imagery*	Raw WorldView-2 satellite imagery provided by DigitalGlobe, including the supporting metadata files (Appendix B). Format: .TIF
\Georeferenced Imagery*	WorldView-2 satellite imagery that was georeferenced to the ESRI basemap (Appendix B). Format: .TIF
\Bathymetry\	Bathymetry data derived from the WorldView-2 satellite imagery (Figure 5). Format: .TIF Metadata: https://inport.nmfs.noaa.gov/inport/item/46150

\Benthic Habitat\	Benthic habitat data derived from the WorldView-2 satellite imagery (Figure 6). Format: .TIF Metadata: https://inport.nmfs.noaa.gov/inport/item/29128
\Ecosystem Assessments	Contains the datasets from the coral reef ecosystem assessment surveys in 2013 described in Chapter 3.
\Fish Surveys\	Reef fish survey data (Figure 8). Format: .CSV and .SHP Metadata: https://inport.nmfs.noaa.gov/inport/item/32998
\Benthic Images\	Benthic photographs collected during the fish surveys. Format: .JPG Metadata: https://inport.nmfs.noaa.gov/inport/item/46160
\Benthic Cover\	Benthic cover data derived from the analysis of the benthic images collected during the fish surveys (Figure 16). Format: .CSV and .SHP Metadata: https://inport.nmfs.noaa.gov/inport/item/46161
\Climate Change Baselines	Contains the baseline datasets collected from the Climate Monitoring sites from 2012 to 2014 described in Chapter 4.
\Temperature\	Temperature data from STRs (Figure 27). Format: .CSV and .SHP Metadata: https://inport.nmfs.noaa.gov/inport/item/46164
\Seawater Chemistry\	Seawater chemistry data from seawater samples (Figure 28). Format: .CSV and .SHP Metadata: https://inport.nmfs.noaa.gov/inport/item/46163
\Calcification Rates\	Calcification rate data from the CAUs (Figure 31). Format: .CSV and .SHP Metadata: https://inport.nmfs.noaa.gov/inport/item/46162
\Biodiversity\	Marine invertebrate specimen and sequenced data, and species and plate photographs from the ARMS (Figure 38). Format: .CSV, .SHP, .FASTQ, and .JPG Metadata: https://inport.nmfs.noaa.gov/inport/item/46159
\Benthic Images\	Benthic photographs collected from the Climate Monitoring sites in 2012 and 2014 (see benthic photograph collages in Appendix E). Format: .JPG and .SHP Metadata: https://inport.nmfs.noaa.gov/inport/item/46160
\Benthic Cover\	Benthic cover data derived from the analysis of the benthic images collected at the Climate Monitoring sites in 2014 (Figure 43). Format: .CSV and .SHP Metadata: https://inport.nmfs.noaa.gov/inport/item/46161

The following file formats are included in the data structure (Table 11), along with links for more information about each format:

- ESRI File Geodatabase (.GDB), includes both vector and raster spatial data, https://www.loc.gov/preservation/digital/formats/fdd/fdd000294.shtml
- ESRI Shapefile (.SHP), vector spatial data, https://www.loc.gov/preservation/digital/formats/fdd/fdd000280.shtml
- GeoTiff (.TIF), raster spatial data, https://www.loc.gov/preservation/digital/formats/fdd/fdd000279.shtml

- JPEG Image Encoding Family (.JPG), optical data (e.g., photographs), https://www.loc.gov/preservation/digital/formats/fdd/fdd000017.shtml
- Comma Separated Values (.CSV), numerical/tabular data, https://www.loc.gov/preservation/digital/formats/fdd/fdd000323.shtml
- FASTQ (.FASTQ), raw sequence reads with corresponding quality scores, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2847217/

Satellite Mapping Data

There are six folders (datasets) within the Satellite Mapping folder, including Image Catalog, Ground Truth, Raw Imagery, Georeferenced Imagery, Bathymetry, and Benthic Habitat. Below, we describe in more detail the data contents within each folder. The raw and georeferenced imagery, bathymetry, and benthic habitat folders contain four subfolders based on the regions of interest (Atauro, North shore, Oecusse, and South shore). Within the raw and georeferenced imagery folders, each region folder includes a subfolder for each image purchased, as each image is essentially a collection of files.

Folder: \TIMOR-LESTE\Data\Satellite Mapping\Image Catalog

The image catalog is provided as an ESRI file geodatabase (WV-2_Image_Catalog_Timor.GDB) and serves two purposes: 1) it is an inventory of all the images purchased by each region of interest (ROI), and 2) it contains features associated with the images, including the ROI, the boundary extent of the available images within each ROI, and the footprints of each image (Figure 44). The ESRI file geodatabase (.GDB) is a proprietary format for use with ArcGIS software; therefore, the datasets are also provided in shapefile format for use with other software programs.

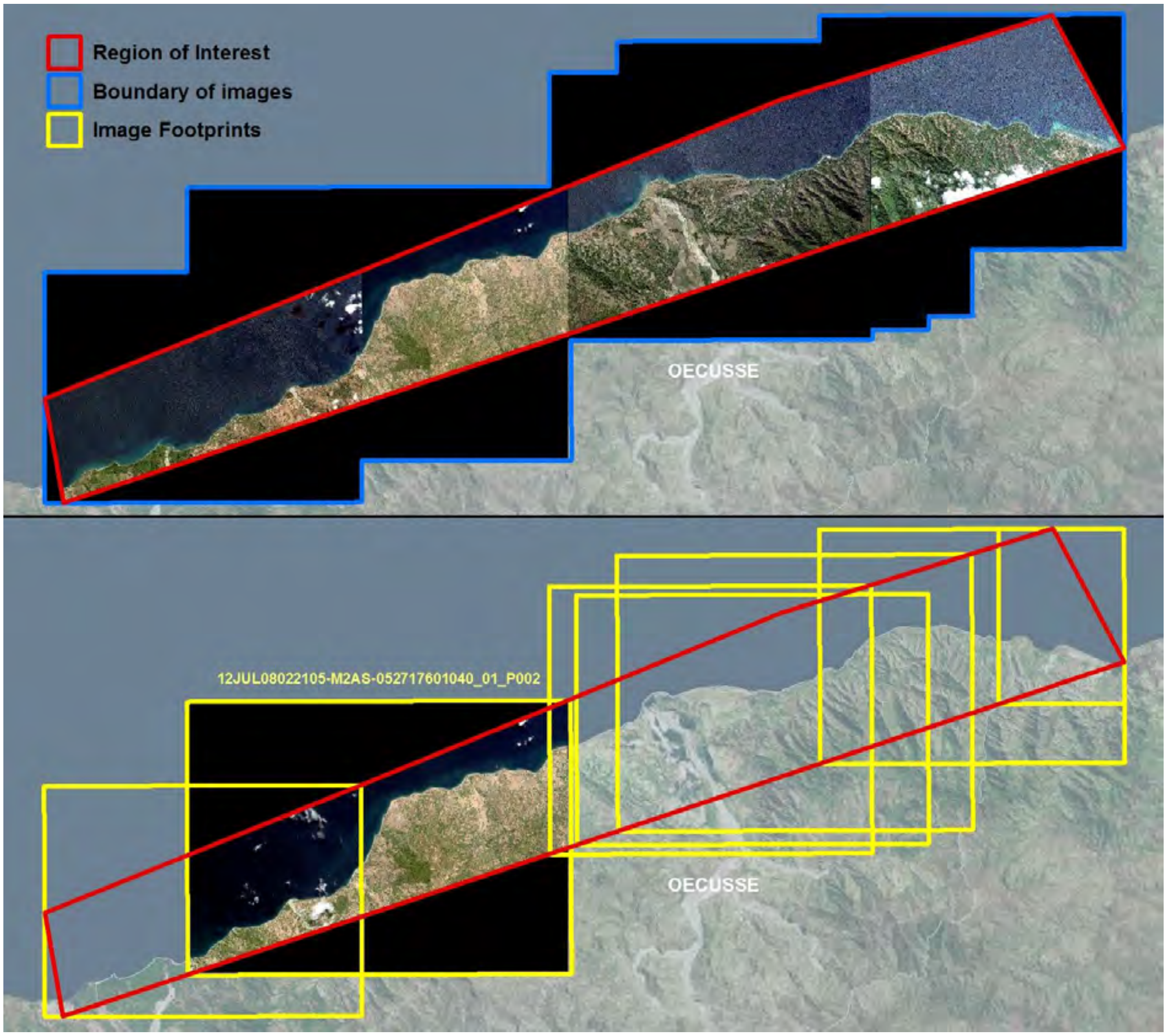


Figure 44. Maps showing the available features in the image catalog for the Oecusse region for the mosaic dataset (*top*) and individual images (*bottom*) including the region of interest (red), boundary of the available images (blue), and the footprints of the seven images (yellow) purchased for the Oecusse region.

The ROI (ROI in .GDB; WV-2_ROI_Timor.SHP) was used to define the desired geographic areas to purchase the satellite imagery from Digital Globe. A collection of raw images was acquired along the coasts of the identified four regions of interest (Atauro, North shore, Oecusse, and South shore). All images associated with each region are stored in what is called a mosaic dataset in the ESRI file geodatabase. Within each mosaic dataset is the boundary (extent) of the available images for each region (Boundary in GDB; WV-2_Image_Boundary_Timor.SHP) and the footprint (Footprint in GDB; WV-2_Image_Footprint_Timor.SHP) for each image within the boundary (Figure 44). Within GIS, the footprints can be used to quickly identify the image files that fall within a geographic area of interest. Furthermore, the associated attribute table indicates if the images were georeferenced and used to derive depths and habitat classes (Appendix B).

Folder: \TIMOR-LESTE\Data\Satellite Mapping\Ground Truth

The ground-truth data include depth soundings collected by NOAA-CREP during the 2012 (WV-2_DepthSoundings_Timor_2012.SHP) and 2013 missions (WV-2_DepthSoundings_Timor_2013.SHP) in shapefile format. Soundings from 2012 were recorded every second and ranged in value from 0 – (-30) m. The 2013 soundings were recorded every 0.1–2 seconds and ranged in value from 0 – (-200) m. These data were used to validate the depths derived from the satellite imagery.

Folder: \TIMOR-LESTE\Data\Satellite Mapping\Raw Imagery

Digital Globe provides an array of satellite products from a variety of sensors. The product that was purchased for this project was WorldView-2, multispectral (8 band), 16-bit, full swath imagery that was provided as a mosaic of individual images (sub-images) in GeoTIFF format, and the product type was Ortho Ready (level 2A) Standard (http://www.c-agg.org/cm_vault/files/docs/DigitalGlobe-Base-Product-FAQ.pdf). All images were projected to the Universal Transverse Mercator (UTM) coordinate system, zone 51S with 2-m pixel resolution.

Within the data structure, each image that was purchased has a corresponding Order ID folder that contains 1) the sub-images (.TIF), 2) a tile map file (.TIL), which is a stitched mosaic of the sub-images, and 3) the metadata files, which are collectively referred to as image support data (ISD; Figure 45).

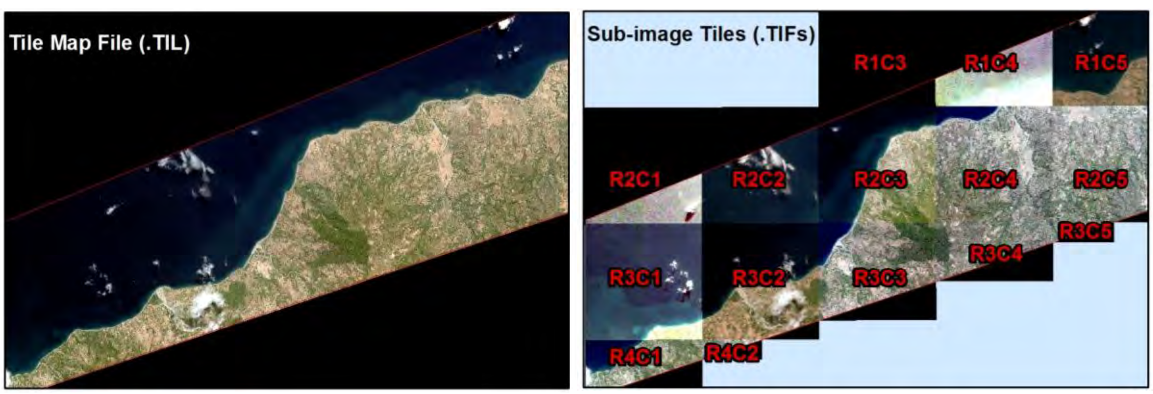


Figure 45. Example of a tile map file (.TIL) for Image ID 12JUL08022105-M2AS-052717601040_01_P002 (*left*) compared with the sub-image tiles (.TIF) for the same Image ID (*right*). The sub-image tiles are labeled by their respective row and column numbers.

The Order ID folder name is based on a unique ID assigned by Digital Globe that includes the Delivery ID, Image Sequence, and Product Type. The Delivery ID is a unique 15-character ID, the Image Sequence is the sequential number for each image in that delivery, and the Product Type is multispectral (MUL). For example:

Order ID:	052717601060_01_P001_MUL
Delivery ID:	052717601060_01
Image Sequence:	P001
Product Type:	MUL

The ISD files included with each image are listed in Table 12 along with an example. Refer to the Product Component-Level ISD documentation for further details about the naming conventions and ISD file descriptions (DigitalGlobe 2014).

Table 12. A list of the image support data (ISD) files provided by DigitalGlobe with each satellite image, and an example of each file name is provided for Image ID 11JUN07021210-M2AS-052717601060_01_P001.

Image Support Data File type	Example file name
Product Component Index Readme File (.TXT)	11JUN07021210-M2AS-052717601060_01_P001_README.TXT
License File (.TXT)	ENTERPRISE.TXT
Image Metadata File (.IMD)	11JUN07021210-M2AS-052717601060_01_P001.IMD
Product Browse File (.JPG)	11JUN07021210-M2AS-052717601060_01_P001-BROWSE.JPG
Tile Map File (.TIL)	11JUN07021210-M2AS-052717601060_01_P001.TIL
RPC00B File (.RPB)	11JUN07021210-M2AS-052717601060_01_P001.RPB
XML File (.XML)	11JUN07021210-M2AS-052717601060_01_P001.XML

All ISD files are named by their Image ID with the exception of the license file. The Image ID is based on the Acquisition Time, Product Info, and Order ID. The Acquisition Time includes the 2-digit collection year, 3-character month, 2-digit day and 6-digit time and the Product Info includes the band, product, and image types. Order ID, as previously described, is included minus the "MUL" suffix. For example:

Image ID: 11JUN07021210-M2AS-052717601060_01_P001.TIF
Acquisition Year: 11 (2011)
Acquisition Month and Day: JUN07 (June 7 th)
Acquisition Time: 021210 (2:12 am, and 10 sec)
Product Info: M2AS (multispectral band, standard product, single/sub-scene image)
Order ID: 052717601060_01_P001

For the sub-image .TIF files, the file name includes the Image ID plus the row and column number of the sub-image in relation to the mosaic (.TIL). For example, sub-image 11JUN07021210-M2AS_R1C4-052717601060_01_P001.TIF is found in row 1, column 4 of the corresponding tile map file (Figure 45). For mapping and visualization, the Tile Map File (rather than the TIFs) is a more user-friendly format to use in GIS.

Folder: \TIMOR-LESTE\Data\Satellite Mapping\Georeferenced Imagery

To improve the geolocation accuracy, the raw images were georeferenced to an ESRI basemap.

The folder structure and naming conventions of the georeferenced imagery are similar to the raw imagery, with the exception of the suffix 'REC' (i.e., rectified) appended to the Order ID folder and the Image ID. For example,

Order ID: 052717601060_01_ P001_MUL_REC
Image ID: 11JUN07021210-M2AS-052717601060_01_P001_REC.TIF

Only images that fulfilled the evaluation requirements were georeferenced and further processed for deriving depths or habitat classes. Typically, only the tile map files were georeferenced and saved as .TIF to the Order ID folder; the sub-image files were only georeferenced as needed, in addition to or instead of the tile map file for depth or habitat derivation. The georeferenced images are provided in the WGS 1984 geographic coordinate system (i.e., unprojected).

Folder: \TIMOR-LESTE\Data\Satellite Mapping\Bathymetry

The final product for the bathymetry data is provided as a mosaic for each region in TIF format, the preferred format to use in GIS. The individual bathymetry files that make up the mosaics, which were derived directly from the georeferenced imagery, are also provided in TIF format. The mosaic datasets are named Bathymetry_mosaic_<REGION>.TIF. The name of each bathymetry file includes the acquisition date (collection month, day, and year) and the image sequence (e.g., 11JUN07_P001.TIF). The individual bathymetry files are projected using UTM coordinate system zone 51S. Mosaic datasets are provided in the same projected coordinate system. Additionally, unprojected versions of the mosaics are also provided (WGS 1984). The bathymetry product has a 'floating point' pixel type (i.e., cell values are numbers with decimals), which is appropriate for continuous data that represent surfaces such as the seafloor.

\Satellite Mapping\Benthic Habitat

The final product for the benthic habitat data is provided in the same manner as the bathymetry product (as described above), with the exception of the pixel type. The pixel type of the benthic habitat product is 'unsigned integer' (i.e., cell values are positive whole numbers); therefore, unlike the bathymetry, it is discrete data that stores the cell values and associated attributes (habitat class and types) in an attribute table. The cell values are codes that represent the 13 habitat classes as shown in Table 13.

Table 13. Numeric cell values in the attribute tables of the benthic habitat data and the corresponding description for the habitat classes and types.

Cell value	Class	Type
1	Hard shallow	Hard substrate
2	Soft shallow	Soft substrate
3	Hard mid	Hard substrate
4	Soft mid	Soft substrate
5	Hard deep	Hard substrate
6	Hard soft	Soft substrate
7	Seagrass	Seagrass
8	Unknown	Unknown
9	Mangrove	Mangrove
10	Intertidal	Intertidal
11	Emergent rocks	Emergent rocks
12	Macroalgae	Macroalgae
13	Lagoon	Lagoon

APPENDICES

Appendix A. Capacity Building and Community Engagement

During 2011 and 2012, NOAA worked with the Government of Timor-Leste, Ministry of Agriculture and Fisheries (MAF), USAID Timor-Leste Mission, and local partners and stakeholders to identify and prioritize some key coastal management tools that could help people and communities adapt to the marine ecosystem impacts of climate change and better sustain fisheries and food security in Timor-Leste. During various meetings, MAF and their partners outlined a critical need for enhanced local, institutional, and organizational capacity to continue long-term observations to bring Timor-Leste's resource managers scientifically-credible observations for informed decision making. NOAA-CREP scientists leveraged the partnership opportunities provided by the Coral Triangle Support Partnership (CTSP) to build and maintain the relationships needed to achieve this objective. Through the generous support of the CTSP, implemented primarily by Conservation International (CI) in Timor-Leste, and working in partnership with local organization Rai Consultadoria, the NOAA-CREP team brought together scientists, managers, and community members to develop a framework for an ecosystem approach to fisheries management (EAFM) and prepare for the impacts of climate and ocean change on coral reef ecosystems. The following is a summary of NOAA-CREP's community engagement and capacity building efforts, which, where applicable, include links to blogs posted by NOAA-CREP about the activities.

Mission Planning – February 2012

In preparation for the first NOAA-CREP led field mission in Timor-Leste planned for later in 2012, NOAA-CREP traveled to Timor-Leste and met with local in-country partners at MAF to provide an overview of the proposed work and identify: 1) how NOAA-CREP could best provide for the needs of Timor-Leste via the NOAA-USAID partnership, 2) what training and local participation was needed, and 3) where NOAA-CREP should establish monitoring sites. NOAA-CREP then traveled overland, visited, and gathered reconnaissance on the 10 proposed monitoring sites identified by MAF officials as important areas for investigations of marine resources and oceanographic conditions.

Mission Preparations and Operations – October 2012

In early October 2012, four members of NOAA-CREP arrived in Dili to commence the first field mission in Timor-Leste. They met with partners from MAF and USAID to outline the schedule for instrument deployment at the 10 monitoring sites. Before the mission officially commenced, MAF staff along with a representative from the Rai Consultadoria joined the NOAA-CREP team to learn firsthand about NOAA-CREP's instrumentation and planned activities, including an introduction to installing autonomous reef monitoring structures (ARMS), calcification accretion units (CAUs), subsurface temperature recorders (STRs) and collecting water samples at Dili Rock (Figure 46).

Figure 46. Preparing for and executing the 2012 field mission in Timor-Leste: prior to the mission, staff from MAF and NOAA-CREP assemble ARMS (*left*); NOAA-CREP dive team and local partners during the mission (middle); and a local partner with an assembled ARMS unit ready to be deployed (*right)*.

This collaboration was intended to be the first of many targeted capacity building efforts between NOAA-CREP and MAF. The majority of the near two-week expedition took place aboard a chartered 12-m (40-ft) catamaran and successfully concluded with instrumentation deployed and surveys conducted at 10 locations along the north and south coasts of Timor-Leste (see Figure 23 in Chapter 4 for a map of the survey locations).

Blog Posts:
Team embarks on field mission in Timor-Leste, posted October 18, 2012:
https://pifscblog.wordpress.com/2012/10/18/cred-mission-timor-leste/

The final count: Timor-Leste expedition completed, posted November 20, 2012:
https://pifscblog.wordpress.com/2012/11/20/final-count-timor-leste/

EAFM LEAD Workshop – March 2013

NOAA-CREP, with support from USAID's Regional Development Mission for Asia and the CTSP, led a two-day training workshop on an Ecosystem Approach to Fisheries Management for Leaders, Executives, and Decision makers (EAFM-LEAD) to help build Timor-Leste's capacity for effective fisheries management using a more holistic ecosystem approach. Leaders from several Timorese government agencies attended the workshop in Dili, including the Secretary of State and the National Director of Fisheries and other MAF staff, the National Directorate of Forestry, the naval component of the Defense Forces of Timor-Leste, and Professors from the National University of Timor-Leste (Figure 47). The workshop concluded with participants feeling optimistic yet realistic about the long-term process required for the transition toward an EAFM.

Figure 47. Representatives from NOAA-CREP and from government agencies, academia, and the naval force of Timor-Leste who participated in a 2-day EAFM LEAD workshop in Dili.

Blog Post:
NOAA helps Timor-Leste leaders build capacity in an Ecosystem Approach to Fisheries Management, posted April 5, 2013: https://pifscblog.wordpress.com/2013/04/05/timor-leste-leaders-eafm/

Mission Planning – May 2013

In preparation for NOAA-CREP's second field mission in Timor-Leste, NOAA-CREP and CI, with support from the CTSP, traveled overland to meet with MAF District Fisheries Officers to familiarize them with the upcoming field mission, confirm logistical support for scientific operations, and discuss engaging with community members during the planned research activities.

Mission Operations and Community Outreach – June 2013

In early June 2013, six members of NOAA-CREP arrived in Dili to initiate NOAA-CREP's second field mission in Timor-Leste (Figure 48). The primary objective of the mission was gathering data on fish species. The team also collected water samples and information about seafloor characteristics, including photographs and depth soundings. During the nearly month-long mission, two local charter vessels were used for conducting underwater surveys at 150 sites along the northern coastline of Timor-Leste, including the Capital of Dili, the Districts of Oecusse, Bobonaro, Liquica, Manatuto, Baucau, and Lautem, as well as Atauro and Jaco Islands.

Figure 48. Staff from NOAA-CREP met with representatives from MAF, CTSP, USAID, and the Secretary of State for Fisheries prior to the start of the team's surveys in Timor-Leste.

To raise awareness during the mission, a banner was attached to the catamaran used for the surveys that read, "Levantamentu dadu kona-ba biomasa ikan iha Timor-Leste nia tasi-feto," (The survey data on fish biomass in Timor-Leste's northern coast) and included the insignia of all cooperating agencies: NOAA, USAID, CI, CTSP, and the Democratic Republic of Timor-Leste (Figure 49).

Figure 49. The catamaran used for the live-aboard portion of the mission, shown here with the banner that was displayed to raise awareness about the NOAA-CREP mission to study reef fish along Timor-Leste's northern coastline.

CI and NOAA-CREP also produced several short videos (2-4 minutes each) that covered various aspects of the mission:

1. Liquica Day 1, engaging the community in Liquica: https://www.youtube.com/watch?v=QYnI62om7_c
2. Liquica Day 2, introduction to water collection methods and instrumentation: https://www.youtube.com/watch?v=vJDh4-7Kxag
3. Liquica Day 3, NOAA-CREP performs data entry following reef fish surveys in the field: https://www.youtube.com/watch?v=7JSNHyLEDek
4. Liquica Day 4, introduction to subsurface temperature recorders: https://www.youtube.com/watch?v=JTo6C8xHlOY
5. Overview of NOAA-CREP dive safety drills and protocols: https://www.youtube.com/watch?v=3hNr3SuQZGs

While the surveys were underway, representatives from NOAA-CREP and CI traveled overland visiting each district prior to the team's arrival by sea to inform the communities about the surveys being conducted in their neighborhoods and to explain how the information will help to manage their reef fisheries. A series of information, education, and communication workshops were hosted to discuss the importance of well-managed marine ecosystems while raising awareness about NOAA-CREP's activities in Timor-Leste. Participants included national, district and suku (local government unit) government personnel, women's groups, fisherfolk, local business owners, and USAID personnel (Figure 50).

Figure 50. Local fishermen attending an IEC (information-education-communication) workshop in the district of Manatuto, Timor-Leste. The banner translates as "Look after the ocean, and the ocean will look after you." (© CI/photo by Claire Farrugia)

A number of informational flyers and posters were created for these workshops, with versions translated into Tetun. These printed materials explained the purpose of the field missions and the ongoing scientific monitoring being conducted at locations in Timor-Leste, including:

1. "Understanding Fish Populations in Timor-Leste" (flyer)
2. "Understanding Ocean Acidification in Timor-Leste" (2-page flyer)
3. "Monitoring Coral Reefs in Timor-Lester" (poster including Tetun translation)
4. "ARMS: From Science to Outreach—A Universal Method to Collect Knowledge of the Unknown" (poster including Tetun translation)
5. "DIVERSITY!" (poster including Tetun translation)

These printed materials are included at the end of this Appendix.

Blog Posts:
Scientists assess reef fish and benthic communities, monitor effects of ocean acidification off Timor-Leste, posted June 3, 2013 by NOAA-CREP:
https://pifscblog.wordpress.com/2013/06/03/fish-acidification-timor-leste/

Update from Timor-Leste: team completes 50 surveys of reef fish and benthic communities in first week, posted June 19, 2013 by NOAA-CREP:
https://pifscblog.wordpress.com/2013/06/19/update-timor-leste-first-week/

Update from Timor-Leste: scientists complete live-aboard mission to survey reef fishes and benthos, assess ocean acidification, posted July 8, 2013 by NOAA-CREP:
https://pifscblog.wordpress.com/2013/07/08/timor-leste-live-aboard/

Timor-Leste Fish Survey Will Help Create Sustainable Fisheries, posted August 7, 2013 by Rui Pinto:
http://blog.conservation.org/2013/08/timor-leste-fish-survey-will-help-create-sustainable-fisheries/

The final count: summary of mission to assess reef fish assemblages, build capacity in Timor-Leste, posted August 13, 2013 by NOAA-CREP:
https://pifscblog.wordpress.com/2013/08/13/final-count-timor-leste-2/

In Timorese Communities, Importance of Fishing May Be Underestimated, posted August 15, 2013 by Rui Pinto:
http://blog.conservation.org/2013/08/in-timorese-communities-importance-of-fishing-may-be-underestimated/

From the Field in Timor-Leste: Giving Communities a Voice in Conservation, posted August 21, 2013, by USAID/Timor-Leste:
https://blog.usaid.gov/2013/08/from-the-field-in-timor-leste-giving-communities-a-voice-in-conservation/

Coral Triangle Day – June 2013

To commemorate "Coral Triangle Day" in Timor-Leste, the NOAA-CREP scientists participating in the field mission led capacity-building activities for local partners from MAF and CTSP. The team provided an overview of the survey method used in assessing fish populations and demonstrated the method onshore before heading into the field for the day (Figure 51). The team then traveled by boat to Dili Rock to demonstrate the survey methods and water sampling to the participants, and show them the underwater suite of monitoring instruments deployed in 2012.

Figure 51. NOAA-CREP staff reviews the stationary-point-count method with MAF and CTSP staff on the beach at Dili Harbor.

At a second location, Black Rock at Caimeo Beach, the NOAA-CREP team provided an in-depth description of the water sampling protocol, and the partners practiced using Niskin bottles to collect and process water samples (Figure 52). A videographer from the local television news captured these activities. The news station featured these Coral Triangle Day events on the local news the following night, highlighting the collaboration between NOAA-CREP and MAF supported by USAID and the CTSP.

Figure 52. Local partners undergoing training in water sampling techniques.

Blog Post:
NOAA scientists, local partners mark Coral Triangle Day in Timor-Leste with capacity-building activities, posted June 18, 2013 by NOAA-CREP:
https://pifscblog.wordpress.com/2013/06/18/coral-triangle-day-timor-leste/

Spatial Data Management Development & Mission Planning – June 2014

NOAA-CREP traveled to Timor-Leste to discuss spatial data management needs as part of NOAA-CREP's activities in Timor-Leste. Meetings with representatives from MAF were held for: 1) sharing progress on the data collected by NOAA-CREP during the 2012 and 2013 missions in Timor-Leste and on the two basemaps being developed from satellite imagery, and 2) gathering requirements for organizing and managing the data to be provided by NOAA-CREP to MAF at the end of the project.

Figure 53. NOAA-CREP staff met with MAF staff and other local partners to discuss spatial data management needs.

Preparations for the third NOAA-CREP mission planned for later in 2014 were also initiated. Meetings were held with numerous in-country partners from various organizations, including service vendors, NGOs, USAID, MAF, and the U.S. Embassy to arrange logistics for the mission (Figure 53).

While in country, NOAA-CREP staff attended a celebration for "World Oceans Day" in Dili with representatives from CI and the U.S. Embassy, and gave a presentation to the Secretary of State for Fisheries and other regional partners on the NOAA-USAID projects in Timor-Leste.

Mission Operations – September/October 2014

For the third and final field mission, NOAA-CREP scientists worked closely with numerous local partners (private, NGO, government, and the community) to facilitate retrieval of the monitoring instruments deployed in 2012 (Figure 54). Through this collaboration, the training and instrumentation provided enabled the participating partners to build skills for the potential continuation of the coral reef monitoring efforts at the established climate monitoring sites in Timor-Leste beyond the NOAA-USAID partnership.

Figure 54. Scientific dive team members en route to recover monitoring instruments during the 2014 mission.

Building on the relationships established through the information, education, and communication workshops conducted in 2013 in each of the districts, the team received a tremendous amount of support and interest from local residents, fishers, and even school children in sorting and identifying the tiny unique organisms collected from the ARMS units that were retrieved after sitting for two years on the seafloor. Several "Hands-on ARMS" outreach events were organized as part of the effort (Figure 55).

Figure 55. Photos from "Hands-on ARMS" community outreach events in Timor-Leste: girls help look for and sort invertebrates from a processed ARMS (*top left*), boys watch a NOAA-CREP personnel filter matter from ARMS (*top right*), children from Beacou help process an ARMS (*middle left*), crabs and other invertebrates found on ARMS are stored for further study (*middle right*), two brothers from Atauro examine sorted invertebrates before they are photographed (*bottom left*), villagers from Beacou help NOAA-CREP personnel process ARMS (*bottom right*).

Blog Posts:

Scientists return to Timor-Leste for reef monitoring mission, posted September 30, 2014 by NOAA-CREP:
https://pifscblog.wordpress.com/2014/09/30/timor-leste-atauro/

Update from Timor-Leste: children help researchers to process invertebrates from a study site off Beacou, posted October 3, 2014 by NOAA-CREP:
https://pifscblog.wordpress.com/2014/10/03/beacou-arms-children/

USAID funds NOAA mission for scientists to return to Timor-Leste to monitor coral reefs, posted October 13, 2014 by USAID Timor-Leste:
https://www.facebook.com/USAIDTimorLeste/posts/766030143443046

GIS Workshop & U.S. Embassy Outreach Event – October 2015

NOAA-CREP conducted a three-day workshop in which MAF's Agriculture and Land-Use Geographic Information System team was introduced to NOAA coral reef data management and linking this with the science to support fisheries management in Timor-Leste. Workshop participants explored making use of the data collected by NOAA-CREP in Timor-Leste through a series of instructional and "hands-on" GIS exercises (Figure 56).

Figure 56. Photos from the GIS workshop in 2015: NOAA-CREP workshop instructor supporting a workshop participant with a question (*top left*), a workshop participant entering field data using best data management practices (*top right*), two workshop participants working together conducting a GIS analysis using NOAA-CREP GIS data for Timor-Leste (*bottom left*), NOAA-CREP instructor demonstrating data collection in the field using a hand-held GPS unit (*bottom right*).

NOAA-CREP participated in a U.S. Embassy Outreach event, "Amérika iha Timor-Leste: Parseria ba Prosperidade (America in Timor-Leste: Partnership for Prosperity)," at Timor Plaza. This event was a day-long exhibition showcasing the relationship between the U.S. and Timor-Leste, and the NOAA booth was one of the most popular stops for many parents and children (Figure 57).

Figure 57. Photos from the U.S. Embassy Outreach event: NOAA and USAID staff with the U.S. Ambassador for Timor-Leste (*left*), and Schoolchildren learn about NOAA through coloring activities (*right*).

Blog Posts:
NOAA Leads GIS Workshop in Timor-Leste, posted November 10, 2015 by NOAA-CREP:
https://pifscblog.wordpress.com/2015/11/10/workshop-timor-leste/

America in Timor-Leste: Partnership for Prosperity, posted October 18, 2015 by U.S. Embassy Timor-Leste:
https://www.facebook.com/USAIDTimorLeste/photos/?tab=album&album_id=948050691907656

Final Deliverables – June 2017

In-country meetings are planned for June 2017 in which the data and information products (including this report) will be delivered. The purpose of these meetings is explaining and demonstrating how the information can best be used in both the short-term and the long-term for more effective management of coastal and fisheries resources in the face of climate and ocean changes.

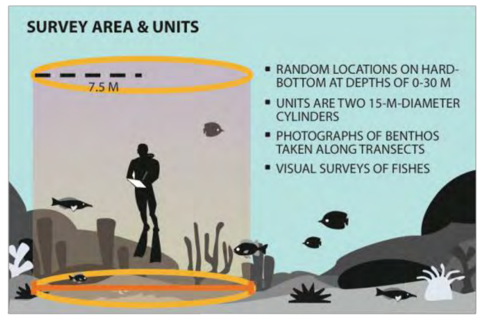
OUTREACH FLYERS AND POSTERS

"Understanding Fish Populations in Timor-Leste" flyer:

UNDERSTANDING FISH POPULATIONS IN TIMOR-LESTE

THE DIVE TEAM

The Coral Reef Ecosystem Division (CRED) of the U.S. National Oceanic and Atmospheric Administration's (NOAA) Pacific Islands Fisheries Science Center will be conducting reef fish and benthic surveys along the entire North Coast of Timor-Leste in conjunction with the Coral Triangle Support Partnership (CTSP), the National University of Timor Leste, and the Ministry of Agriculture and Fisheries (MAF). Based in Hawaii, CRED conducts ecosystem assessments and long-term monitoring, benthic habitat mapping, and applied research on coral reef ecosystems in the US Pacific. With support from the USAID Timor Leste and in collaboration with the above partners, NOAA's current work in Timor-Leste focuses on providing technical assistance and building capacity to sustainably manage and conserve fisheries, biodiversity, and coral reefs.



REEF SURVEYS OF THE NORTH COAST

Six NOAA scientists using SCUBA will conduct surveys to assess coral reef fish populations and benthic habitats along the north coast of Timor-Leste. The survey methods used will provide information about the relative abundance, size, and diversity of the coral reef fishes, including surveys near Atauro Island, Jaco Island, Oecusse, Batugade, Liquisa, Dili, Maubara, Baucau, Manatuto, Tutuala and Com. In total, the team aims to conduct up to 150 surveys at different sites on the north coast of Timor-Leste between 03 June and 28 June 2013.

WHY DO REEF SURVEYS?

The data collected on fish abundance and size (used to estimate biomass) and composition of benthic habitats will provide important information to local fisheries and coastal resource managers, and local communities, that can be used as a basis for determining the status of the nearshore fishery resources of Timor-Leste. The data will also be useful for planning and evaluating potential fisheries and resource management and conservation strategies. The estimates of reef fish abundance will serve as the baseline for comparison with future surveys.

USAID FROM THE AMERICAN PEOPLE
NOAA
CONSERVATION INTERNATIONAL

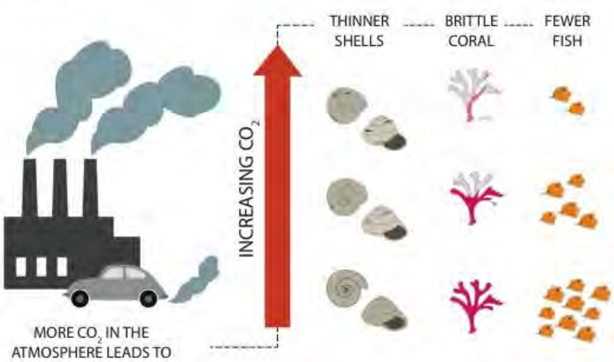
“Understanding Ocean Acidification in Timor-Leste” flyer:

UNDERSTANDING OCEAN ACIDIFICATION IN TIMOR-LESTE

WHAT IS OCEAN ACIDIFICATION?

The release of carbon dioxide (CO_2) into our atmosphere has been increasing steadily since humans began burning fossil fuels (gas, coal, and oil) more than 200 years ago. When the ocean absorbs CO_2, a series of chemical reactions take place, and they make the water more acidic. This process, called ocean acidification, has widespread and varied effects on marine organisms. As ocean acidity increases, it becomes more difficult for shellfish to build their shells and for corals to grow or build their skeletons. A number of potential effects on fish populations are being investigated. NOAA scientists are using the following instruments and sample types to learn how ocean acidification affects the biodiversity and ecosystems of coral reefs in Timor-Leste.

NOAA scientists have collected samples and deployed instruments on several locations around Timor-Leste.



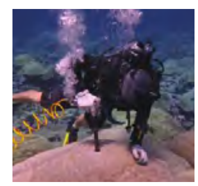
Calcif cation Accretion Units (CAUs) are simple devices that are deployed in reef environments to measure production of calcium carbonate by corals, calcifying algae, and other shelled organisms. CAUs are left in the f eld for two to three years. After that time, they are retrieved and the weight of the growth on the plates is measured. There are currently 50 CAUs deployed around Timor-Leste.

Subsurface Temperature Recorders (STR) are deployed on coral reefs in shallow water (<30 m) to measure water temperature. Temperature information provides insight into several water properties that af ect coral reefs.

Water Samples are collected by divers to help scientists understand the ef ects of ocean acidif cation on the reefs of Timor-Leste.

Autonomous Reef Monitoring Structures (ARMS) are collecting devices that imitate the natural structure of coral reefs to attract colonizing marine invertebrates. These small invertebrates, which form the base of the coral reef food web, can be af ected by acidif cation. There are currently 30 ARMS deployed around Timor-Leste.

Coral Cores of large corals have been collected in Timor-Leste. After coring, the holes in corals are plugged and new coral growth covers them. The cores have growth rings, like those of a tree, that are used to measure historical growth rates of corals. A 40-cm-long core allows scientists to measure growth rates over the past 10—30 years.



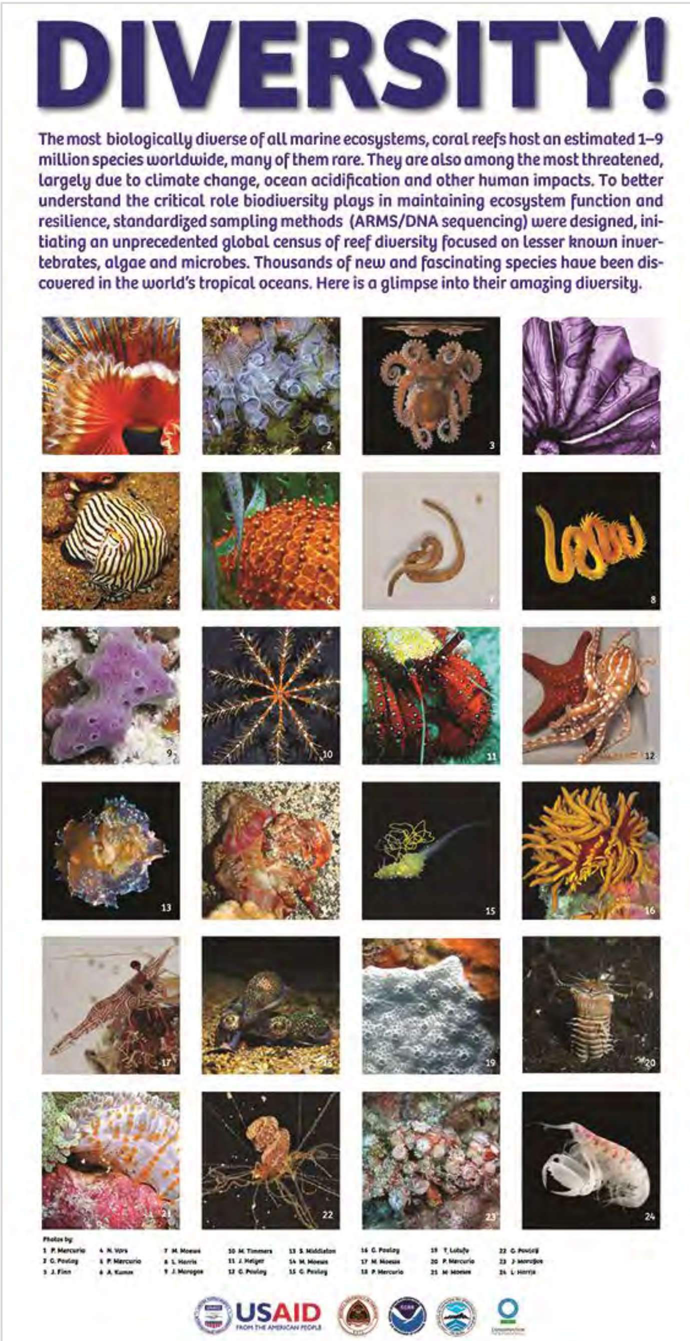
Resource managers can use the information gathered from these instruments and samples to make better decisions to protect the coral reefs that the people of Timor-Leste depend on for their food and livelihoods.

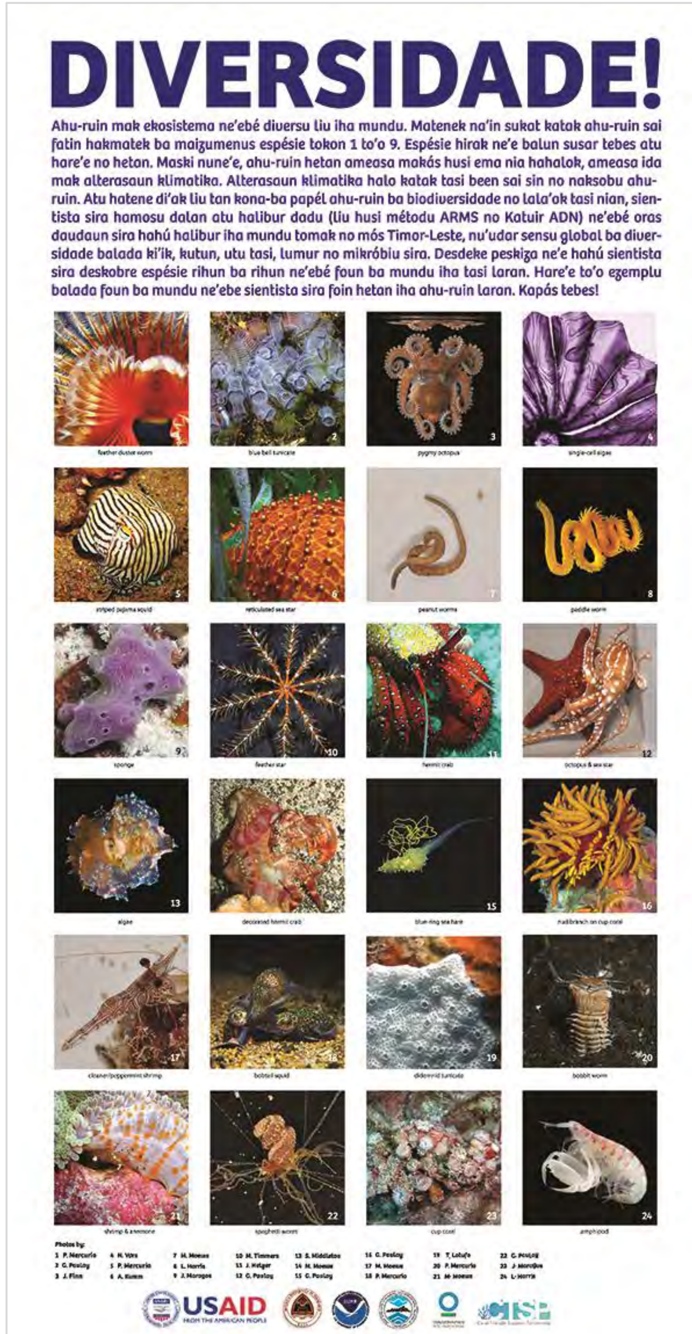
Scientists from NOAA Fisheries collaborate with the Timor-Leste Ministry of Agriculture and Fisheries, and Conservation International to study ocean acidif cation on the coral reefs of Timor-Leste. This project is funded by USAID Timor-Leste and NOAA.

"Monitoring Coral Reefs in Timor-Leste" posters:

"ARMS: From Science to Outreach" posters:

ARMS "DIVERSITY!" posters:





Appendix B. Satellite Mapping Image Catalog

Table 14. List of WorldView-2 satellite images by region, purchased (IMAGE NAME) from DigitalGlobe by NOAA-CREP for Timor-Leste, including the coordinates for the center point of the image (CENTER X and CENTER Y) and whether the image was georeferenced and used to derive bathymetry or benthic habitat classes (Y: yes). Also included is the name of the folder where the image is located in the GEOREFERENCED_IMAGERY folder (see Chapter 5, *Developing a Spatial Data Framework* for more details).

IMAGE FOLDER	IMAGE NAME	CENTER X	CENTER Y	GEOREFERENCED	BATHYMETRY	BENTHIC HABITAT
Atauro Island						
052717601050_01_P001_MUL	12NOV26022320-M2AS-052717601050_01_P001	125.633	-8.207	Y	Y	Y
052717601050_01_P002_MUL	12JUL08022135-M2AS-052717601050_01_P002	125.531	-8.234	Y	Y	Y
052717601110_01_P001_MUL	13AUG19021837-M2AS-052717601110_01_P001	125.586	-8.218	Y	Y	Y
Oecusse						
052717601040_01_P001_MUL	11JUL15022145-M2AS-052717601040_01_P001	124.096	-9.298	Y	Y	Y
052717601040_01_P002_MUL	12JUL08022105-M2AS-052717601040_01_P002	124.179	-9.268	Y	Y	Y
052717601040_01_P003_MUL	10NOV16021039-M2AS-052717601040_01_P003	124.356	-9.211	Y	Y	Y
052717601040_01_P004_MUL	11OCT24021636-M2AS-052717601040_01_P004	124.376	-9.199	Y	Y	Y
052717601040_08_P001_MUL	13JUL20022630-M2AS-052717601040_08_P001	124.337	-9.212	Y	–	–
052717601090_01_P001_MUL	12NOV26022344-M2AS-052717601090_01_P001	124.503	-9.162	Y	Y	Y
052717601100_01_P001_MUL	13JUN01023220-M2AS-052717601100_01_P001	124.461	-9.177	Y	Y	Y
North Shore						
052717601060_01_P001_MUL	11JUN07021210-M2AS-052717601060_01_P001	124.967	-8.874	Y	Y	Y
052717601060_01_P002_MUL	12JUL24023138-M2AS-052717601060_01_P002	125.785	-8.509	Y	Y	Y
052717601060_01_P003_MUL	11OCT27020543-M2AS-052717601060_01_P003	125.925	-8.486	Y	Y	Y
052717601060_01_P004_MUL	11OCT16020934-M2AS-052717601060_01_P004	126.771	-8.400	Y	–	–
052717601060_01_P005_MUL	11JUN04022102-M2AS-052717601060_01_P005	125.340	-8.582	Y	Y	Y
052717601060_01_P007_MUL	11NOV04021148-M2AS-052717601060_01_P007	125.567	-8.543	Y	Y	Y
052717601060_01_P008_MUL	11OCT16020907-M2AS-052717601060_01_P008	126.479	-8.446	Y	Y	Y
052717601060_01_P009_MUL	12JUL08022045-M2AS-052717601060_01_P009	125.088	-8.766	Y	Y	Y
052717601060_01_P010_MUL	11NOV23021436-M2AS-052717601060_01_P010	125.436	-8.565	Y	Y	Y
052717601060_01_P011_MUL	11OCT16021005-M2AS-052717601060_01_P011	126.046	-8.490	Y	Y	Y
052717601060_01_P012_MUL	12JUN30021525-M2AS-052717601060_01_P012	126.655	-8.438	Y	Y	Y
052717601060_01_P013_MUL	10FEB09015944-M2AS-052717601060_01_P013	125.227	-8.610	Y	Y	Y
052717601060_03_P001_MUL	12OCT22021251-M2AS-052717601060_03_P001	126.312	-8.455	Y	–	–
052717601060_03_P002_MUL	12SEP03021928-M2AS-052717601060_03_P002	127.035	-8.344	Y	–	–
052717601060_03_P003_MUL	12NOV26022324-M2AS-052717601060_03_P003	125.683	-8.525	Y	Y	Y
052717601060_03_P004_MUL	12APR18020542-M2AS-052717601060_03_P004	126.987	-8.346	Y	–	–
052717601060_04_P001_MUL	13OCT29020629-M2AS-052717601060_04_P001	126.094	-8.485	–	–	–
052717601060_04_P002_MUL	13OCT02020031-M2AS-052717601060_04_P002	127.041	-8.345	Y	Y	Y
052717601060_04_P003_MUL	13AUG22020853-M2AS-052717601060_04_P003	126.983	-8.346	–	–	–
052717601060_04_P004_MUL	13OCT02020017-M2AS-052717601060_04_P004	127.224	-8.376	Y	Y	Y
052717601060_04_P005_MUL	13AUG14020354-M2AS-052717601060_04_P005	127.166	-8.375	–	–	–

052717601060_04_P006_MUL	13NOV17020757-M2AS-052717601060_04_P006	127.337	-8.412	–	–	–
052717601140_01_P010_MUL	12APR18020542-M2AS-052717601140_01_P010	126.986	-8.346	Y	–	–
052717601140_01_P001_MUL	11OCT13021929-M2AS-052717601140_01_P001	126.902	-8.359	–	–	–
052717601140_01_P002_MUL	12JUN30021550-M2AS-052717601140_01_P002	126.935	-8.353	–	–	–
052717601140_01_P003_MUL	13AUG22020853-M2AS-052717601140_01_P003	126.983	-8.346	–	–	–
052717601140_01_P004_MUL	13DEC30022450-M2AS-052717601140_01_P004	126.921	-8.357	–	–	–
052717601140_01_P005_MUL	11OCT16020934-M2AS-052717601140_01_P005	126.771	-8.400	–	–	–
052717601140_01_P006_MUL	13APR19021521-M2AS-052717601140_01_P006	126.908	-8.358	–	–	–
052717601140_01_P007_MUL	12JUN30021641-M2AS-052717601140_01_P007	126.796	-8.392	–	–	–
052717601140_01_P008_MUL	13DEC11022428-M2AS-052717601140_01_P008	126.923	-8.356	Y	–	Y
052717601140_01_P009_MUL	11JUN29020701-M2AS-052717601140_01_P009	126.790	-8.394	Y	Y	Y
052717601150_01_P001_MUL	13FEB13021027-M2AS-052717601150_01_P001	126.322	-8.453	Y	Y	Y
052717601150_01_P002_MUL	12OCT22021251-M2AS-052717601150_01_P002	126.312	-8.455	–	–	–
052717601150_01_P003_MUL	12MAR27021514-M2AS-052717601150_01_P003	126.182	-8.476	–	–	–
052717601150_01_P004_MUL	13AUG14020325-M2AS-052717601150_01_P004	126.325	-8.453	–	–	–
052717601150_01_P005_MUL	12AUG04022628-M2AS-052717601150_01_P005	126.205	-8.472	–	–	–
052717601150_01_P006_MUL	13FEB13021047-M2AS-052717601150_01_P006	126.164	-8.478	Y	Y	Y
052717601150_01_P007_MUL	12FEB10020841-M2AS-052717601150_01_P007	126.327	-8.452	–	–	–
South Shore						
052717601070_01_P001_MUL	12DEC20023830-M2AS-052717601070_01_P001	125.802	-9.170	Y	–	–
052717601070_01_P002_MUL	12NOV18021828-M2AS-052717601070_01_P002	125.231	-9.381	Y	–	Y
052717601070_01_P003_MUL	12OCT22021257-M2AS-052717601070_01_P003	126.311	-8.989	Y	–	–
052717601070_08_P001_MUL	13MAR20022023-M2AS-052717601070_08_P001	125.571	-9.243	Y	–	–
052717601070_08_P002_MUL	13MAR20022012-M2AS-052717601070_08_P002	125.673	-9.210	–	–	–
052717601070_08_P003_MUL	14JAN02021431-M2AS-052717601070_08_P003	127.158	-8.553	Y	–	–
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052717601070_10_P006_MUL	13DEC03021830-M2AS-052717601070_10_P006	126.414	-8.963	–	–	–
052717601070_22_P001_MUL	13DEC14021447-M2AS-052717601070_22_P001	126.349	-8.983	–	–	–
052717601070_22_P002_MUL	13DEC17020337-M2AS-052717601070_22_P002	126.096	-9.057	Y	–	–
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052717601070_22_P008_MUL	12NOV10021226-M2AS-052717601070_22_P008	125.980	-9.102	Y	–	–
052717601070_22_P009_MUL	12NOV07022342-M2AS-052717601070_22_P009	125.121	-9.440	Y	–	–
052717601070_22_P010_MUL	12OCT03021330-M2AS-052717601070_22_P010	125.678	-9.175	Y	–	Y
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052717601070_22_P021_MUL	13DEC17020410-M2AS-052717601070_22_P021	126.445	-8.922	Y	–	–
052717601070_22_P022_MUL	13NOV06021206-M2AS-052717601070_22_P022	126.367	-8.973	–	–	–
052717601070_22_P023_MUL	11OCT18023706-M2AS-052717601070_22_P023	125.218	-9.382	–	–	–
052717601070_22_P024_MUL	12SEP14021513-M2AS-052717601070_22_P024	126.689	-8.829	Y	–	–
052717601070_22_P015_MUL	11JUN07021226-M2AS-052717601070_22_P015	125.097	-9.449	Y	–	–
052717601070_22_P025_MUL	13FEB13021033-M2AS-052717601070_22_P025	126.321	-8.984	–	–	–
052717601070_22_P026_MUL	12JUN30021713-M2AS-052717601070_22_P026	126.516	-8.880	Y	–	–
052717601070_22_P027_MUL	13OCT29020709-M2AS-052717601070_22_P027	126.428	-8.941	Y	–	Y
052717601070_22_P028_MUL	12AUG12023136-M2AS-052717601070_22_P028	127.042	-8.639	–	–	–
052717601070_22_P029_MUL	14MAR19021510-M2AS-052717601070_22_P029	127.022	-8.660	–	–	–
052717601070_22_P030_MUL	12SEP22021949-M2AS-052717601070_22_P030	126.490	-8.895	–	–	–
052717601070_22_P031_MUL	13DEC11022432-M2AS-052717601070_22_P031	126.923	-8.719	–	–	–
052717601070_22_P032_MUL	13OCT29020742-M2AS-052717601070_22_P032	126.738	-8.817	Y	–	Y
052717601070_22_P033_MUL	12JUN16023145-M2AS-052717601070_22_P033	127.040	-8.640	Y	–	Y
052717601070_22_P034_MUL	13OCT29020720-M2AS-052717601070_22_P034	126.584	-8.861	–	–	–
052717601070_22_P035_MUL	12JUN30021645-M2AS-052717601070_22_P035	126.796	-8.792	Y	–	–
052717601070_22_P036_MUL	10JUL07020725-M2AS-052717601070_22_P036	125.110	-9.444	–	–	–
052717601070_22_P037_MUL	12JUN30021554-M2AS-052717601070_22_P037	126.935	-8.712	Y	–	–
052717601070_22_P038_MUL	14MAR27022030-M2AS-052717601070_22_P038	125.417	-9.297	–	–	–
052717601070_23_P001_MUL	14AUG10020511-M2AS-052717601070_23_P001	125.489	-9.267	–	–	–
052717601070_23_P002_MUL	14JUL27022206-M2AS-052717601070_23_P002	125.492	-9.265	Y	–	–
052717601070_23_P003_MUL	12AUG07021627-M2AS-052717601070_23_P003	125.531	-9.253	–	–	–

Appendix C. Methods: Satellite Mapping

The process for deriving estimated depths and classifying benthic features from WorldView-2 satellite imagery and available ground-truth data is schematically shown in Figure 58 and described in detail below.

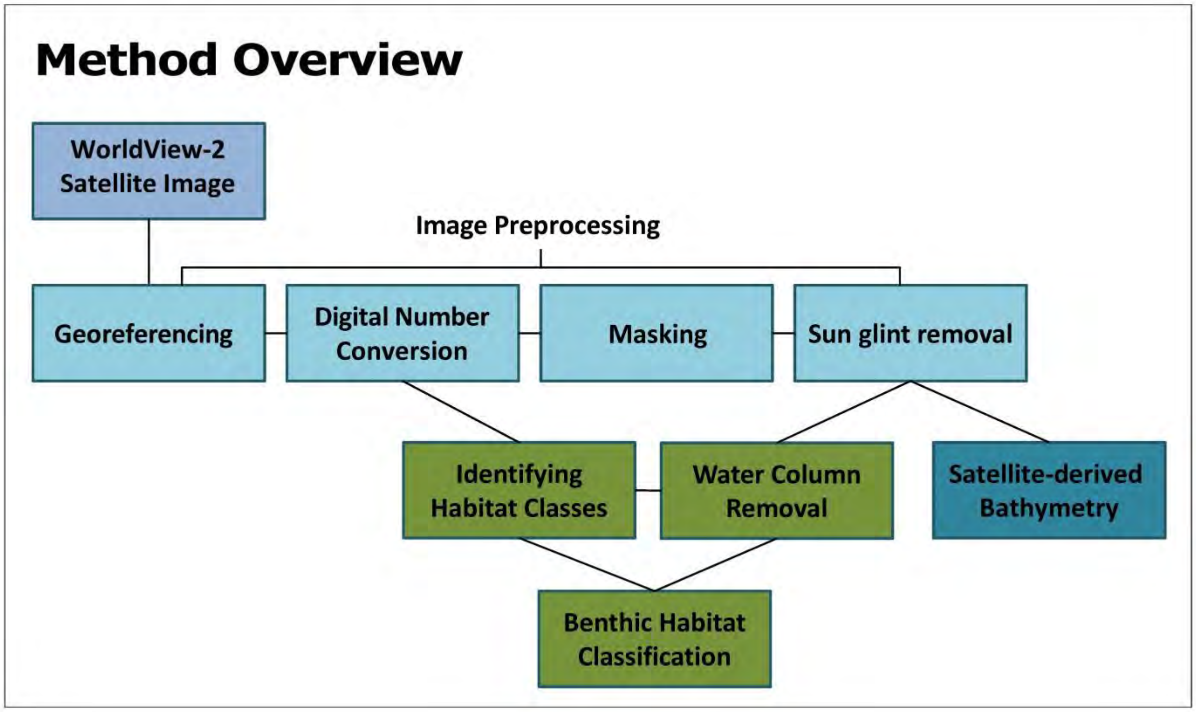


Figure 58. Schematic of deriving estimated depths (bathymetry) and classifying benthic features from WorldView-2 satellite imagery, including the image preprocessing steps.

Image Preprocessing

Prior to deriving depth and benthic habitat classes from the WorldView-2 imagery, four preprocessing steps were performed on the images. The georeferencing and digital number conversion steps correct for distortions due to characteristics of the WorldView-2 satellite system, and the masking and sun glint removal steps account for the atmospheric and ocean conditions, which both vary within and among images. The details for each of the four steps are as follows:

Step 1: Georeferencing

The location information for some of the satellite images was inadequate; therefore, the images did not align properly with each other or with other data (Figure 59). The images were spatially adjusted (georeferenced) to align with ArcGIS basemaps—provided by ESRI with ArcGIS products (http://www.esri.com/data/basemaps). The georeferencing step was performed using the georeferencing tools in ArcGIS 10.X desktop software.

Figure 59. Side by side figures showing a WorldView-2 satellite image overlaid on top of the reference basemap before (*left*) and after (*right*) georeferencing. Partial transparency is applied to the WorldView-2 image, thus features in the reference basemap in the background are visible through the WorldView-2 image in the foreground. The positional error is apparent when comparing the location of a structure between the WorldView-2 satellite image and the reference basemap (yellow arrow).

Step 2: Data Conversion

The pixel values of the WorldView-2 satellite images provided by DigitalGlobe are digital numbers (0-255), which have not been calibrated into physically meaningful units (i.e., solar radiance). The digital numbers must therefore be converted to capture the radiance at the satellite sensor using a calibration formula (Updike and Comp 2010). The satellite sensor is routinely calibrated, and thus the coefficients provided by DigitalGlobe (in the metadata files) are unique to each image. The conversion was conducted in ENVI (Environment for Visualizing Images) image analysis software provided by Harris Geospatial Solutions (http://www.harrisgeospatial.com/ProductsandTechnology/Software/ENVI.aspx).

Step 3: Masking

All nonaquatic or otherwise unsuitable features for deriving bathymetry or benthic features (e.g., terrestrial areas, clouds, breaking surf, boats, and turbidity) were removed from each image by manually digitizing a “mask” that was used for extracting unwanted areas (Figure 60). The ‘Extract by Mask’ tool in the ArcGIS Extraction toolbox was used to perform the extraction.

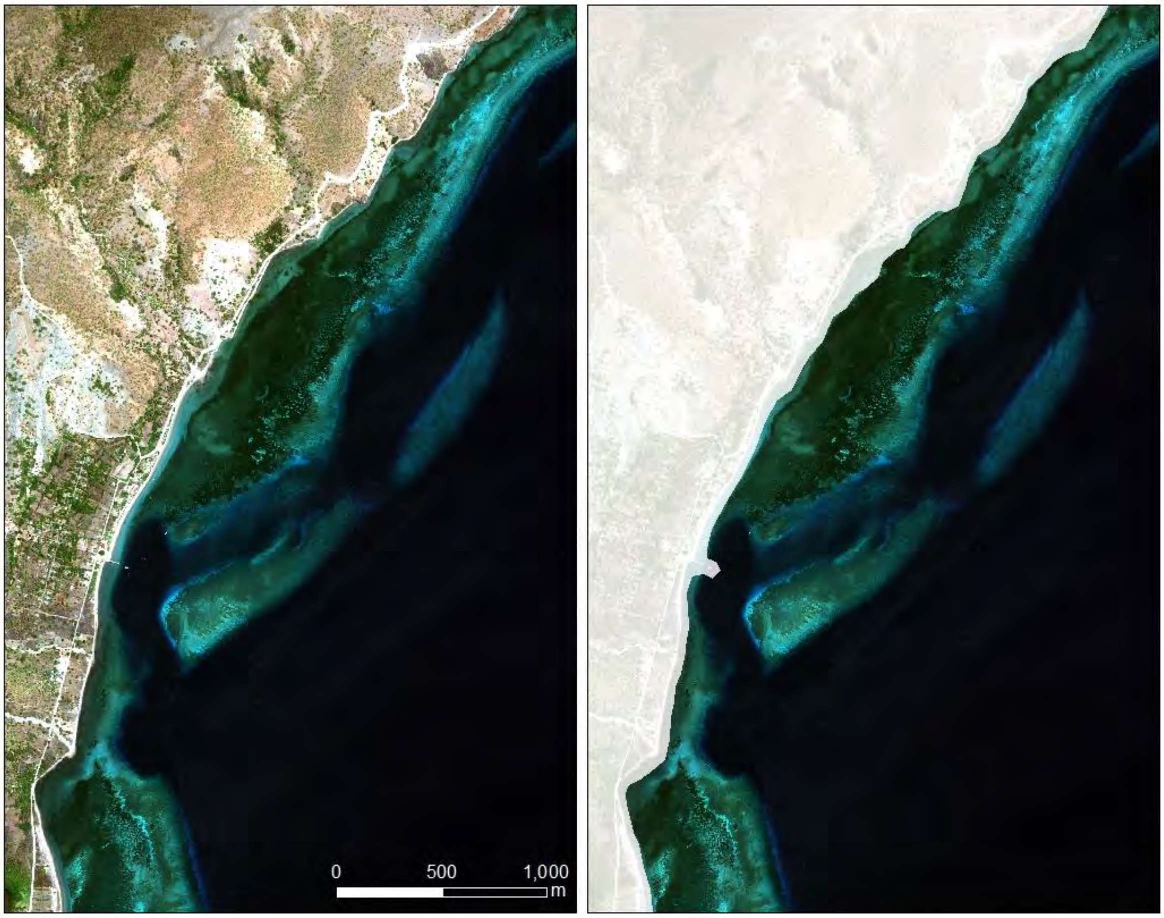


Figure 60. Example of a WorldView-2 satellite image before (*left*) and after (*right*) masking. The light area in the right image is excluded from the analyses to derive bathymetry and benthic habitat classes. Land, manmade structures, and areas covered by clouds are typically masked.

Step 4: Sun Glint Removal

Solar radiance recorded by the WorldView-2 satellite sensor differs from the actual radiance reflected from the surface of the water. To account for this difference, sun glint from the visible bands of the satellite images was removed using the method developed by Hedley et al. (2005; Figure 61). This method is based on the assumption that the amount of sun glint in an image is measured in the near-infrared portion of the electromagnetic spectrum and is linearly related to the amount of sun glint in the visible bands.

Pixel values were extracted from a deep-water area of an image and a linear regression model was created for each visible band against the near-infrared band. The slope value from the regression model was then applied to the formula developed by Hedley et al. (2005). The formula was applied to each band using ENVI software. The resulting image with the sun glint removed is hereafter referred to as the 'deglinted' image.

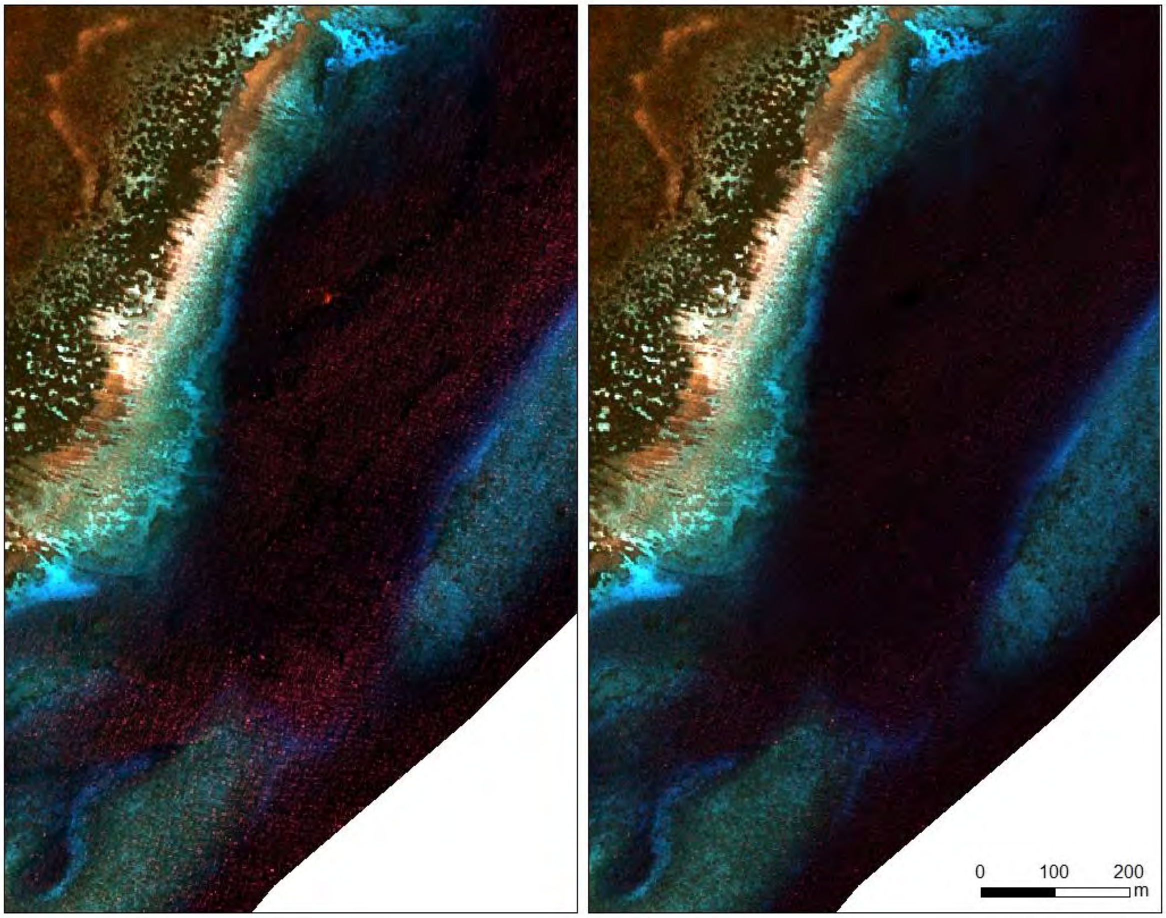


Figure 61. Example of a WorldView-2 satellite image before (*left*) and after (*right*) removing sun glint. After the correction, most sun glint effects are removed from the scene in the deglinted image.

Satellite-derived Bathymetry

Following is an overview of the method for deriving estimated depths from WorldView-2 satellite imagery. See Ehses and Rooney (2015) for the detailed methodology.

A multiple linear regression analysis method developed by Lyzenga (1979; 1981; 1985) and Lyzenga et al. (2006) was applied for deriving depth using the coastal, blue, green and yellow bands of the preprocessed images and depth soundings collected in the field in 2012 and 2013.

The resulting regression slopes and y-intercepts were used in the multivariate equation for deriving depth (Figure 62). The satellite data acquisition time and environmental conditions across the study area were not uniform; therefore, each image had to be processed separately. The method was tuned to each image and a variety of band combinations were used.

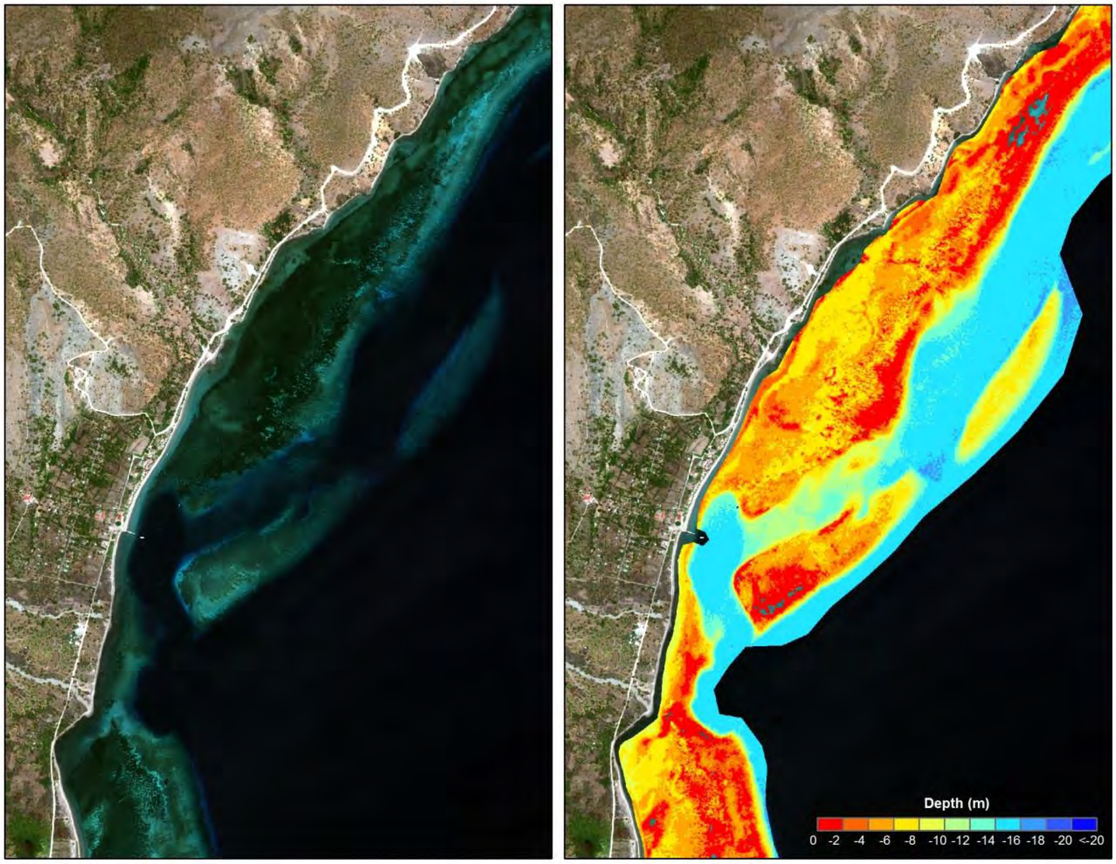


Figure 62. Example of a WorldView-2 satellite image (*left*) and the satellite-derived bathymetry (*right*) for the same area on the east side of Atauro Island.

Benthic Habitat Classification

Following is an overview of the method for classifying benthic features using WorldView-2 satellite imagery. See Watkins (2015) for the detailed methodology. Benthic habitat classification was a multi-step process that resulted in a total of 12 habitat classes identified across the region, including: 1) hard shallow, 2) soft shallow, 3) hard mid, 4) soft mid, 5) hard deep, 6) soft deep, 7) seagrass, 8) mangrove, 9) intertidal, 10) emergent rocks, 11) algae, and 12) lagoon.

The initial step was calculating a depth invariant index layer (Edwards 1999) using the preprocessed WorldView-2 satellite image. Image pixel values were extracted over sandy bottom in shallow and deep waters to investigate the relationship between the spectral signatures of similar benthic features in different water depths. The 3-band pairs with the strongest relationship were identified and used to build a 3-band depth invariant index layer (shallow, mid, and deep).

Based on the radiance multi-band image generated in preprocessing step 2, a region of interest was created for each of the classes, except lagoon. The regions of interest were then used as training classes to determine if a specific image pixel matched one of the eleven habitat classes. A variety of supervised classification methods allow pixel identification across a whole image. Three classification methods in

ENVI software—mahalanobis distance, maximum likelihood, and minimum distance—were applied to both the depth invariant index layer and the deglinted image. The resulting habitat classifications were compared to select the method that produced the best results for each of the WorldView-2 images. If necessary, the post-classification steps 'sieve' and 'sieve clump' were applied to the initial classification output to combine nearby pixels with the same habitat class assignment and remove isolated pixels from the data layer (https://www.harrisgeospatial.com/docs/ClassificationTools.html).

Lagoons (the 12th habitat class) were manually digitized using the habitat classifications generated in the previous step in combination with the satellite image—as the lagoon areas could be visually discerned in the satellite images. This combination of auto and manual classification improved the results of the initially derived habitat features.

Finally, areas where the habitat class could not be resolved, typically in deeper waters, were labeled as unknown (and are excluded from all maps in this report).

See Figure 63 for an example of a subset of the habitat classes that were derived for the nearshore waters around Timor-Leste.

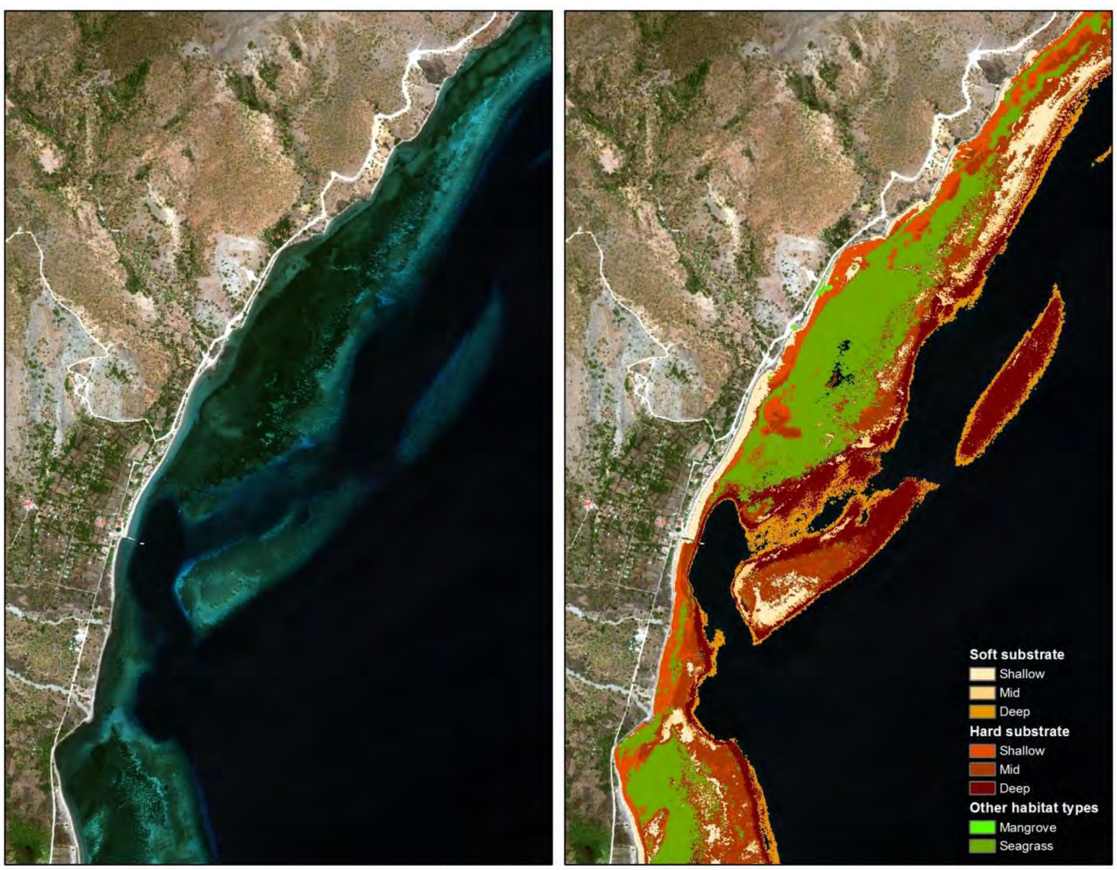


Figure 63. Example of a WorldView-2 satellite image (*left*) and the derived benthic habitat classes (*right*) for the same area on the east side of Atauro Island.

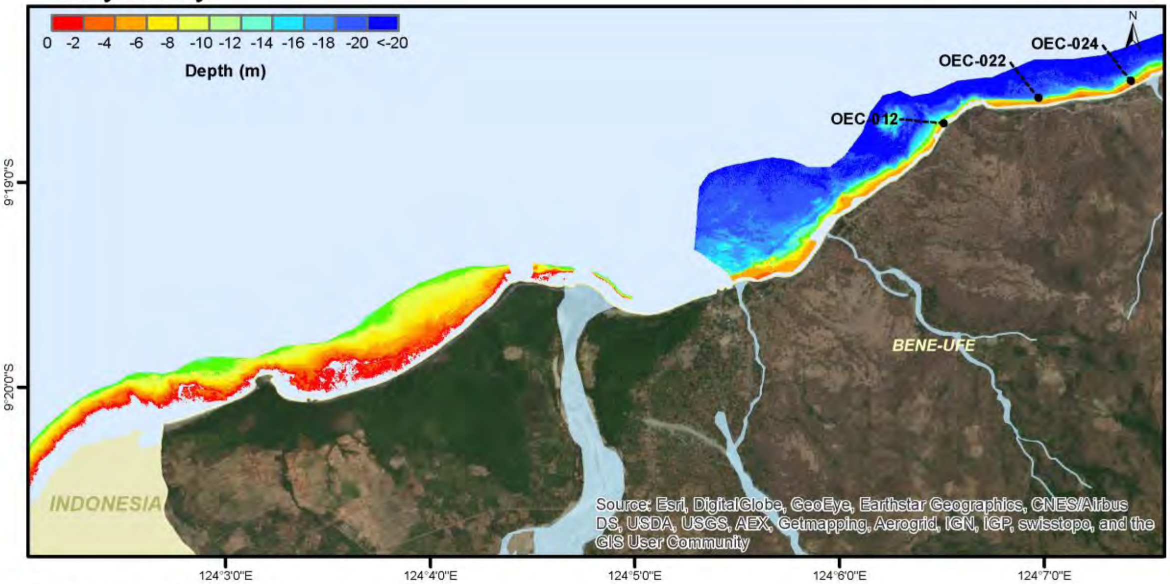
Appendix D. Map Book for the Coastline of Timor-Leste

A map book of the bathymetry and benthic habitat data derived from WorldView-2 satellite imagery has been prepared for the coastline of Timor-Leste. The map book includes 56 tiles (pages) that follow the associated index (Figure 64). Each map book page is labeled by district and tile number and contains a bathymetry frame, a benthic habitat frame, and an overview frame. Depth data were only derived for Oecusse (tiles 1–6), Atauro Island (tiles 7–11), and the north shore of Timor-Leste (tiles 12–43); therefore, the bathymetry frames show no data for the south shore tiles (44–56). Benthic habitat data are included in all 56 tiles. In each benthic habitat frame, the benthic habitat classes are displayed using the same color scheme; however, the map legend includes only the habitat classes that are visible in the map extent for that particular frame. The orientation of north for the bathymetry and benthic habitat frames changes to maximize the extent of the data within each frame. Several additional datasets are included in the bathymetry and benthic habitat frames, including: coral reef ecosystem assessment survey sites (location of reef fish and benthic surveys), 10 climate monitoring sites, ESRI imagery basemaps (including the citation for the source data in each frame), rivers and waterbodies (provided by MAF), village (suco) boundaries from the Census 2010 (provided by MAF), and a mask covering the ocean areas to emphasize the bathymetry and benthic habitat data. The ocean mask is intentionally not included in tile 15 to demonstrate the high turbidity in that section of coastline, which was a common issue that prevented the derivation of accurate depths for several areas. The overview frames include the map book index with the current index tile outlined in red.

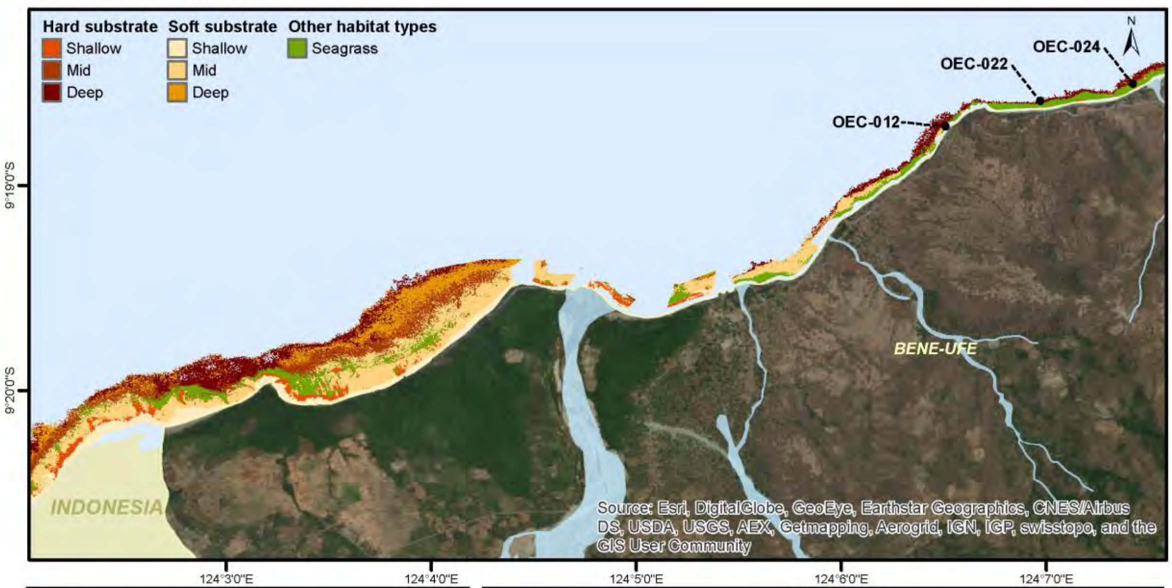
Figure 64. A map book index for the coastline of Timor-Leste where bathymetry and/or benthic habitat classes were derived from WorldView-2 satellite imagery. The tiles for each district include: Oecusse (tiles 1–6), Dili (tiles 7–11, and 21–24), Bobonara (tiles 12–15), Liquica (tiles 16–20), Manatuto (tiles 25–28, and 52–53), Baucau (tiles 29–35), Lautem (tiles 36–49), Viqueque (tiles 50–51), Manufahi (tiles 54–55), and Cova Lima (tile 56).

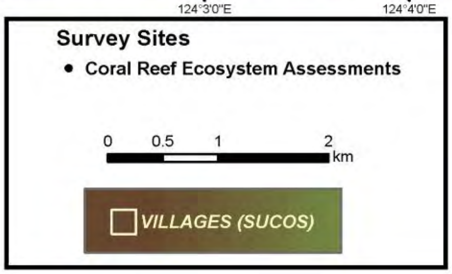
DISTRICT: Oecusse
TILE: 1

Bathymetry



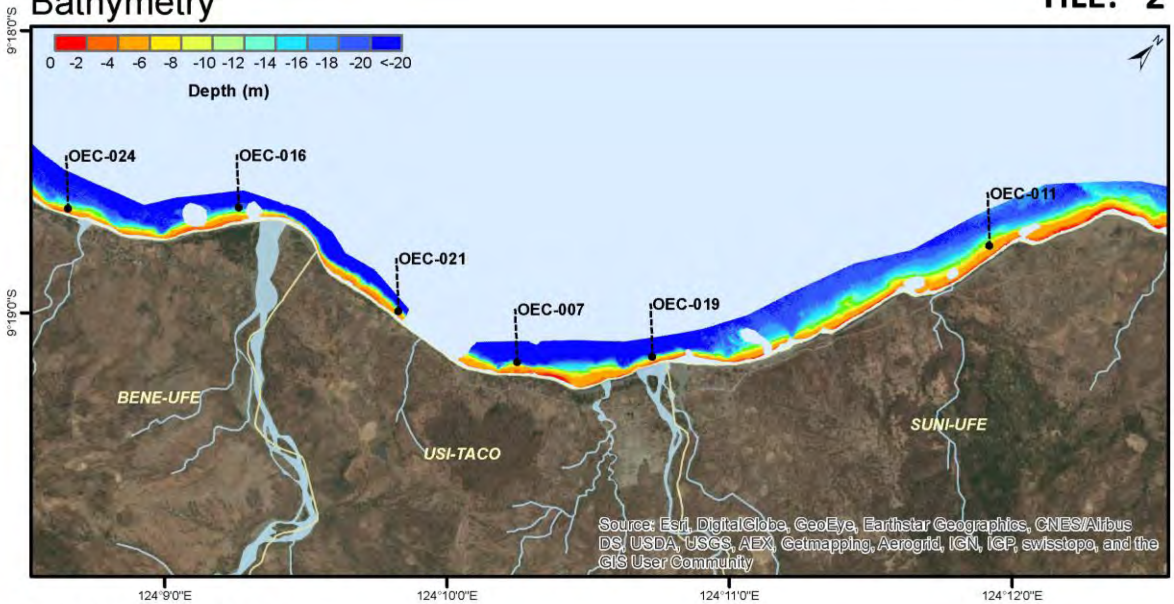
Benthic Habitat



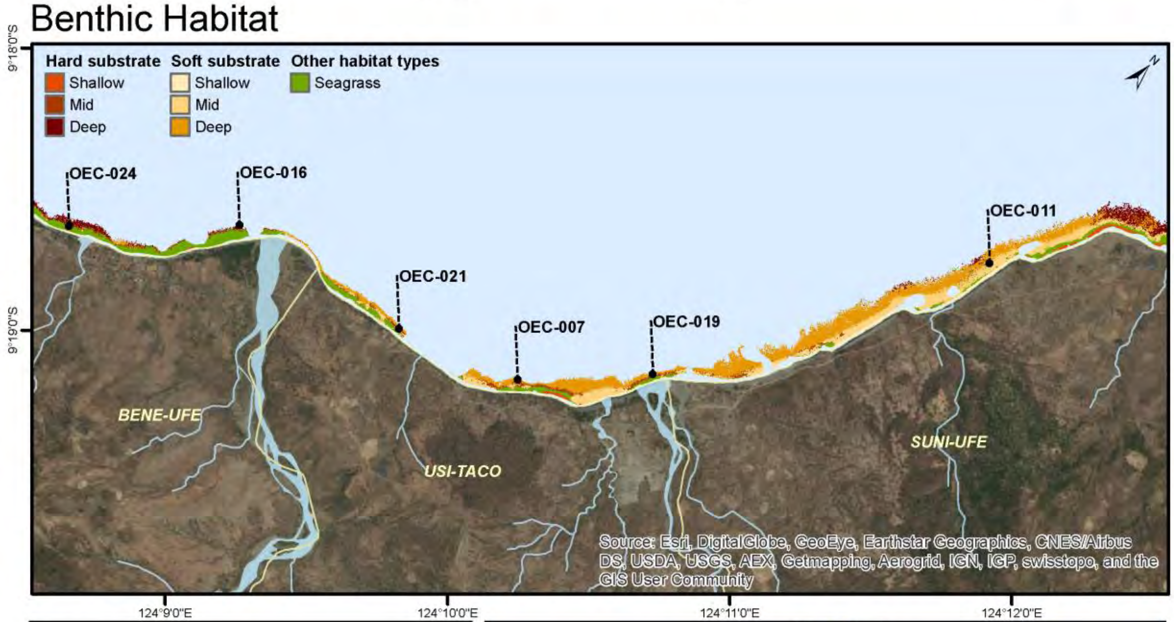


DISTRICT: Oecusse
TILE: 2

Bathymetry



Benthic Habitat



Survey Sites

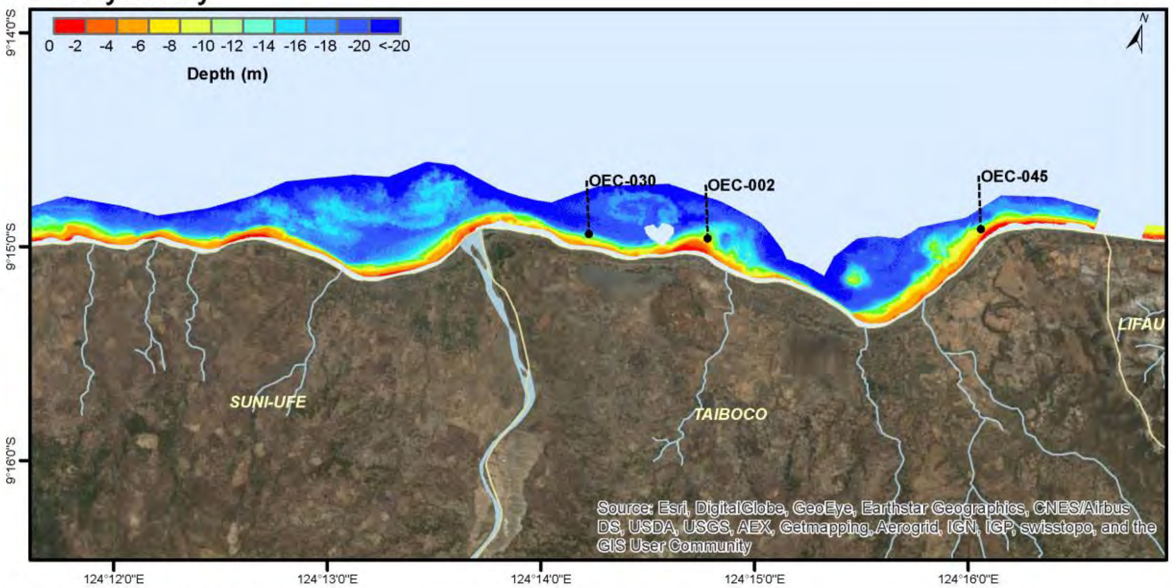
- Coral Reef Ecosystem Assessments

0 0.5 1 2 km

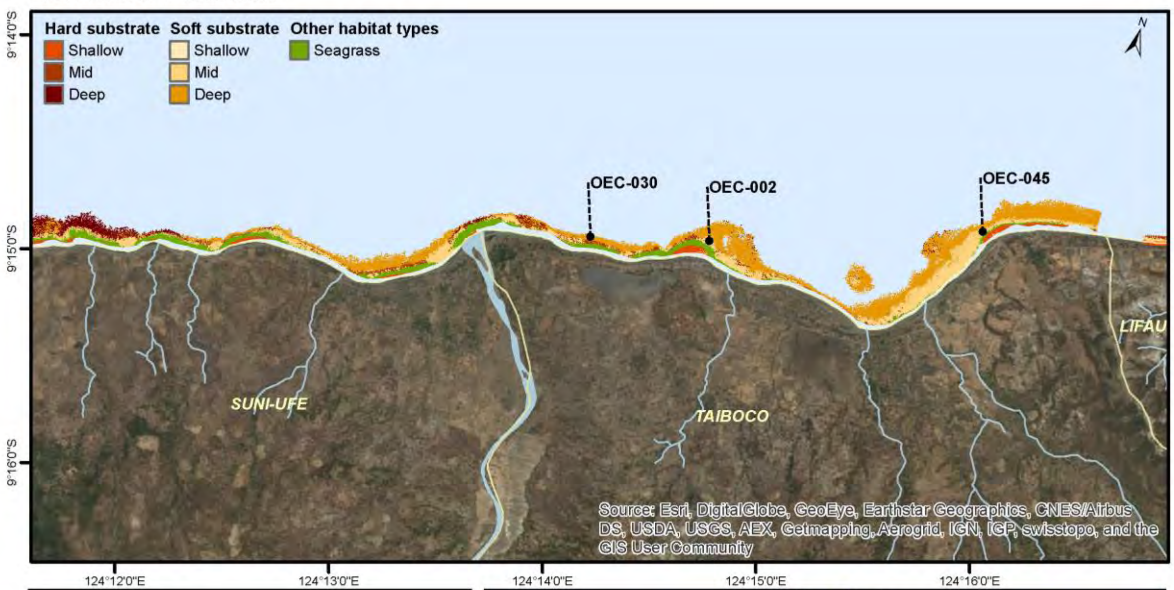
VILLAGES (SUCOS)

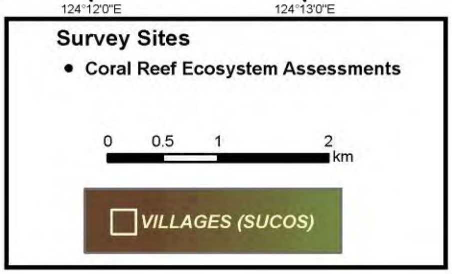
DISTRICT: Oecusse
TILE: 3

Bathymetry



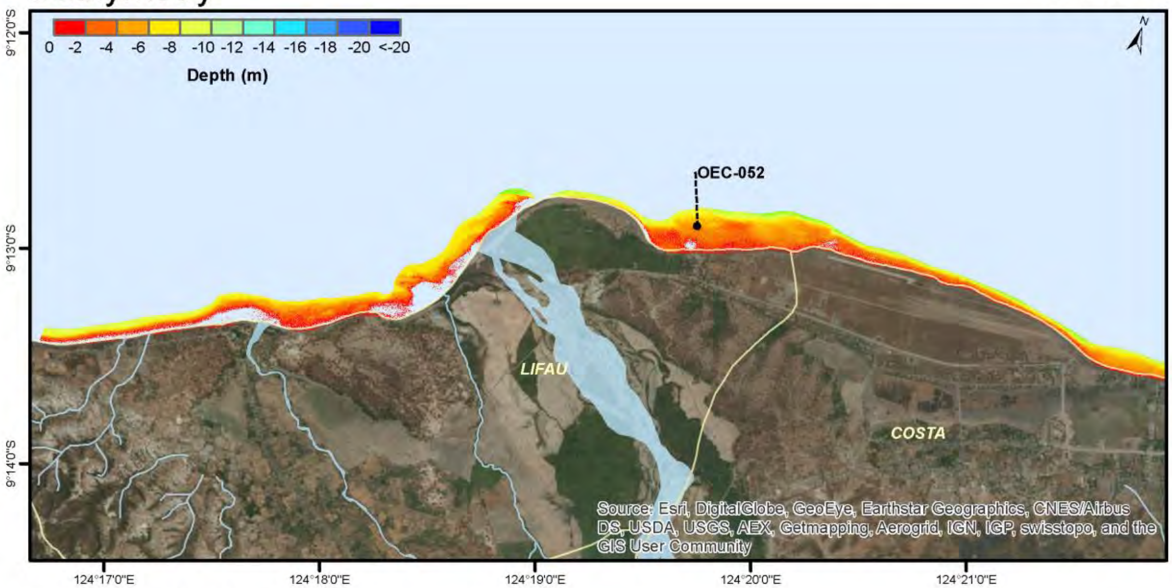
Benthic Habitat



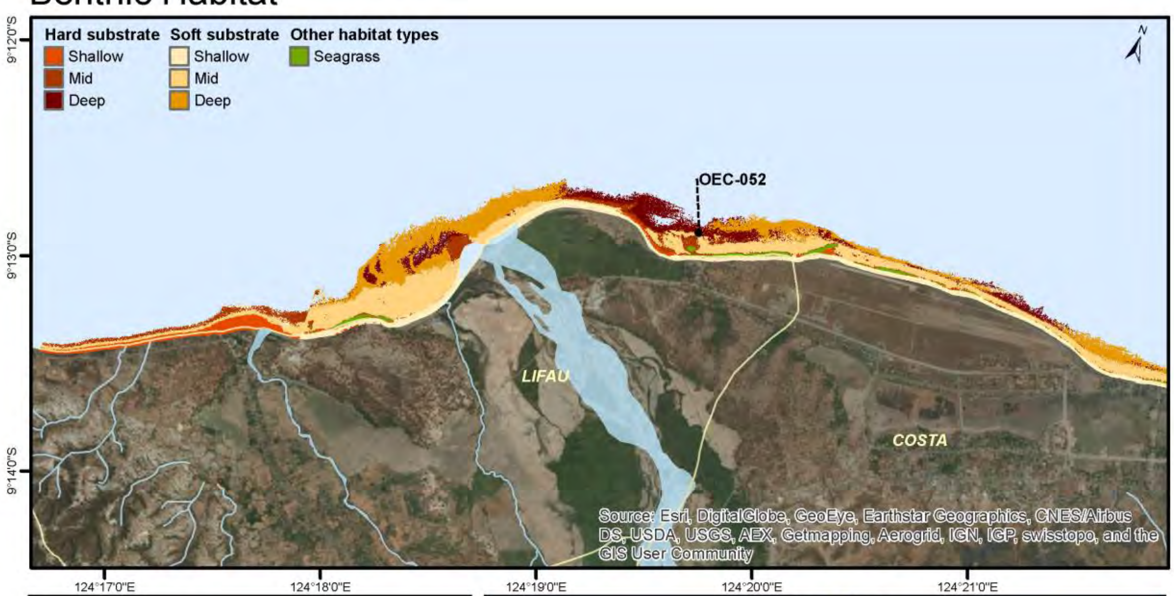


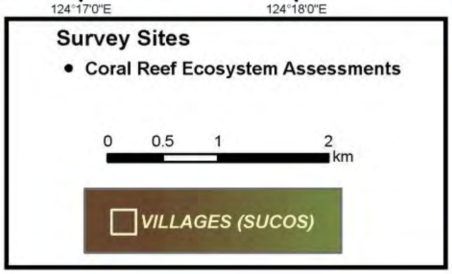
DISTRICT: Oecusse
TILE: 4

Bathymetry



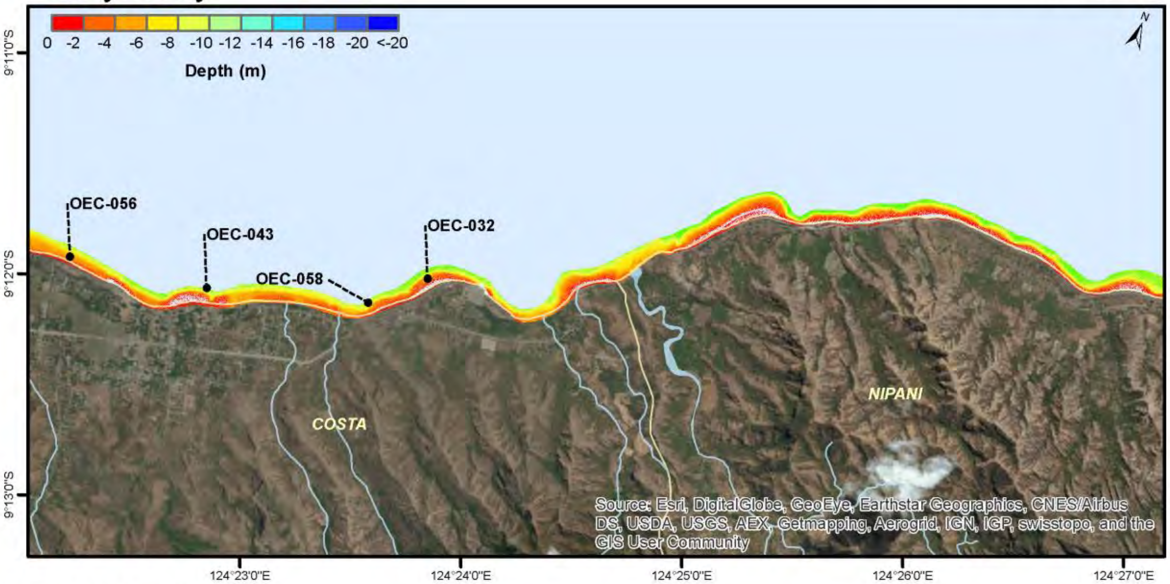
Benthic Habitat



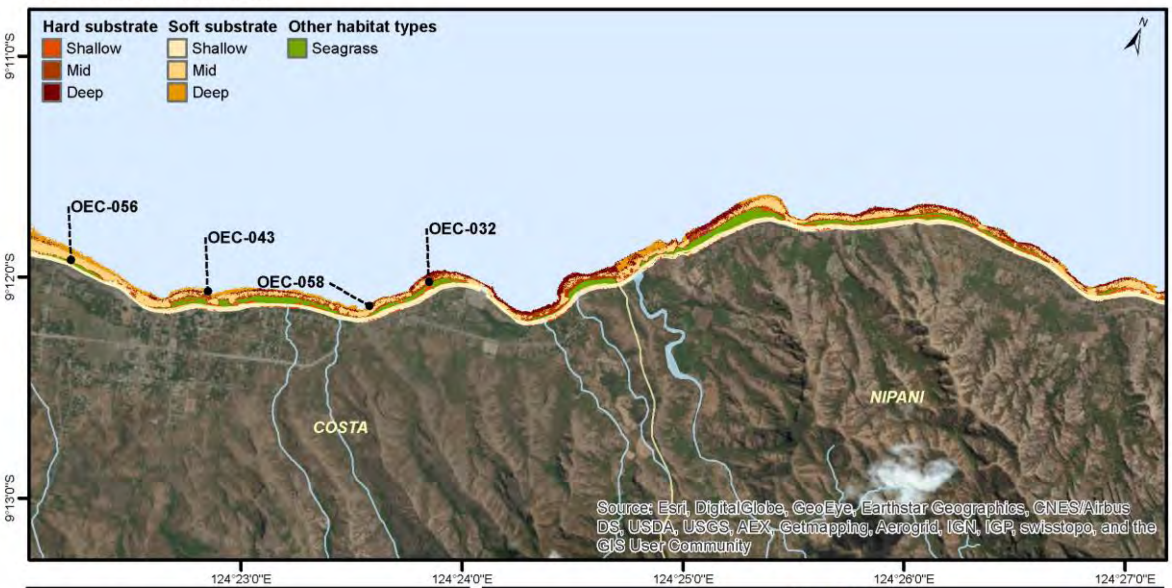


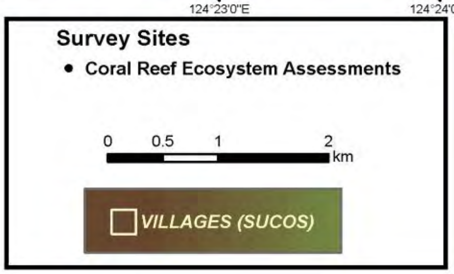
DISTRICT: Oecusse
TILE: 5

Bathymetry



Benthic Habitat

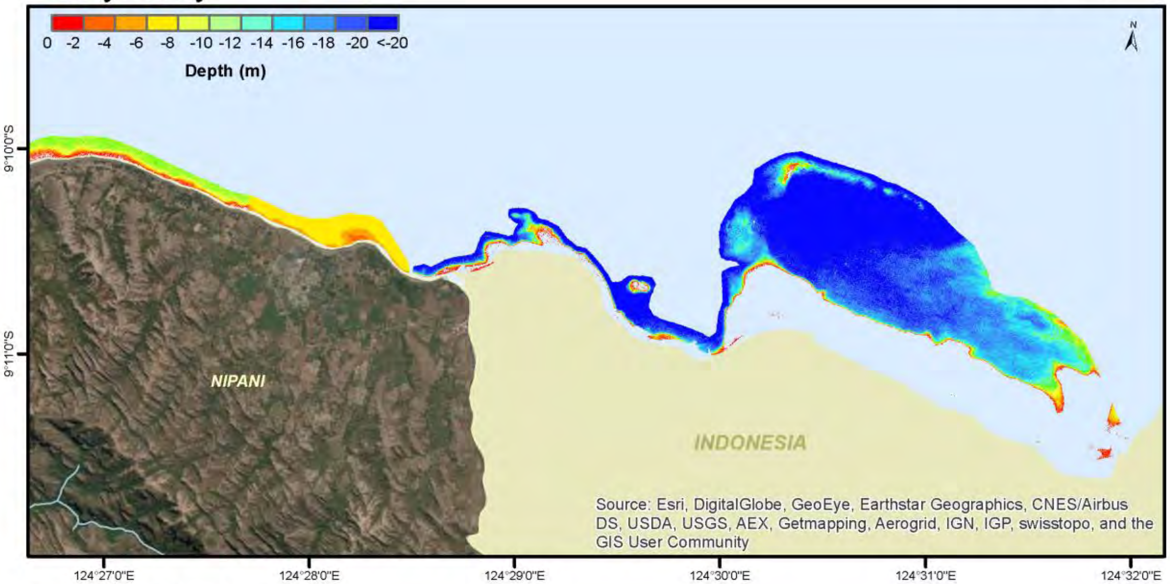




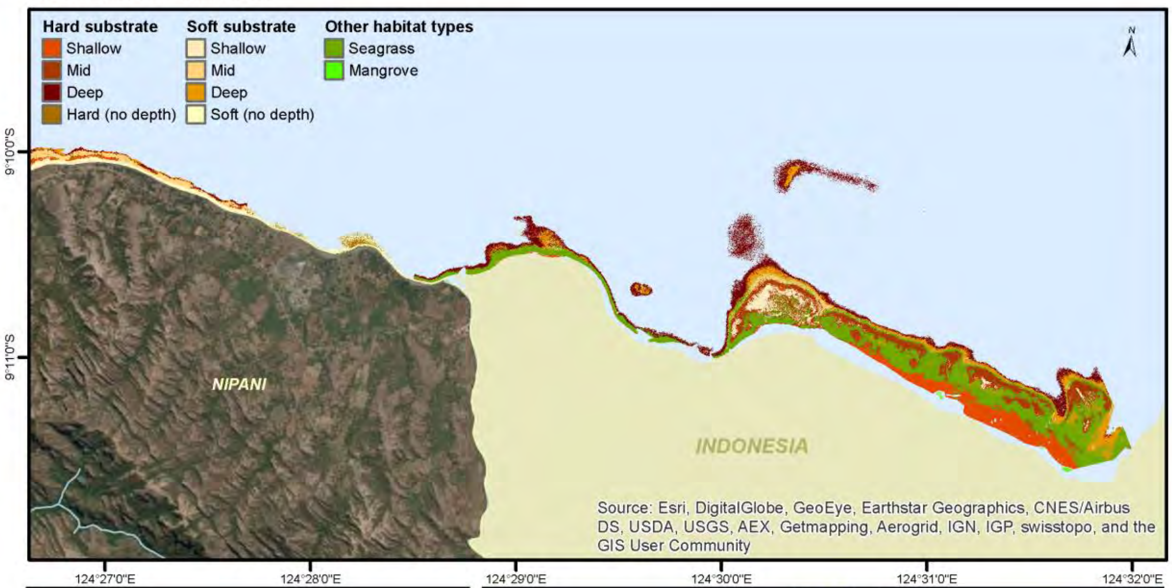
DISTRICT: Oecusse

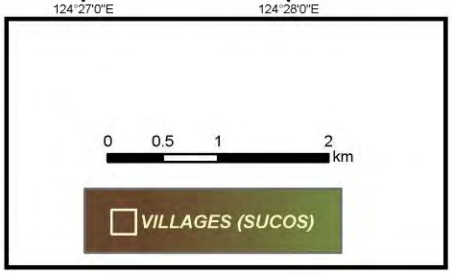
TILE: 6

Bathymetry



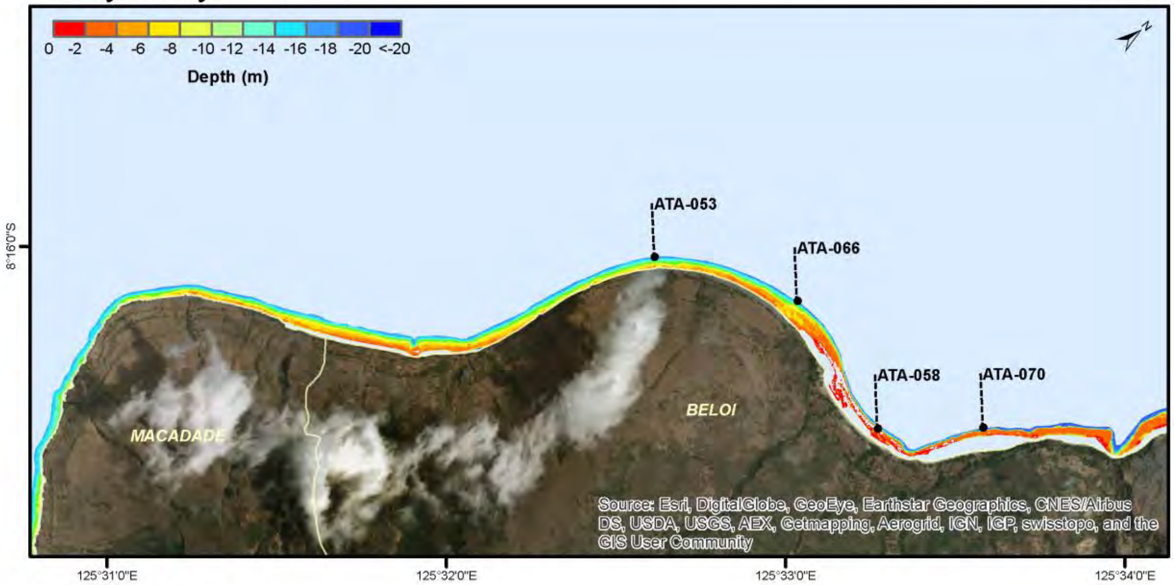
Benthic Habitat



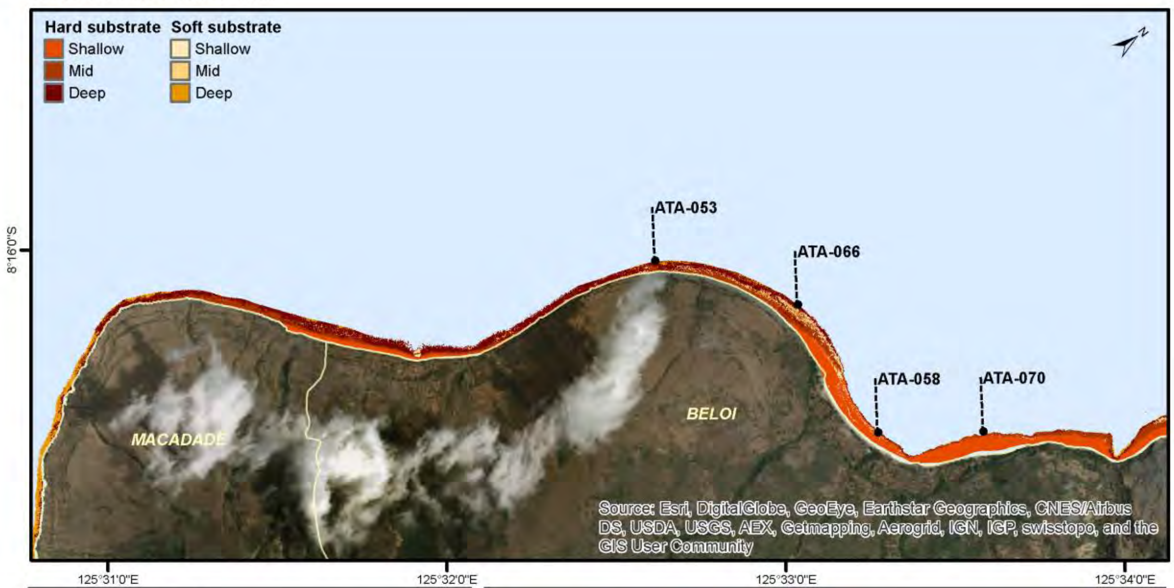


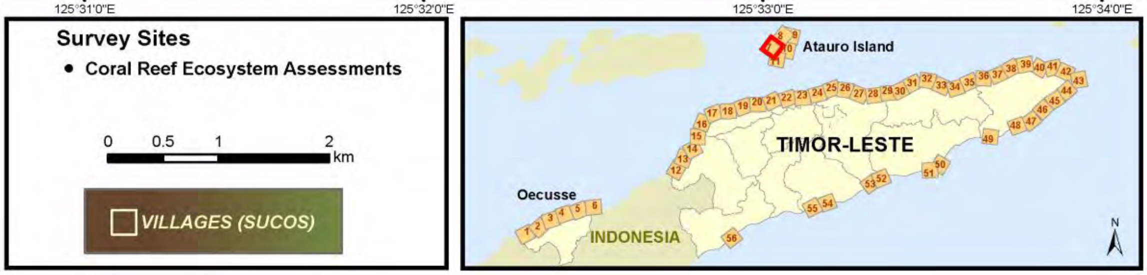
DISTRICT: Dili (Atauro Island)
TILE: 7

Bathymetry



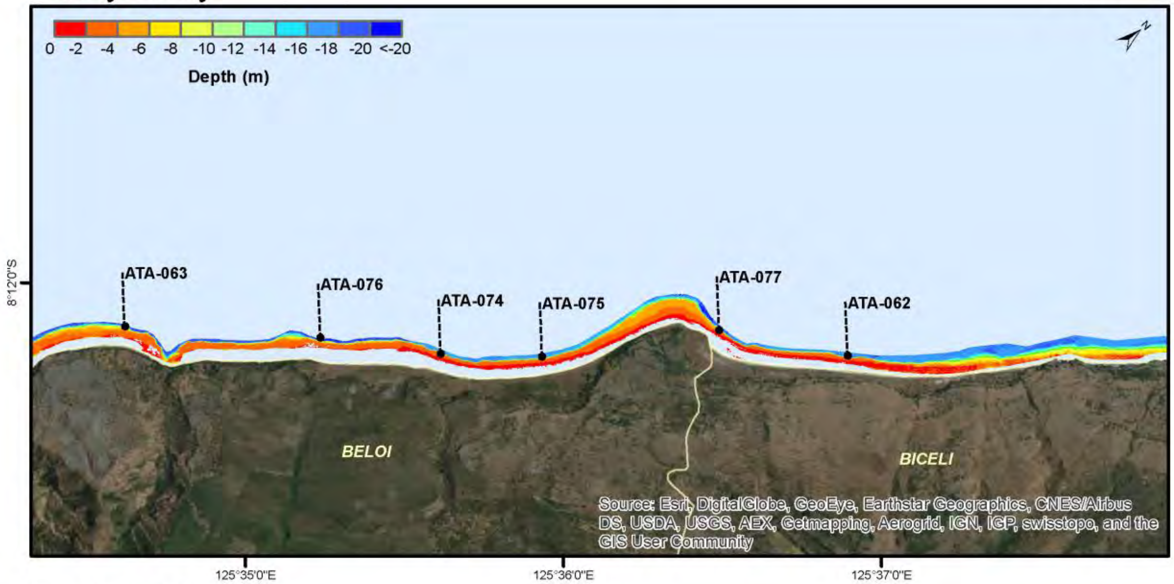
Benthic Habitat



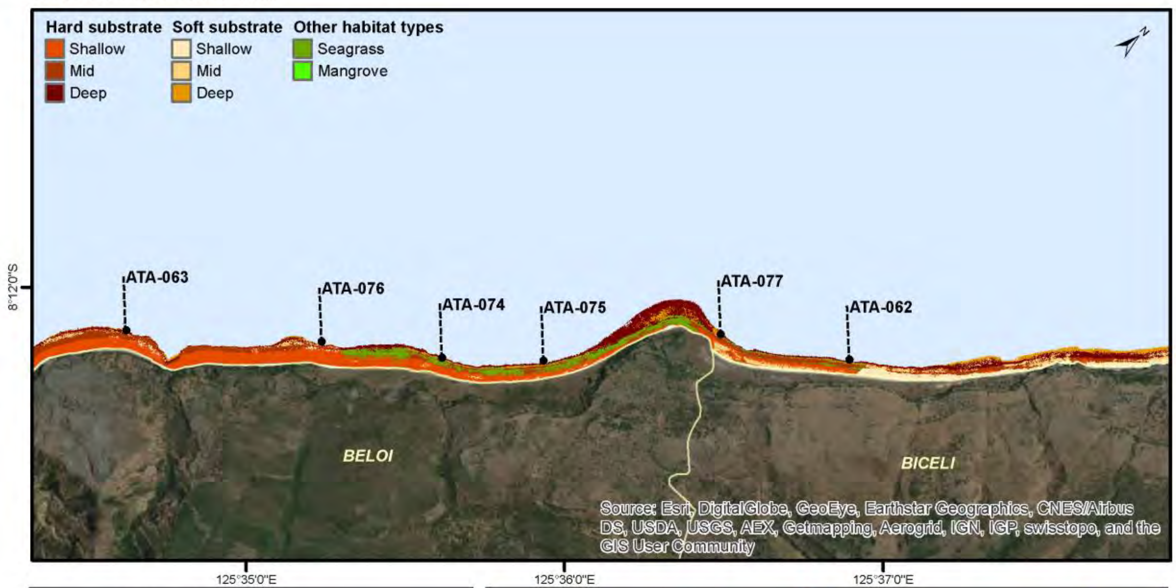


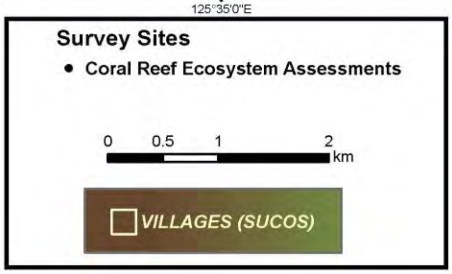
DISTRICT: Dili (Atauro Island)
TILE: 8

Bathymetry



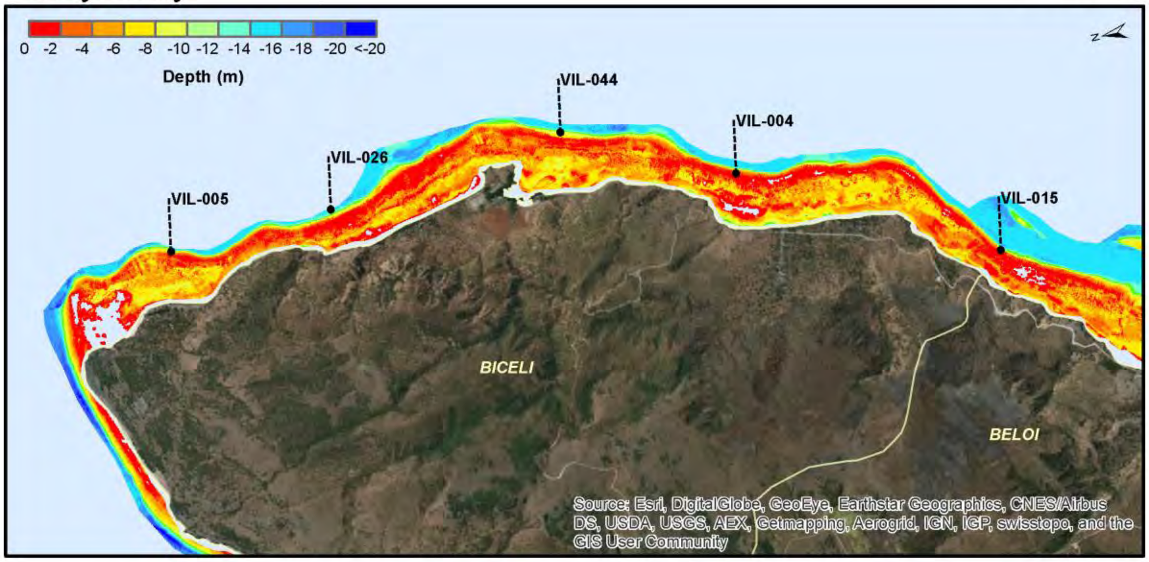
Benthic Habitat



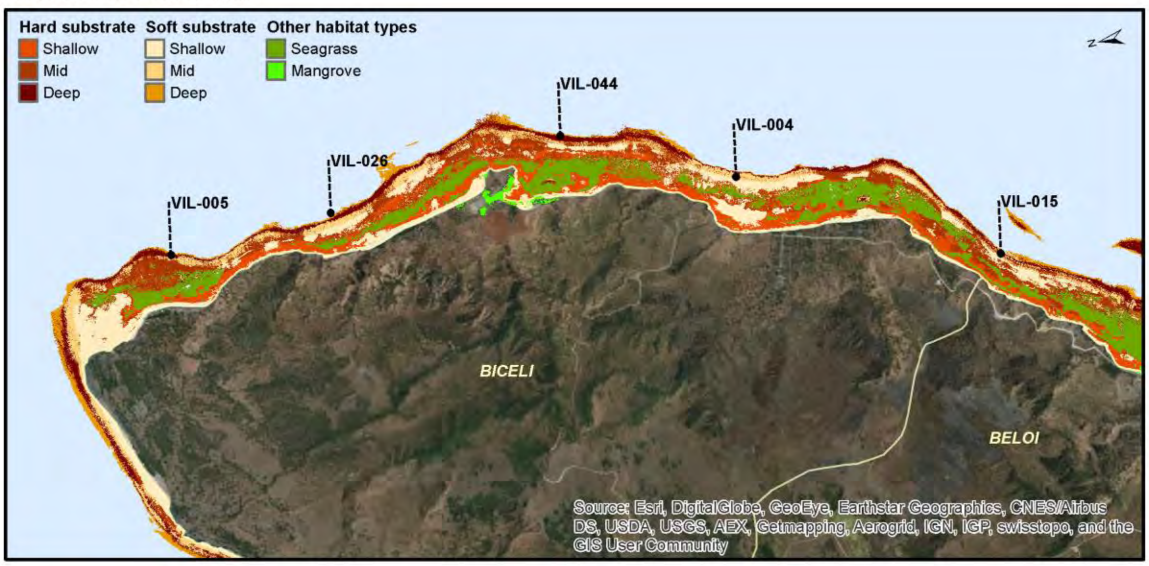


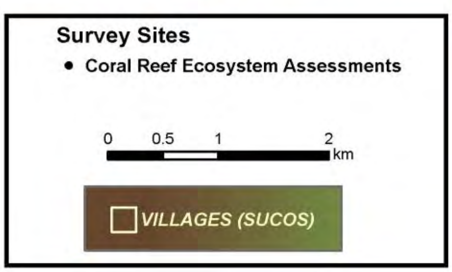
DISTRICT: Dili (Atauro Island)
TILE: 9

Bathymetry



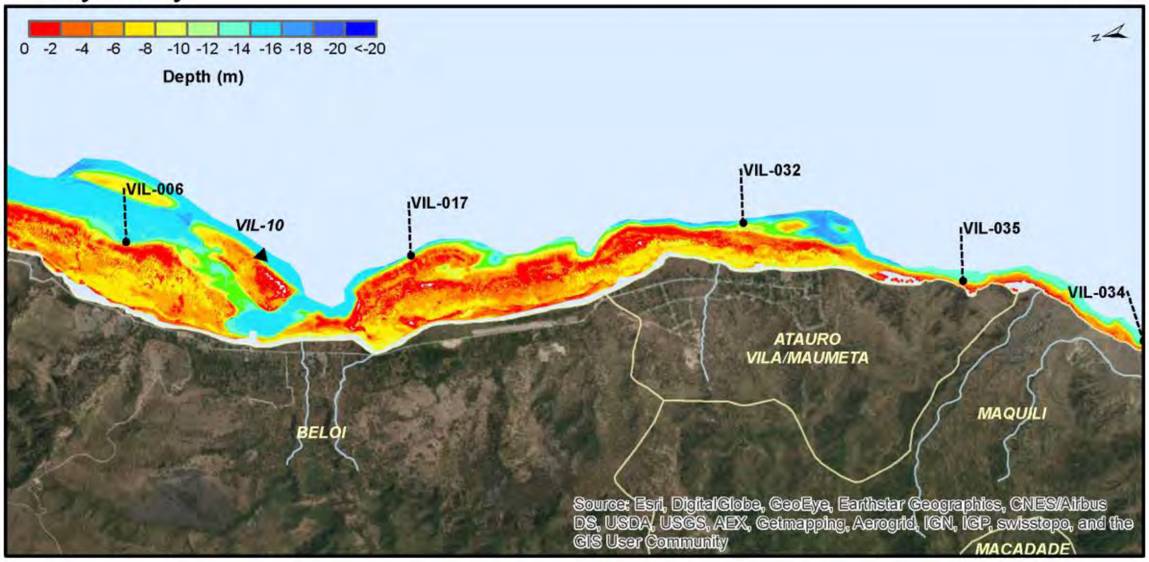
Benthic Habitat



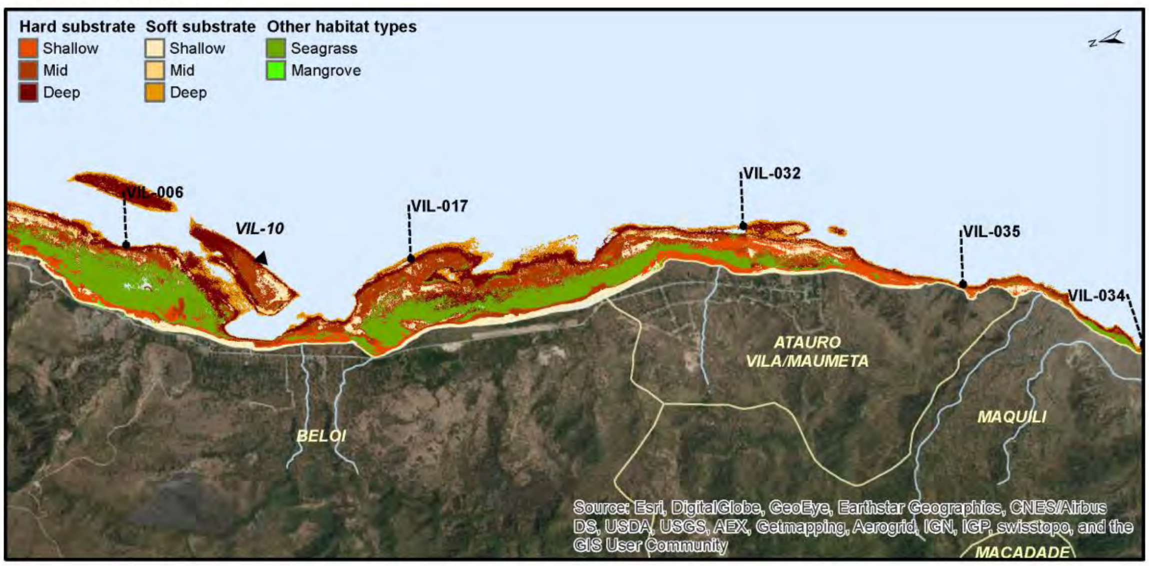


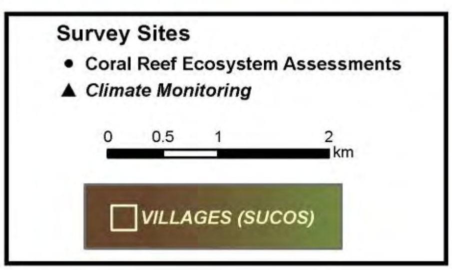
DISTRICT: Dili (Atauro Island)
TILE: 10

Bathymetry



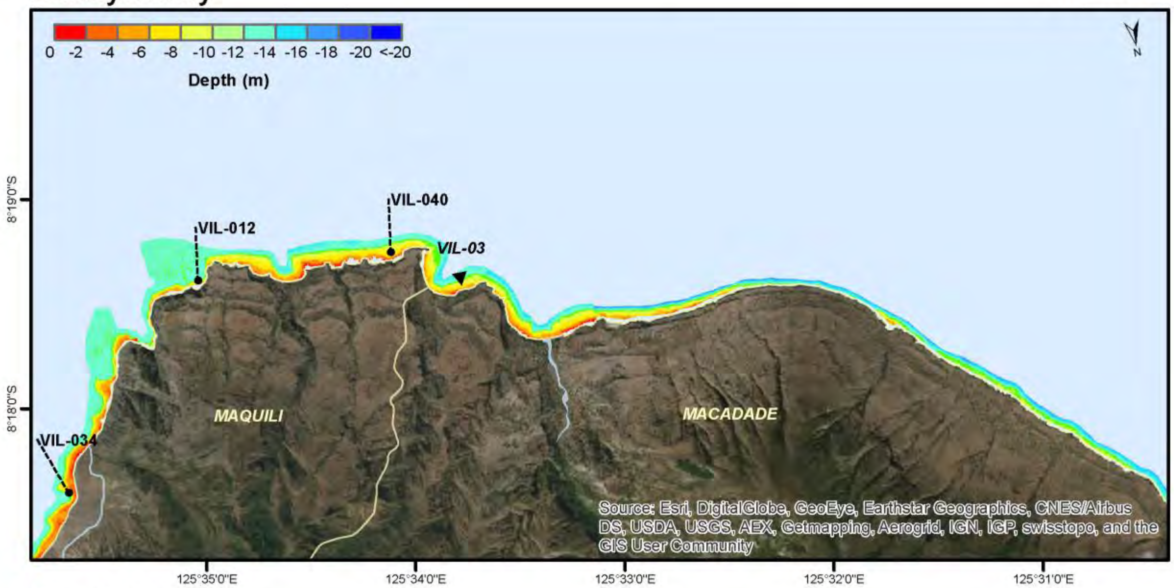
Benthic Habitat



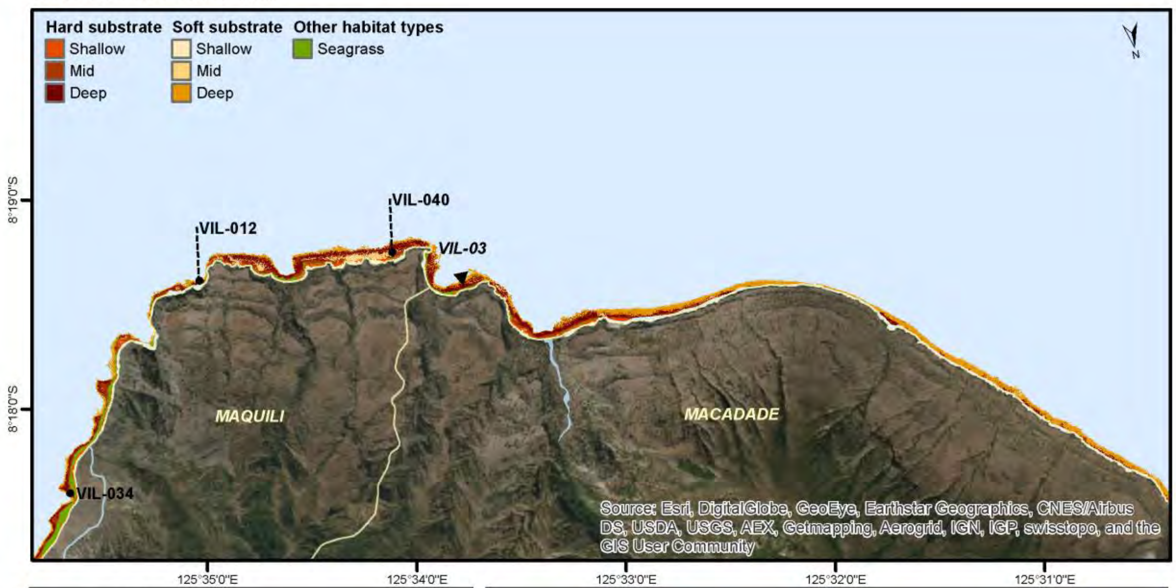


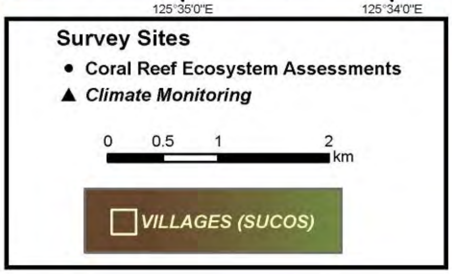
DISTRICT: Dili (Atauro Island)
TILE: 11

Bathymetry



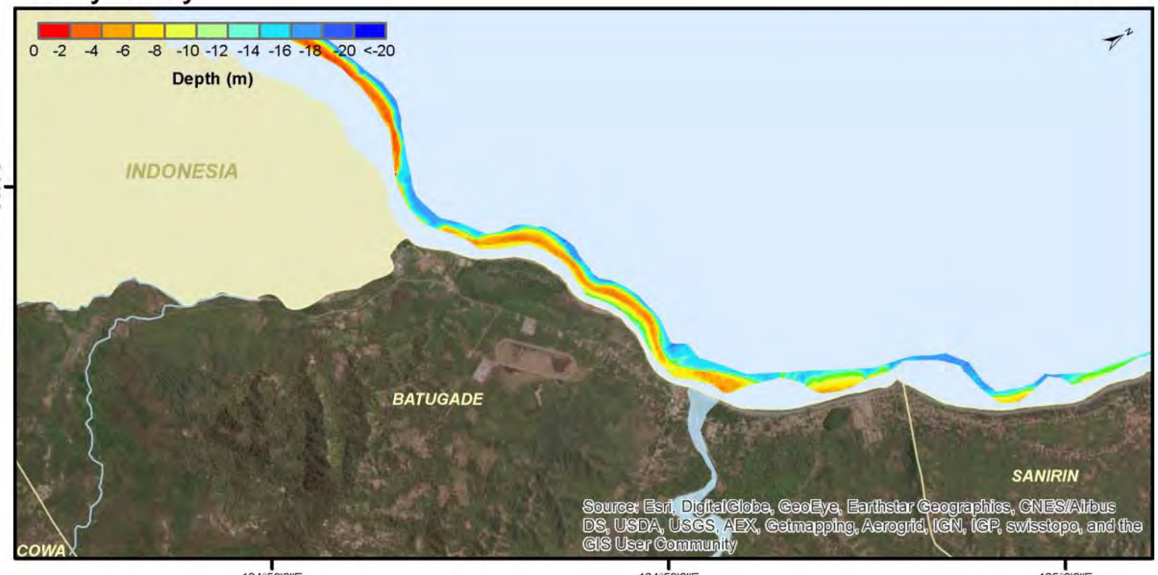
Benthic Habitat



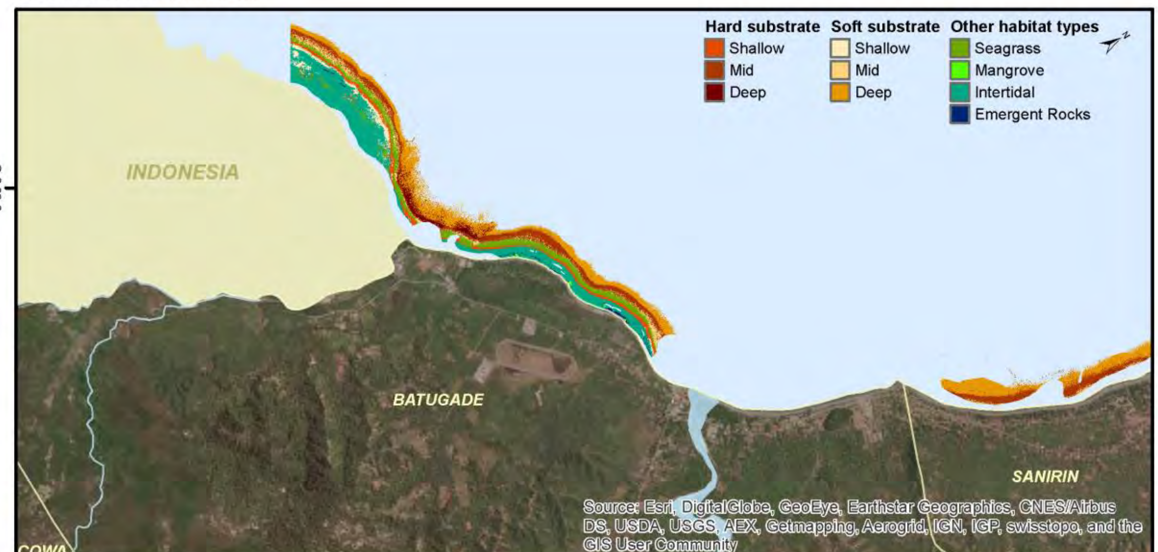


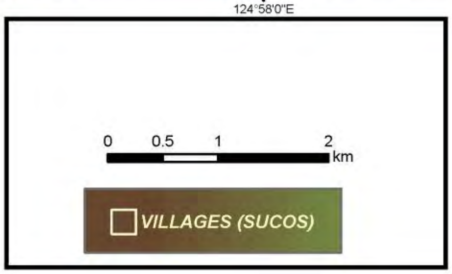
DISTRICT: Bobonaro
TILE: 12

Bathymetry



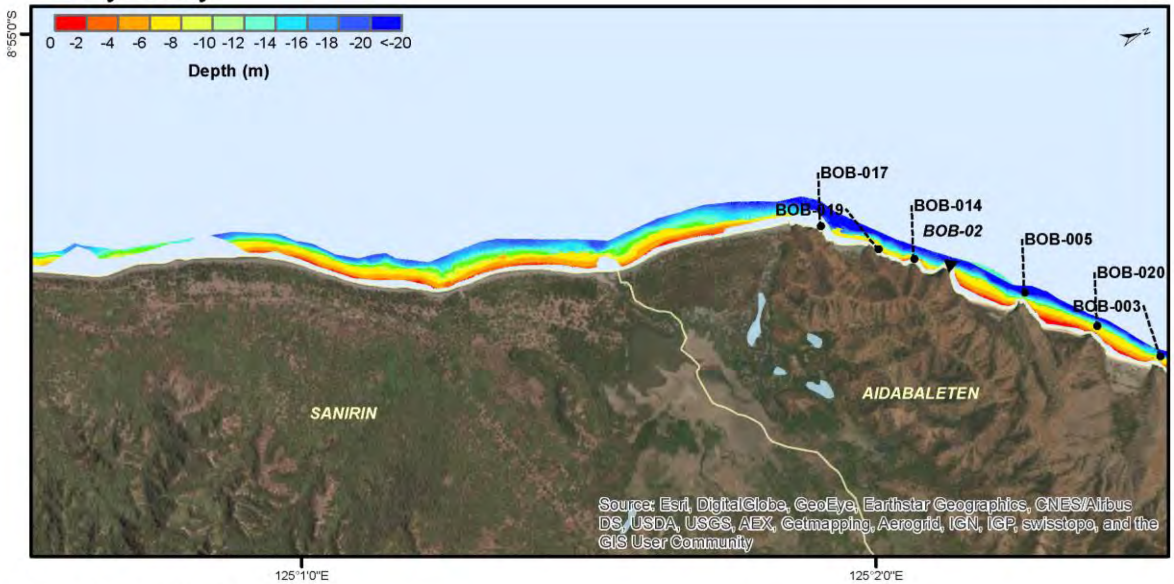
Benthic Habitat



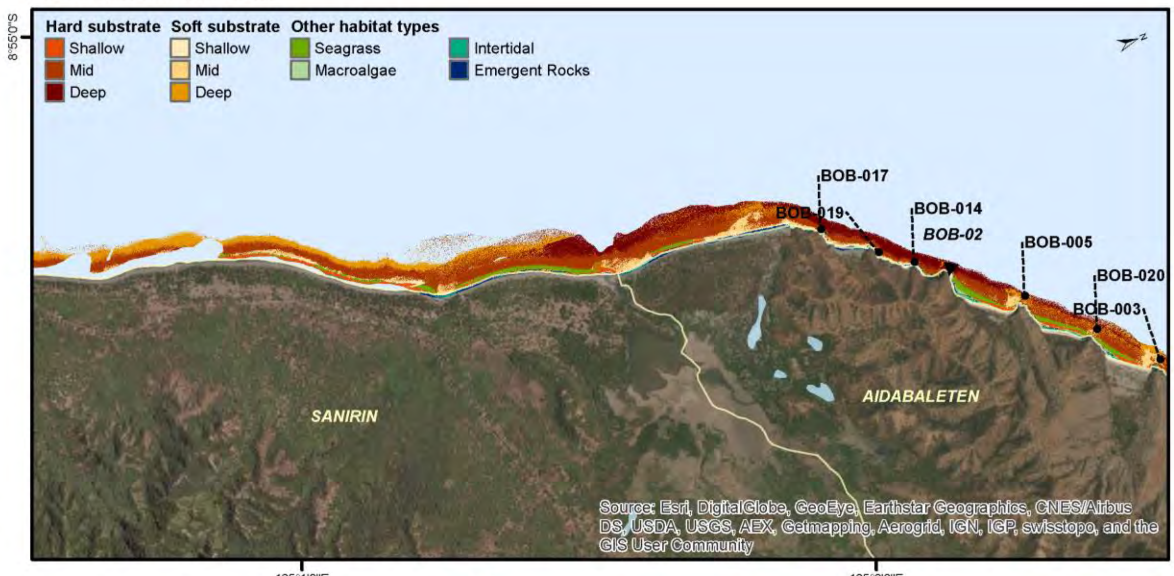


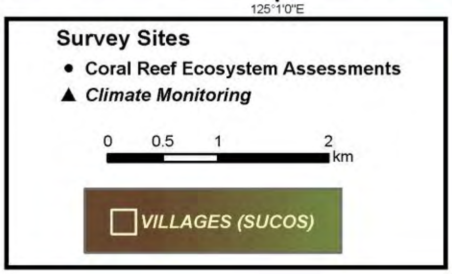
DISTRICT: Bobonaro
TILE: 13

Bathymetry



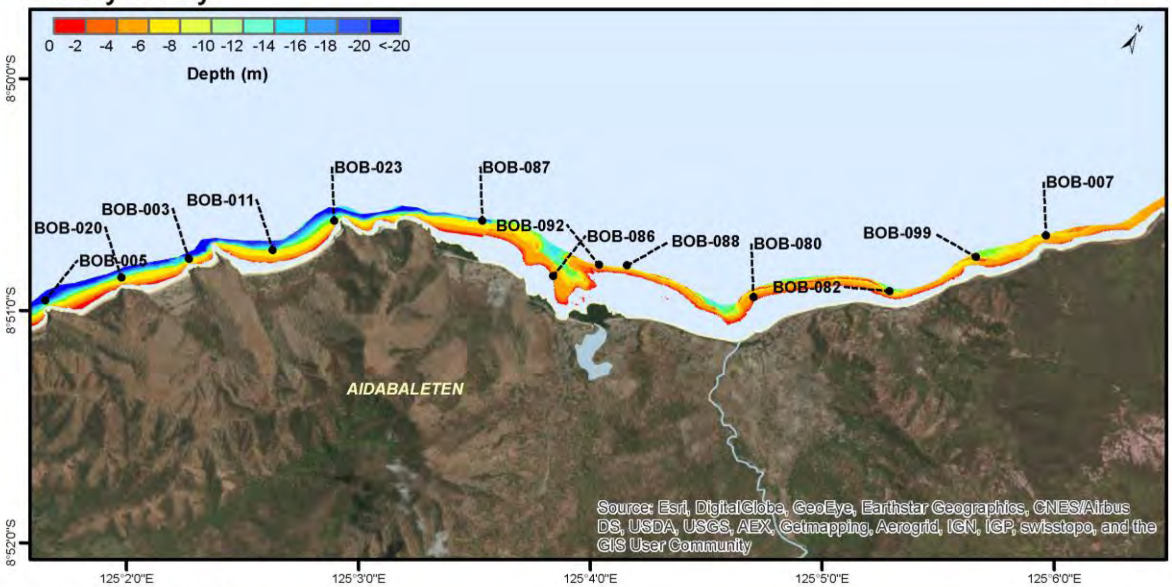
Benthic Habitat



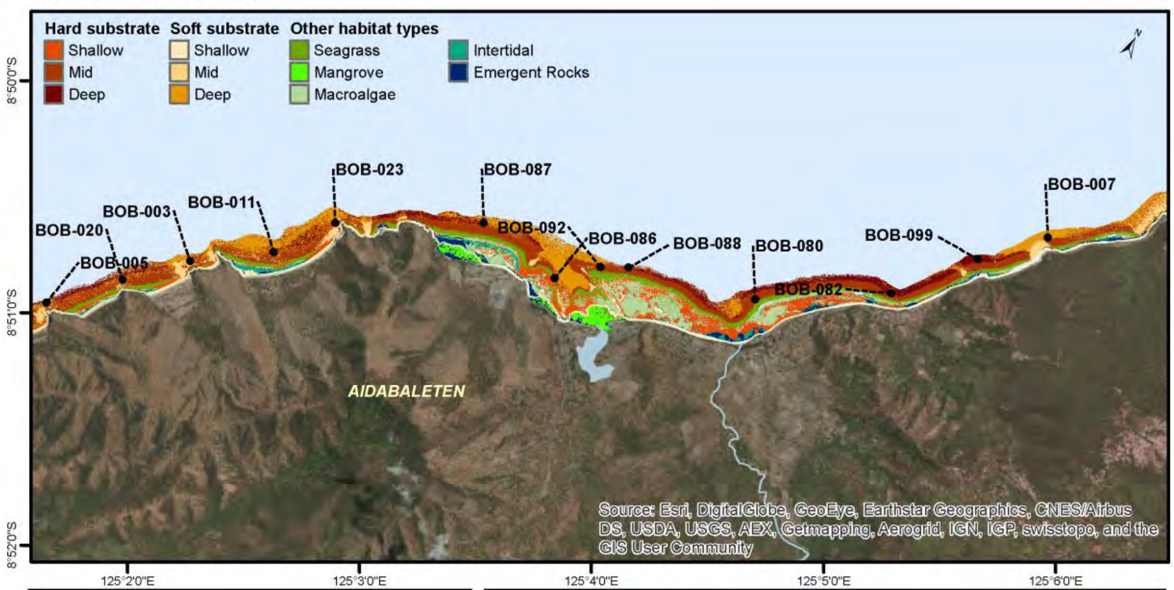


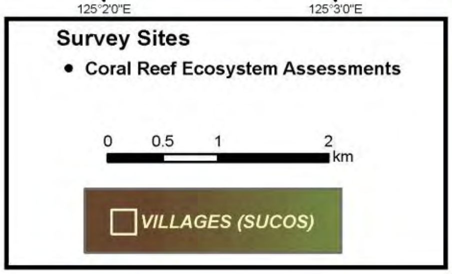
DISTRICT: Bobonaro
TILE: 14

Bathymetry



Benthic Habitat

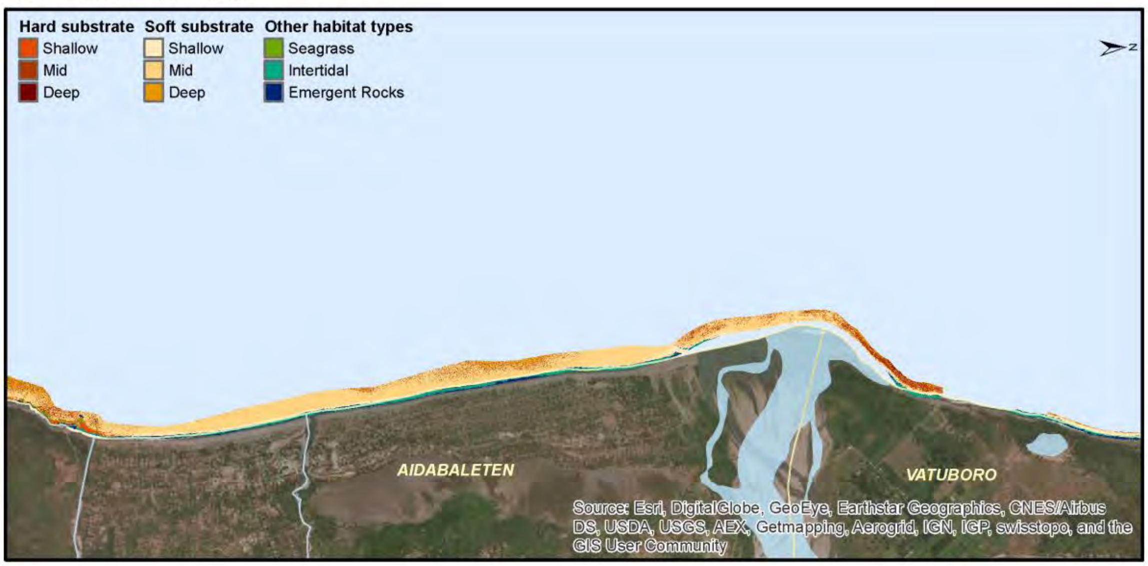


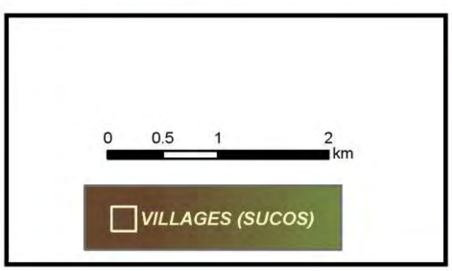


DISTRICT: Bobonaro
TILE: 15

Bathymetry

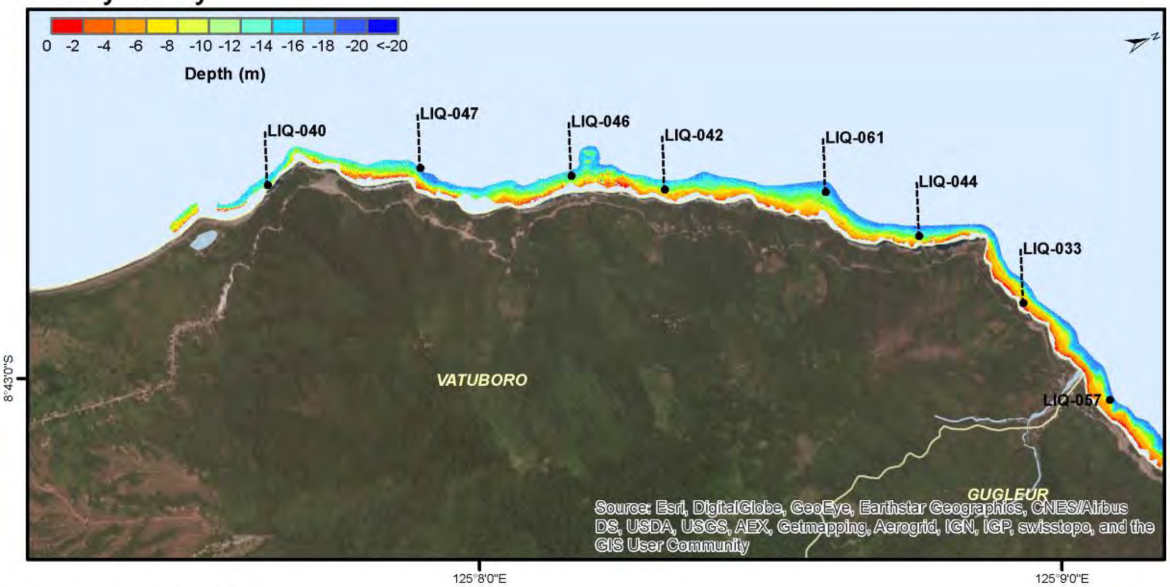
Benthic Habitat



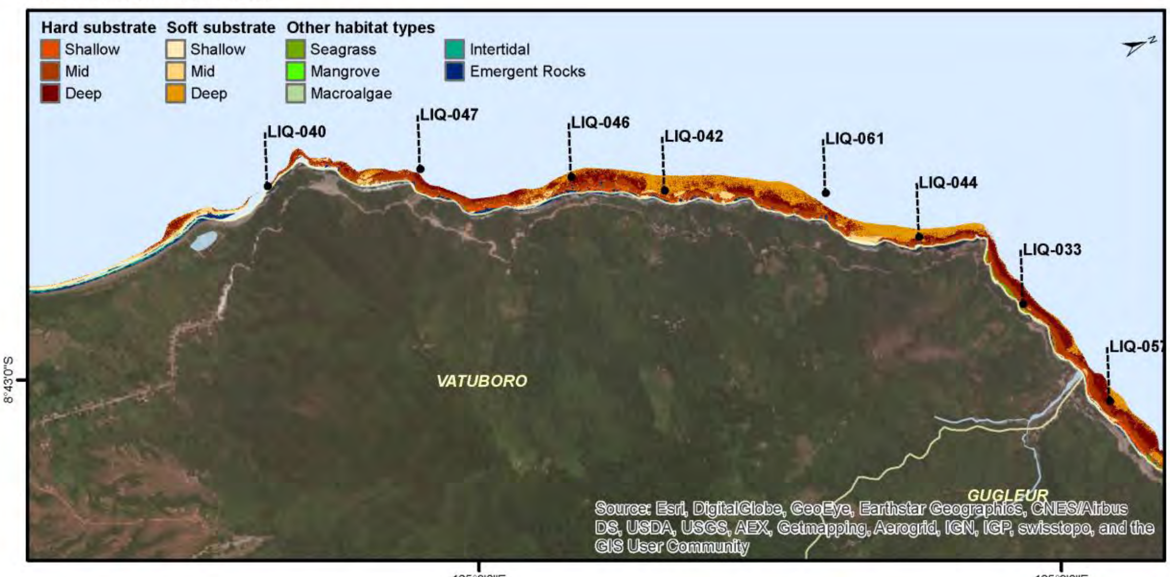


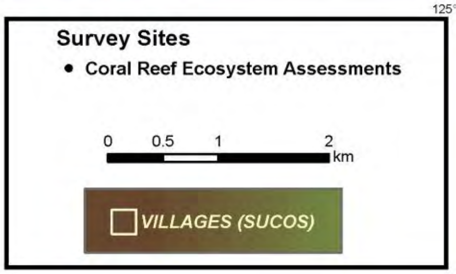
DISTRICT: Liquica
TILE: 16

Bathymetry



Benthic Habitat





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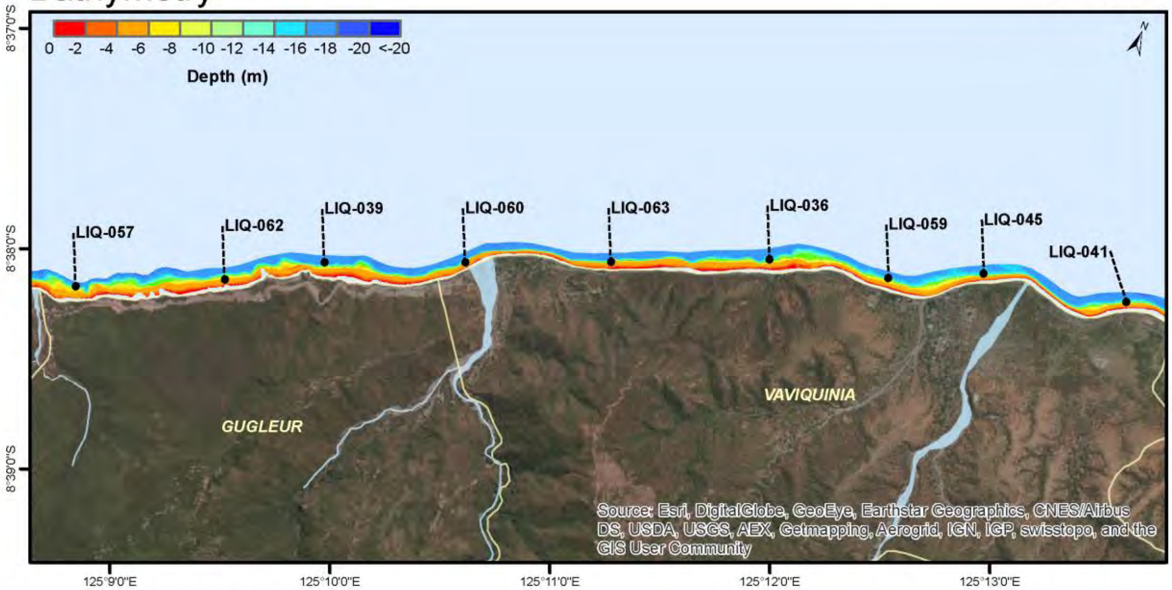
Bathymetry



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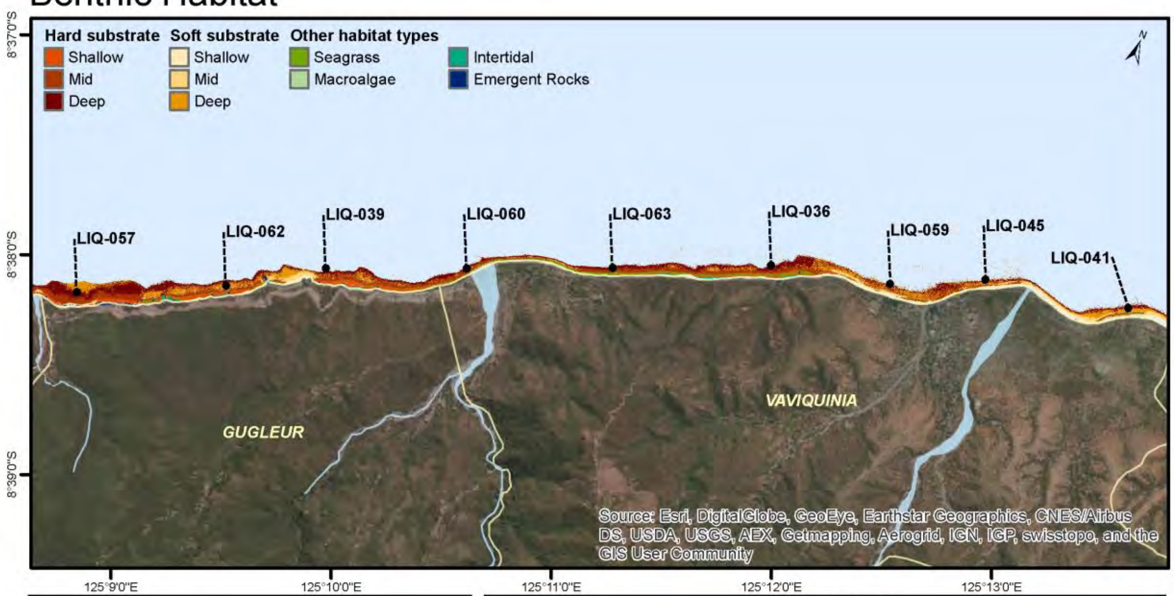

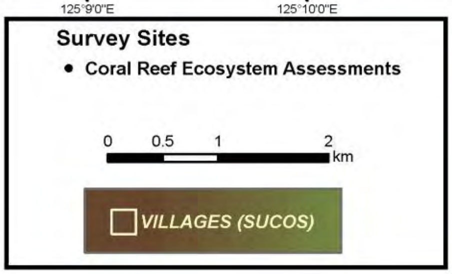

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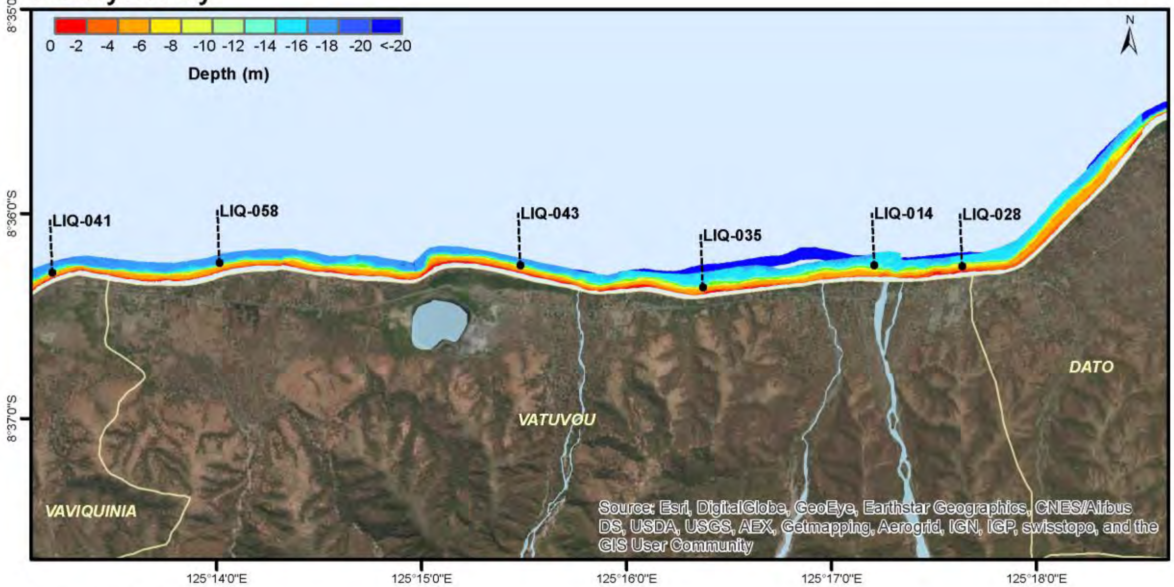
Bathymetry



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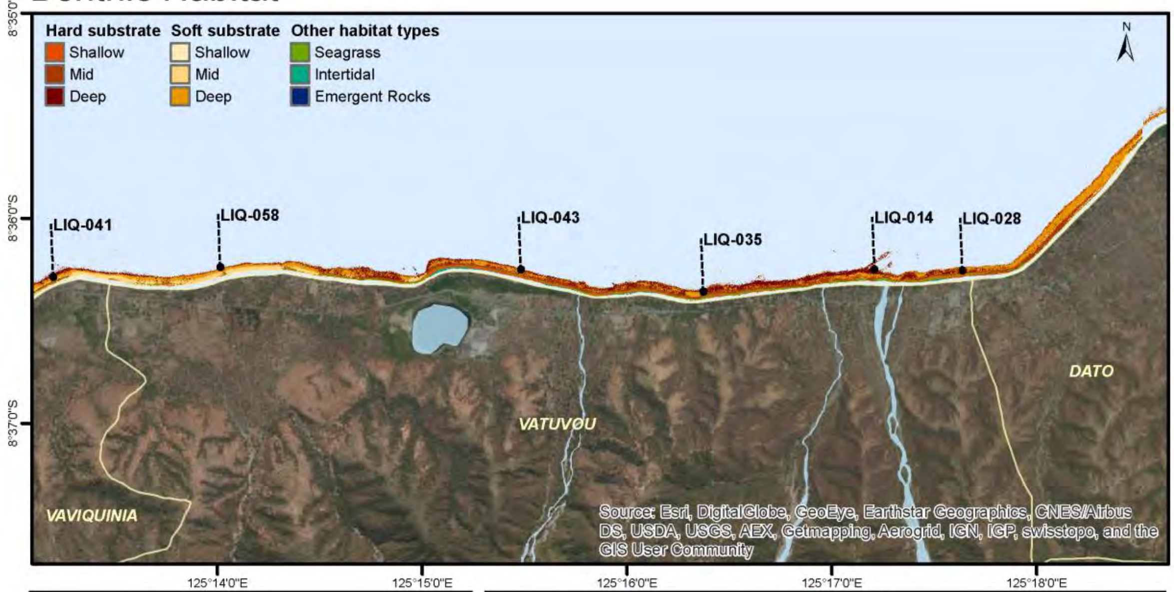

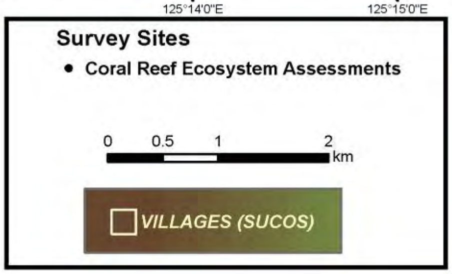

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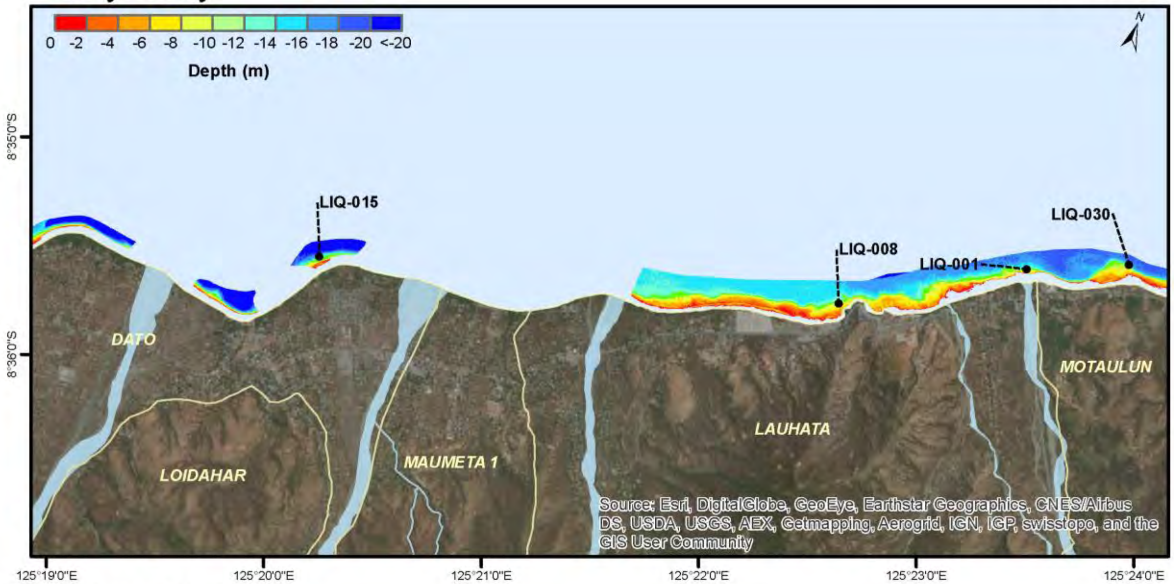

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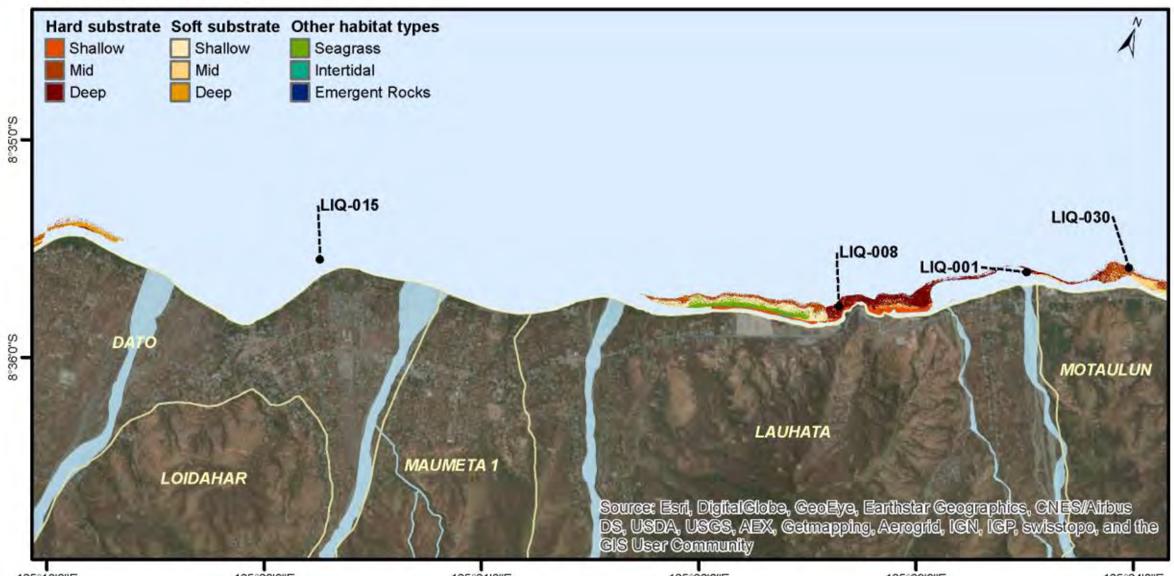

Survey Sites

- Coral Reef Ecosystem Assessments

0 0.5 1 2 km

VILLAGES (SUCOS)

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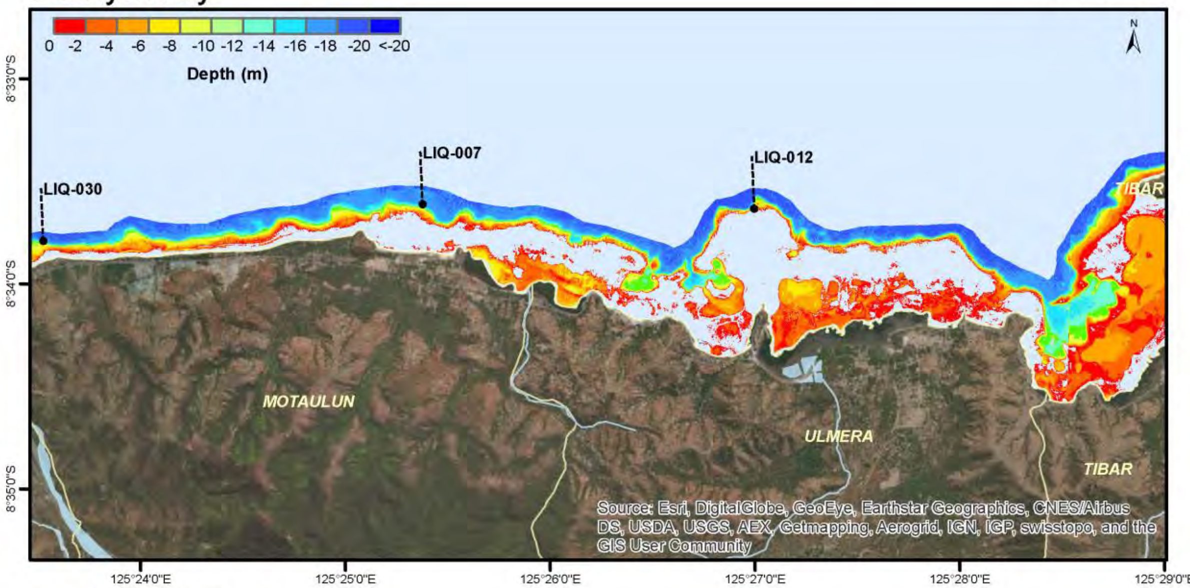
TILE: 20

Bathymetry



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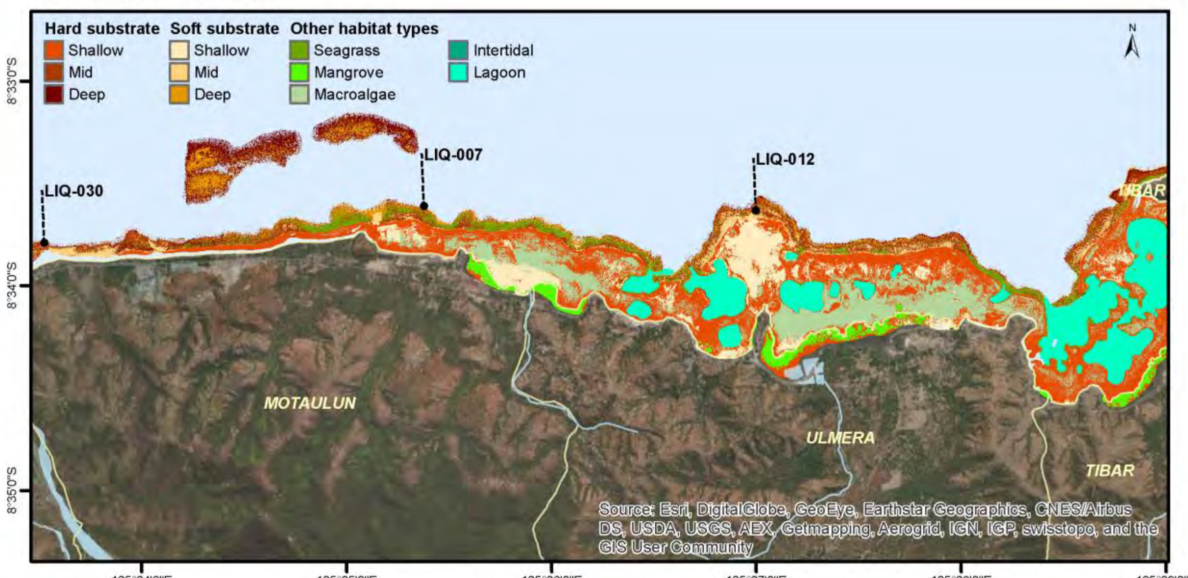

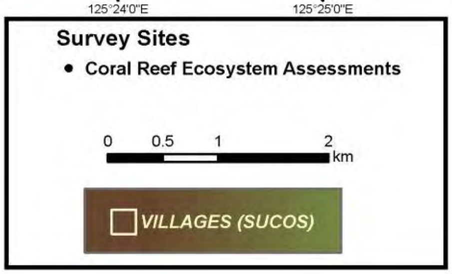

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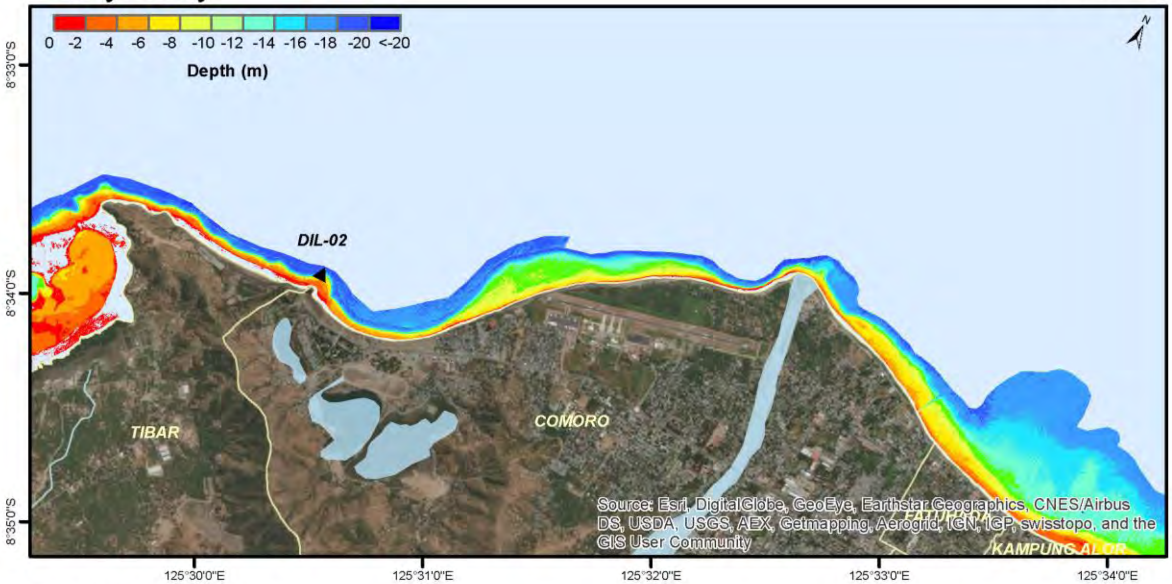
Bathymetry



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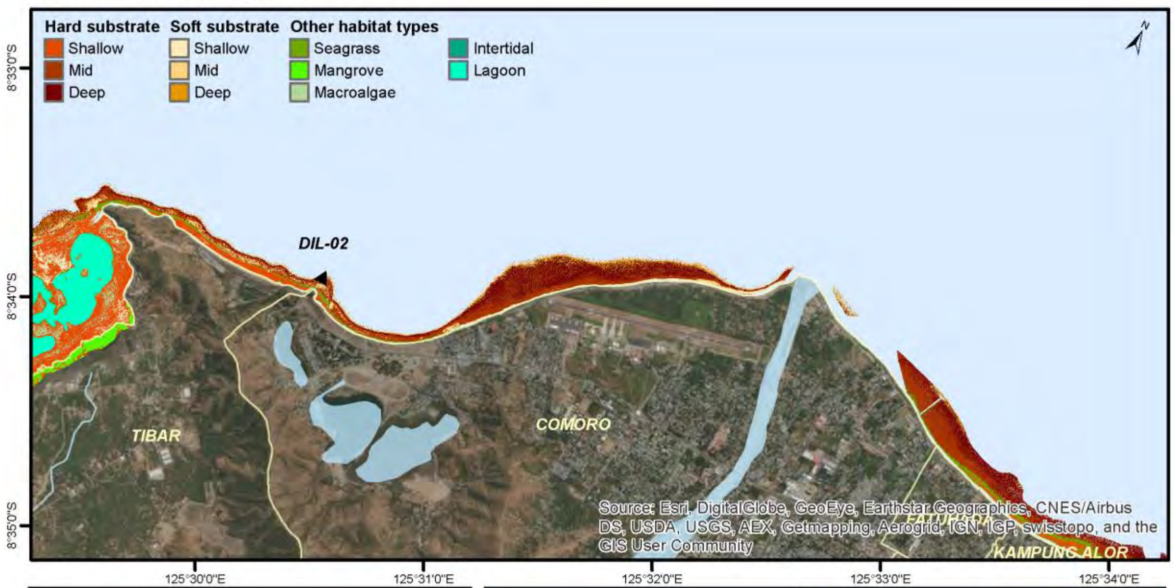

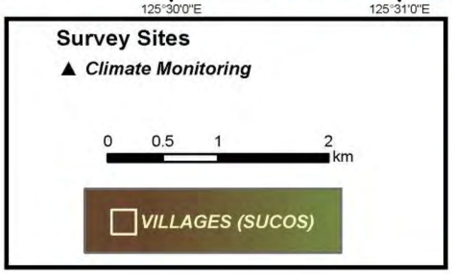

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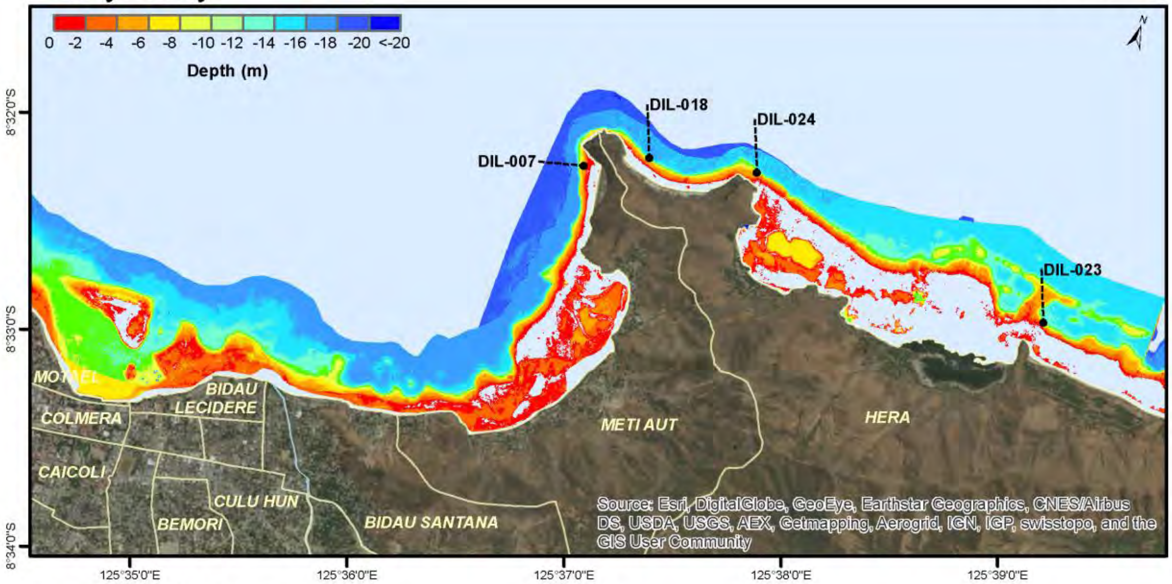

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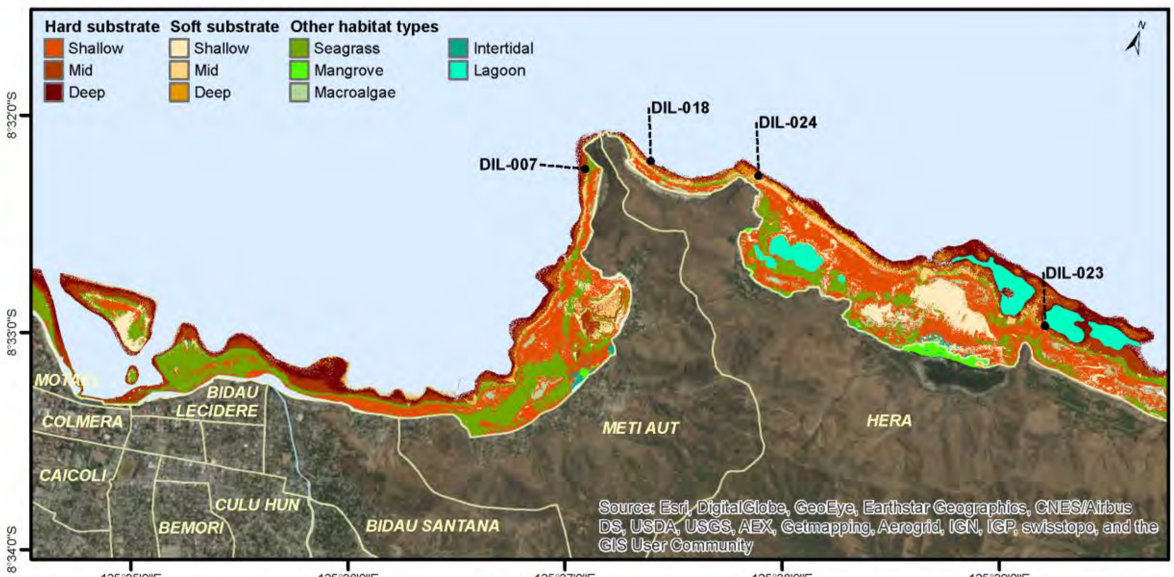

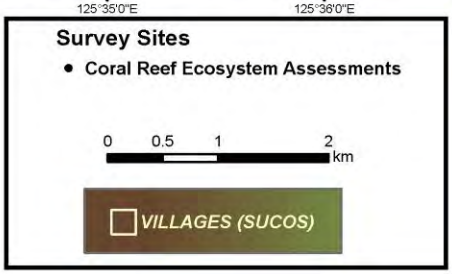

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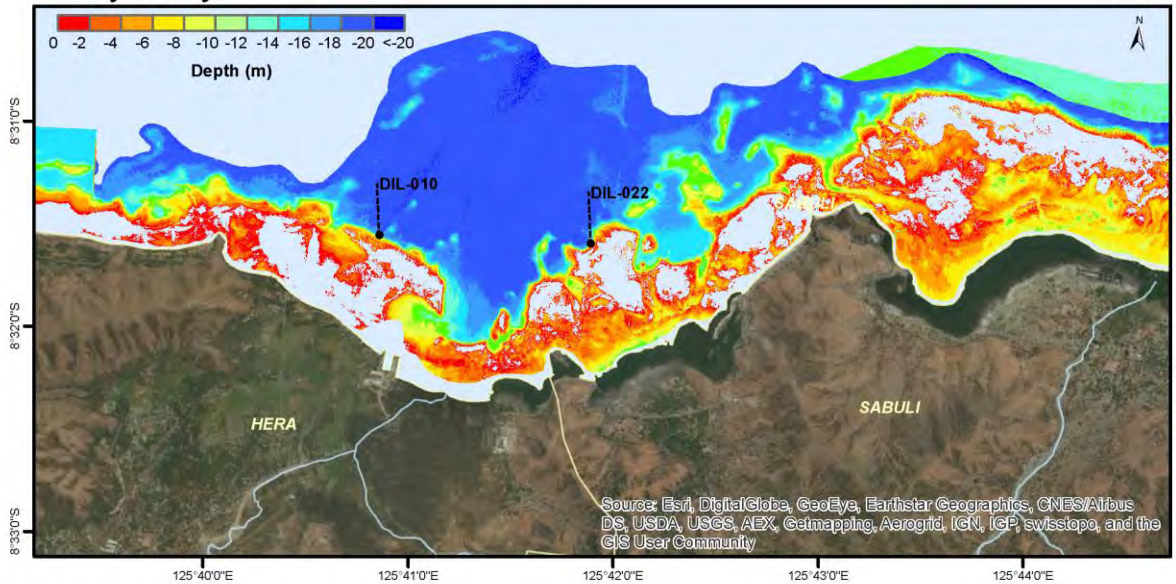
Bathymetry



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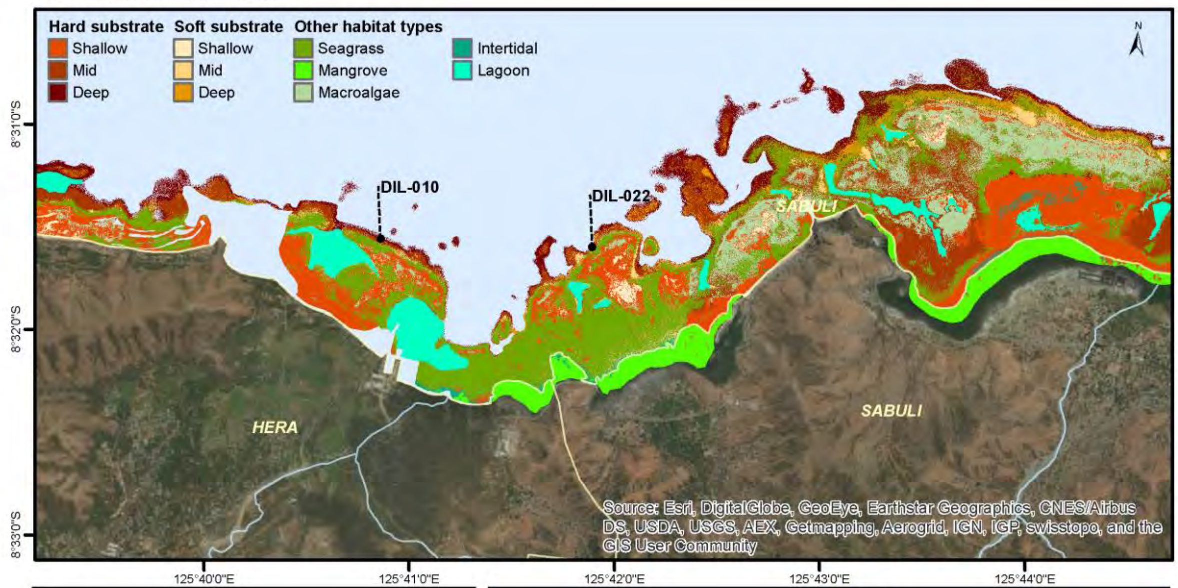

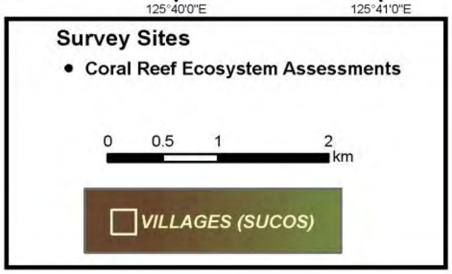

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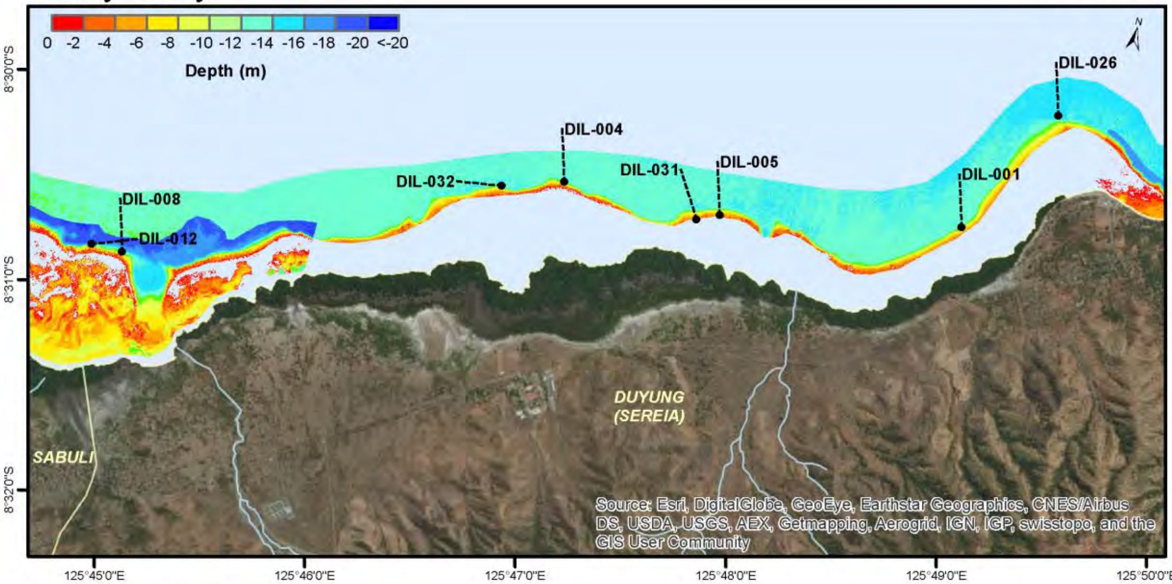

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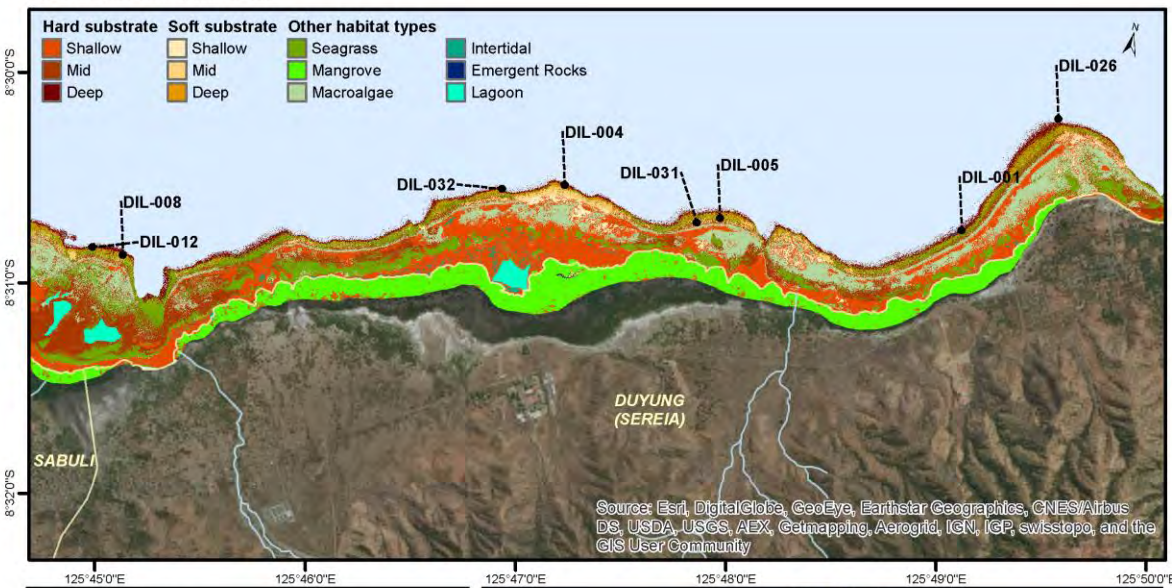

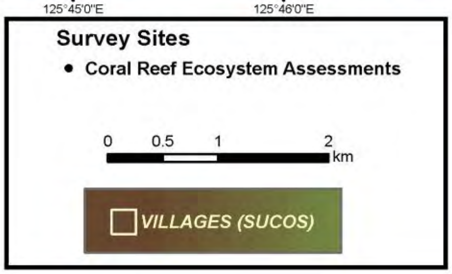

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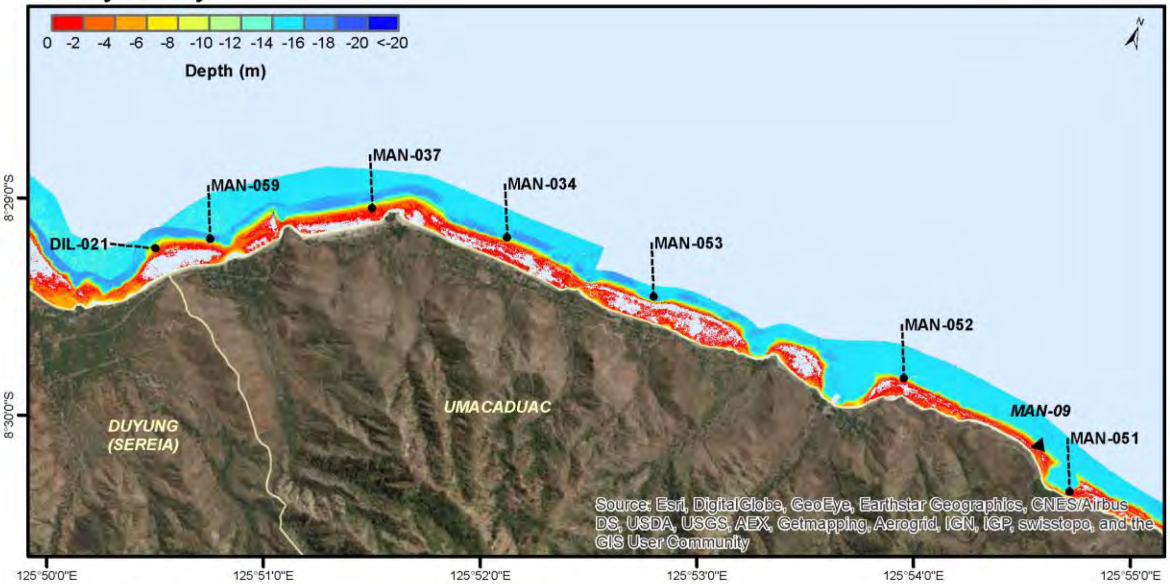

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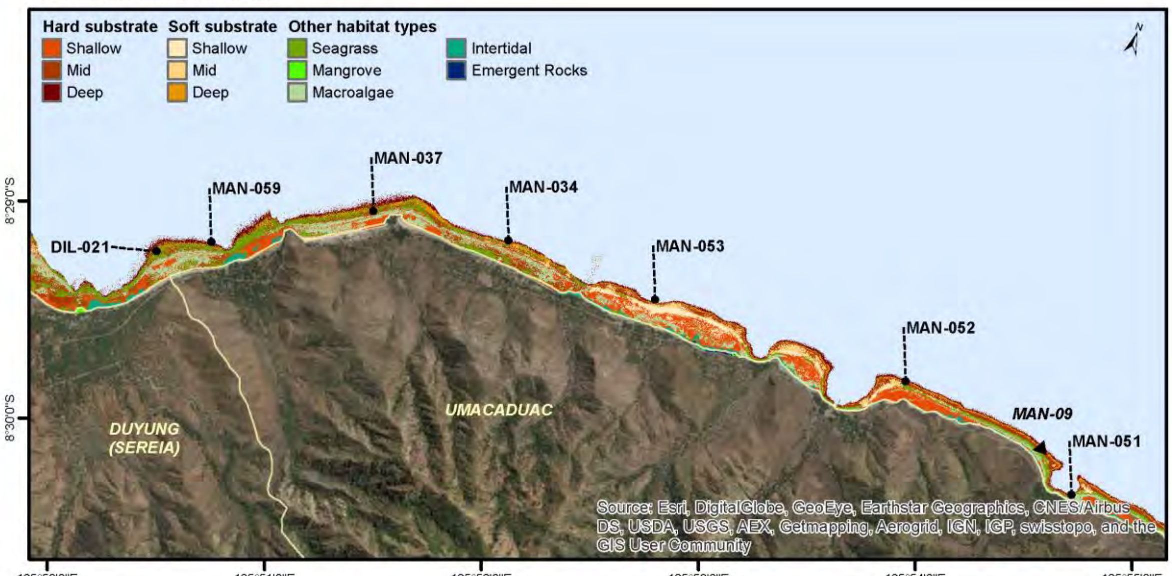

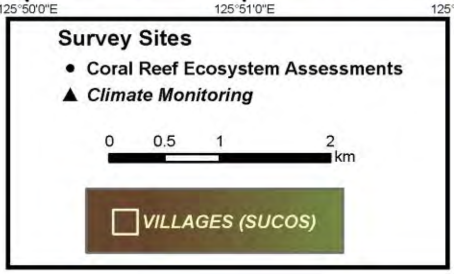

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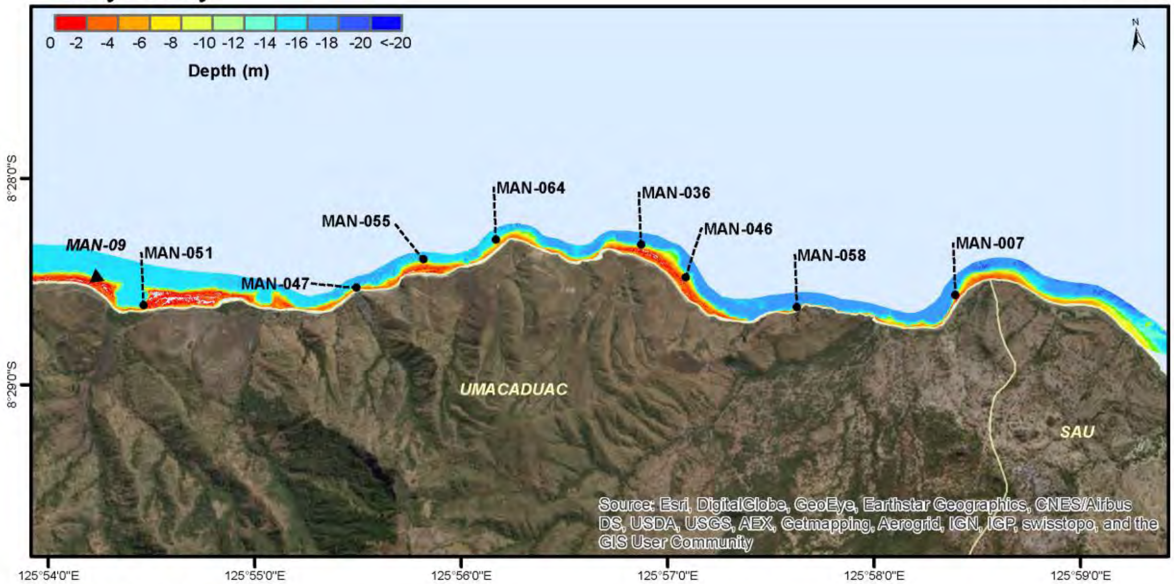

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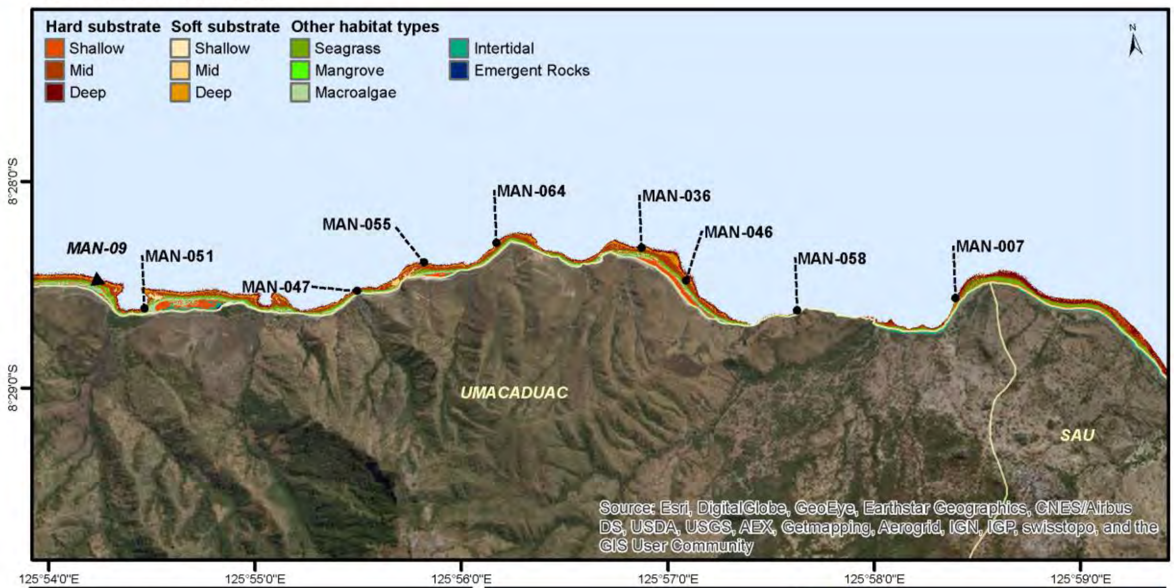

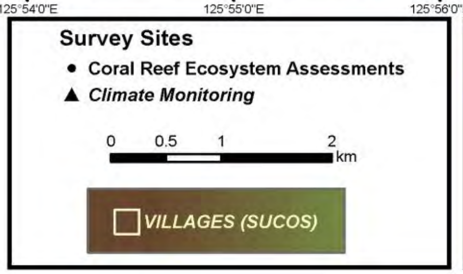

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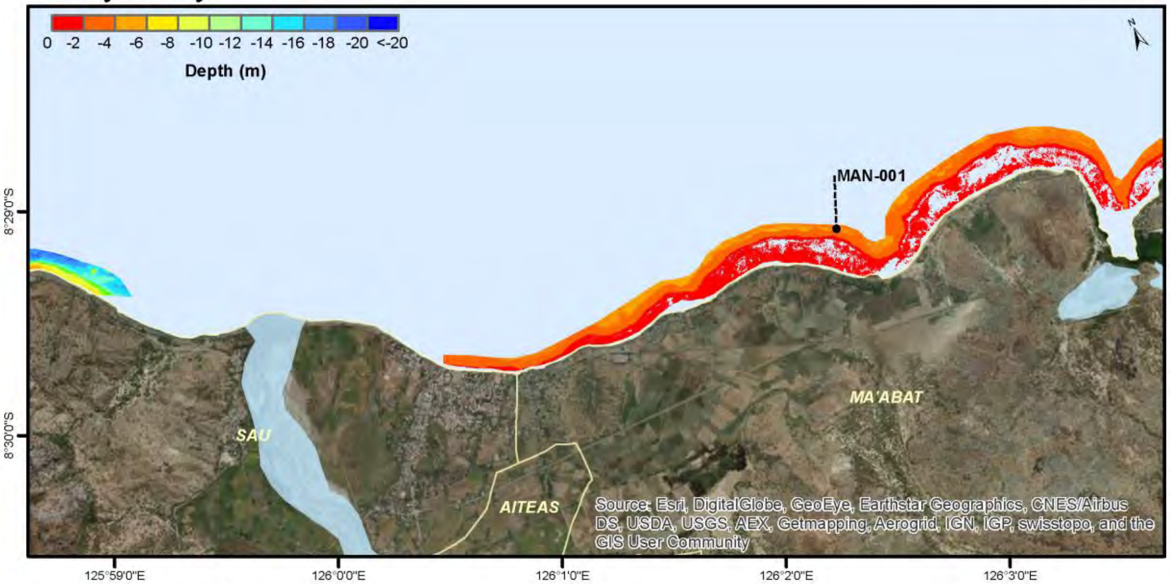

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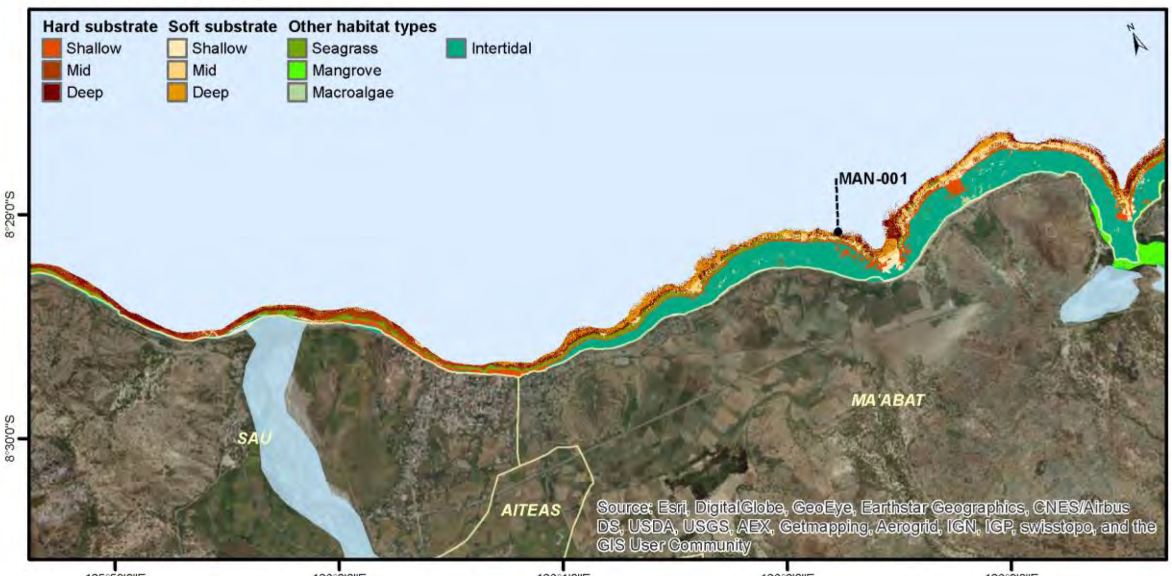

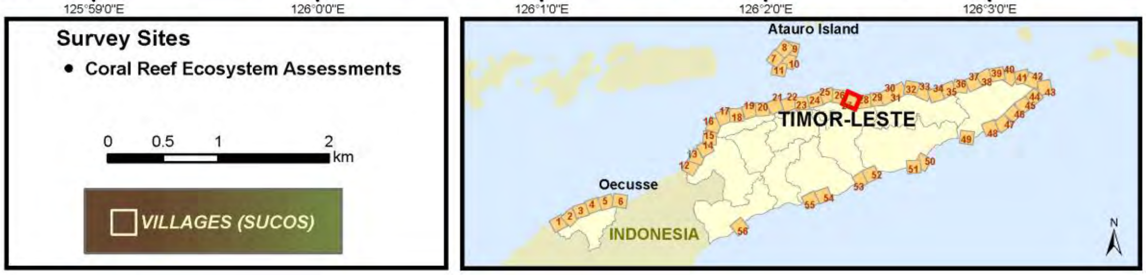

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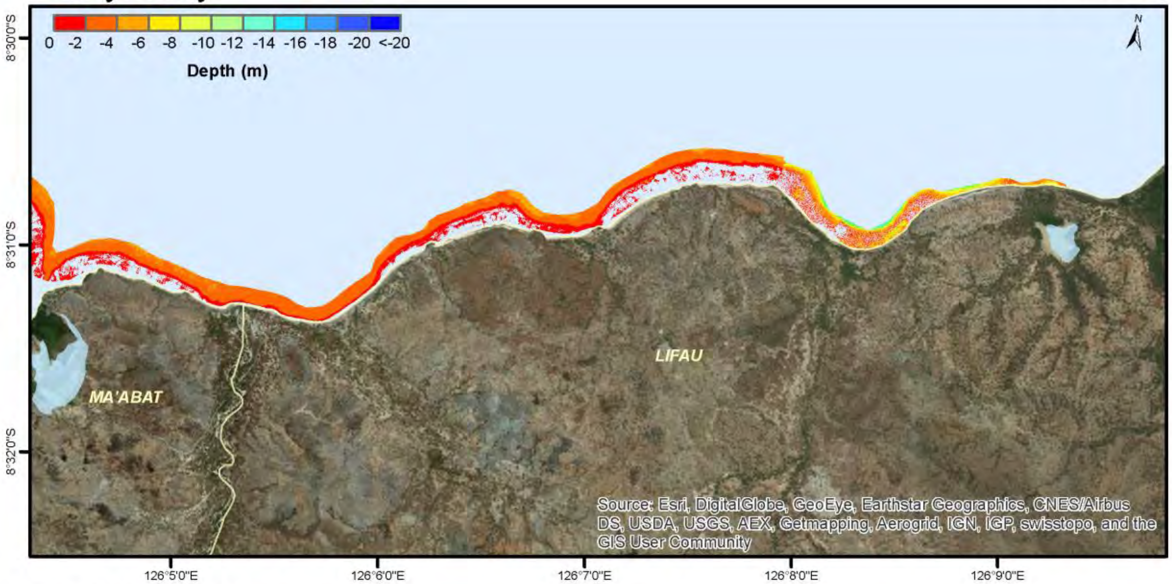

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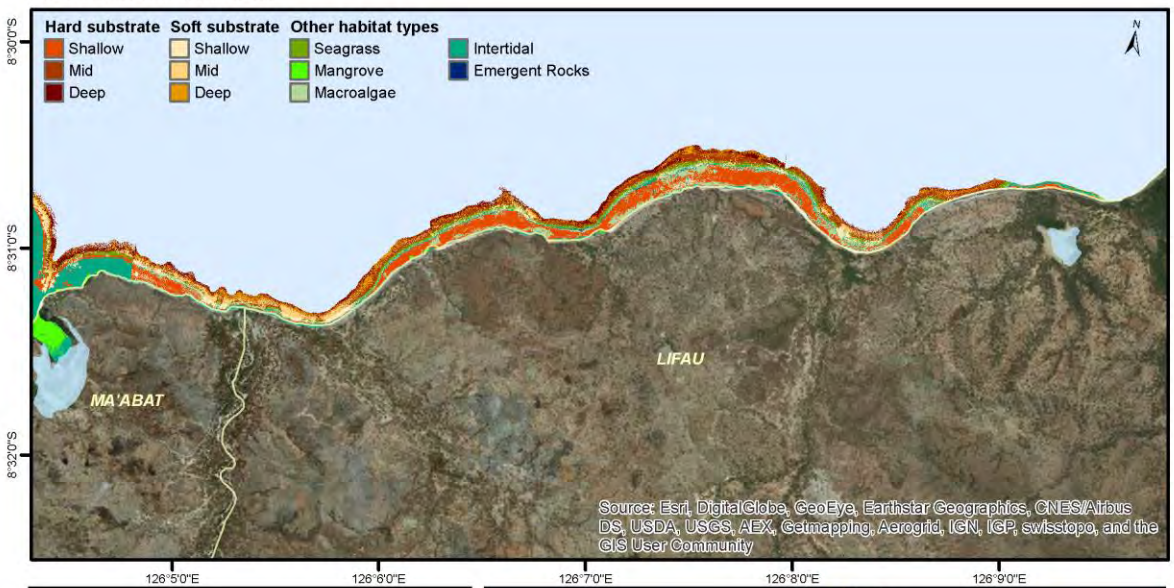

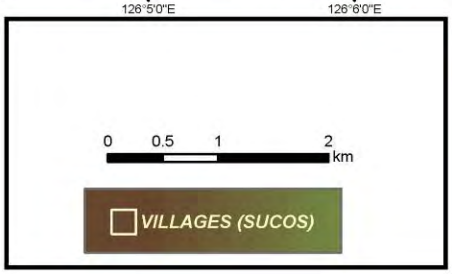

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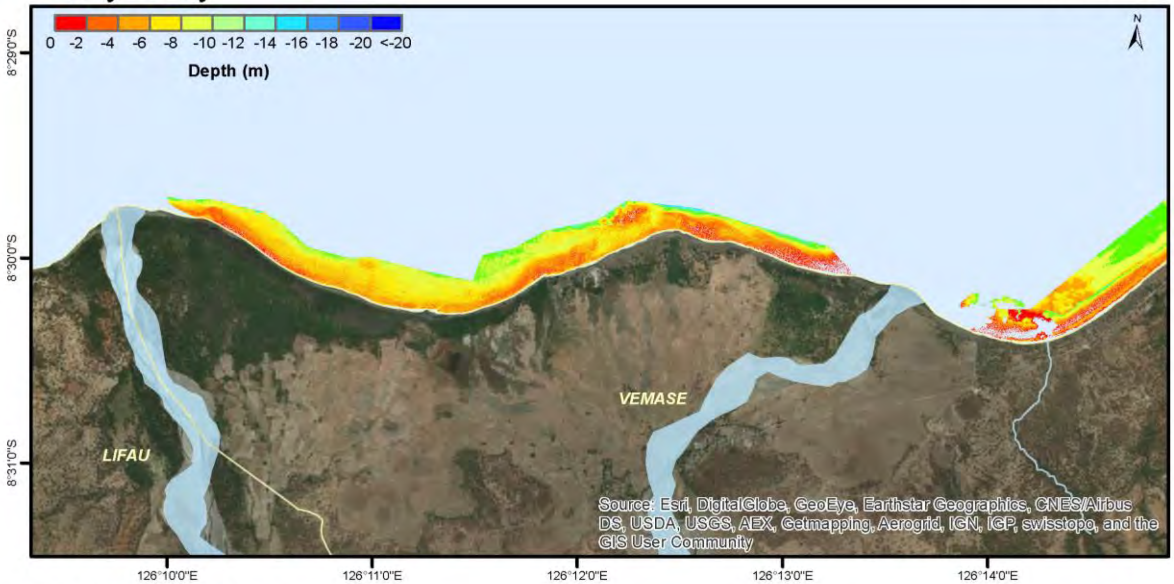

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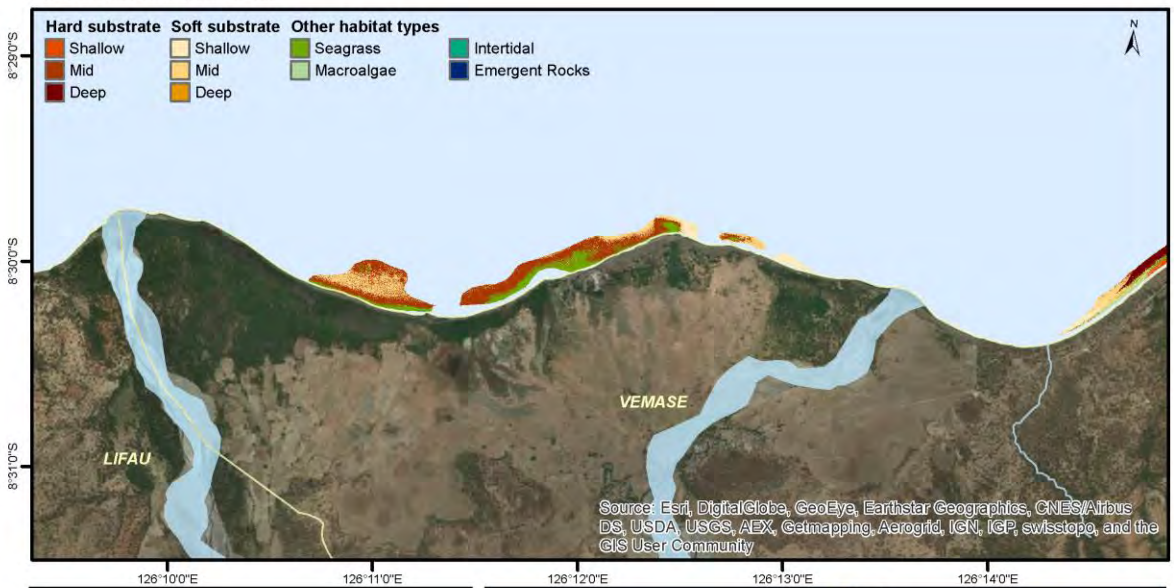

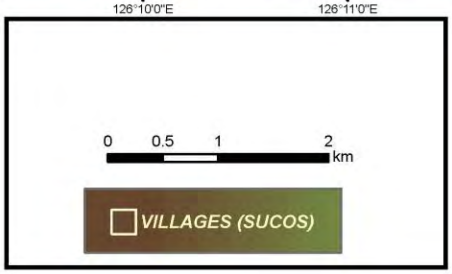

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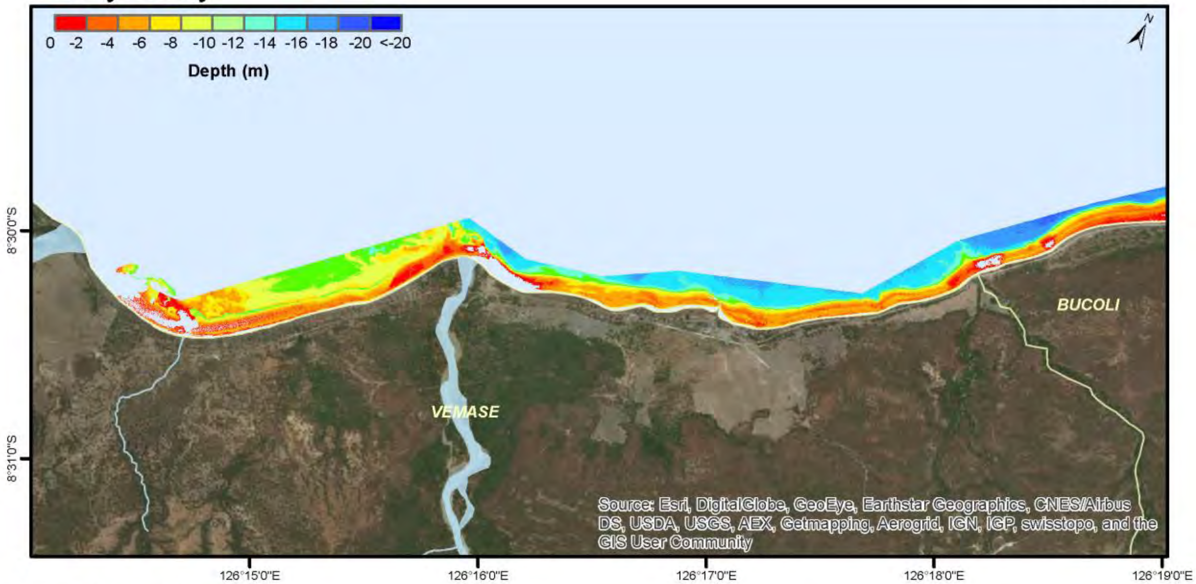

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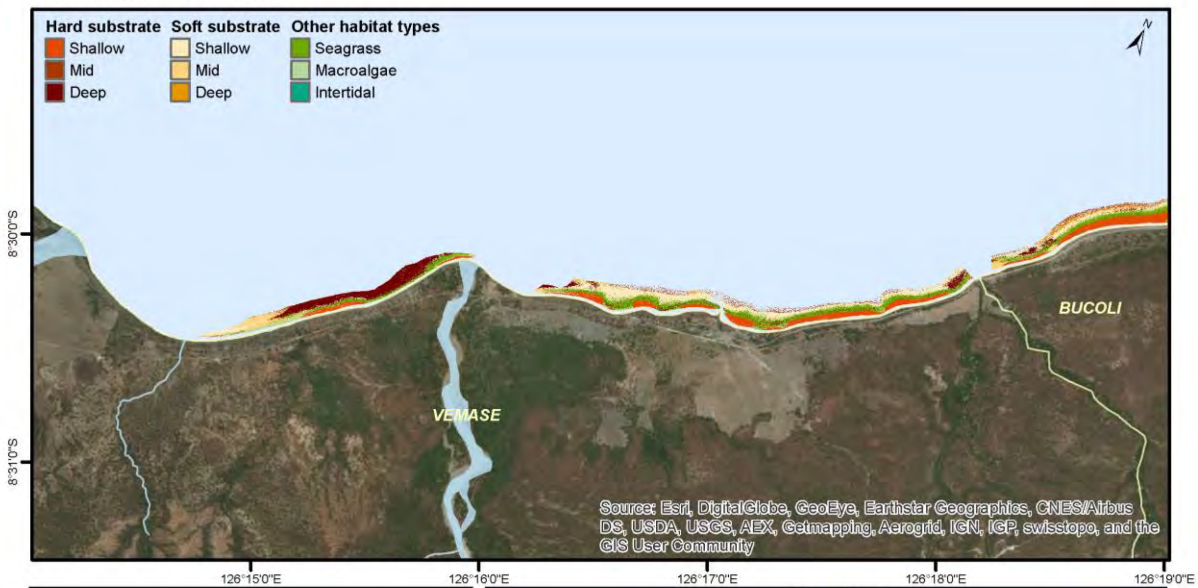

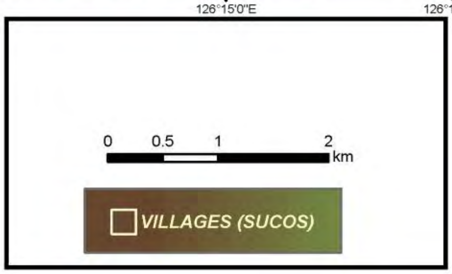

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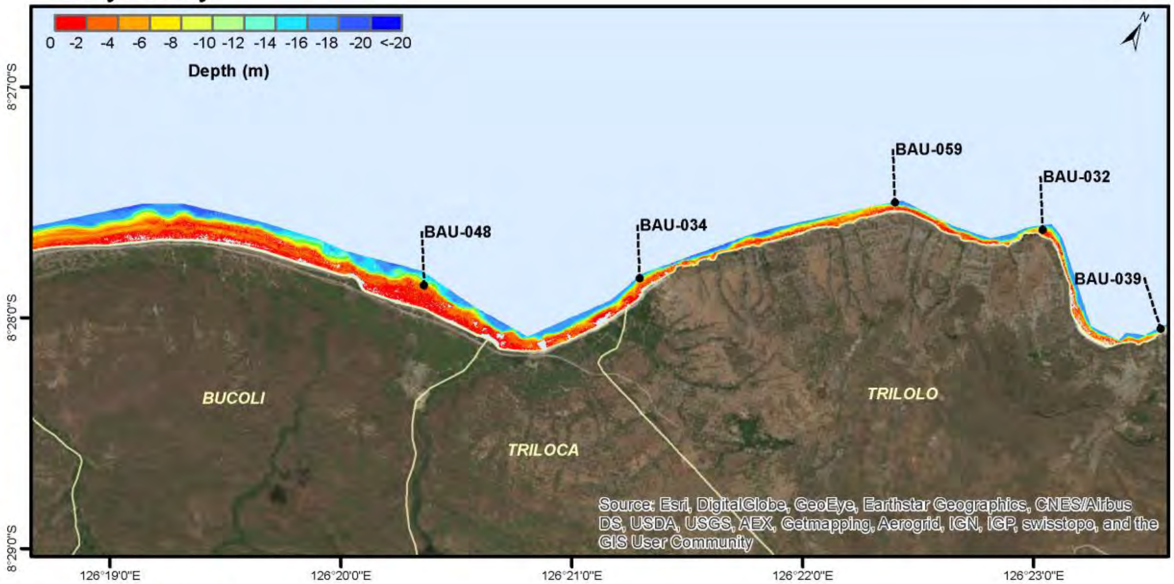

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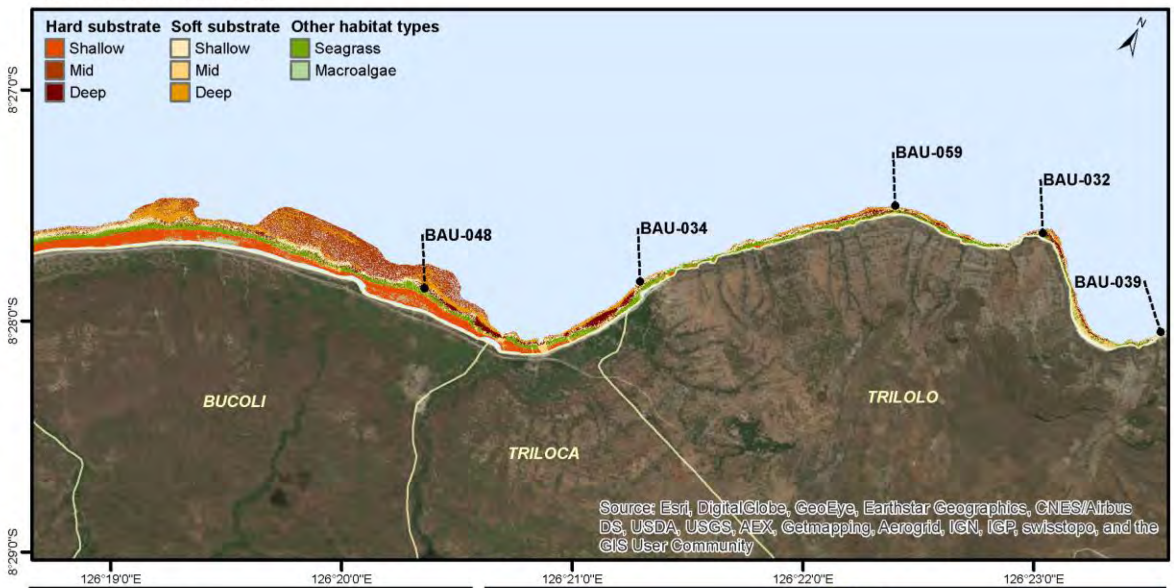

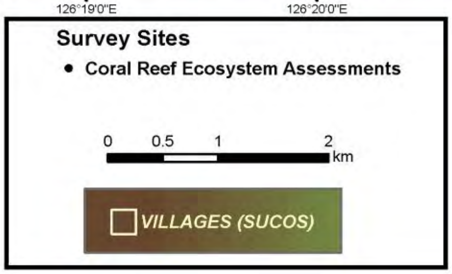

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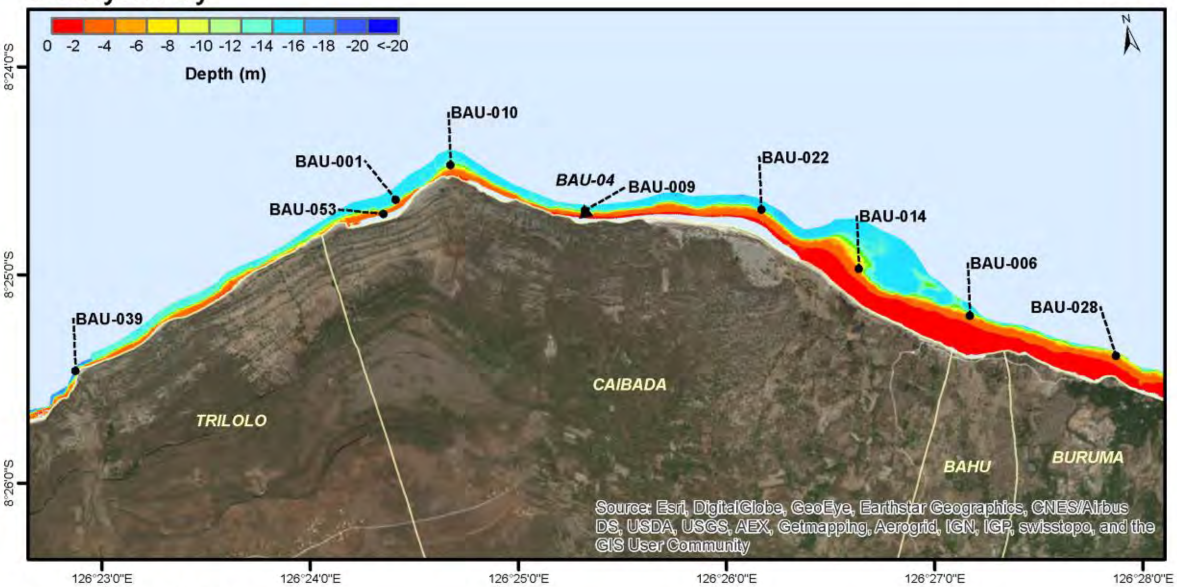

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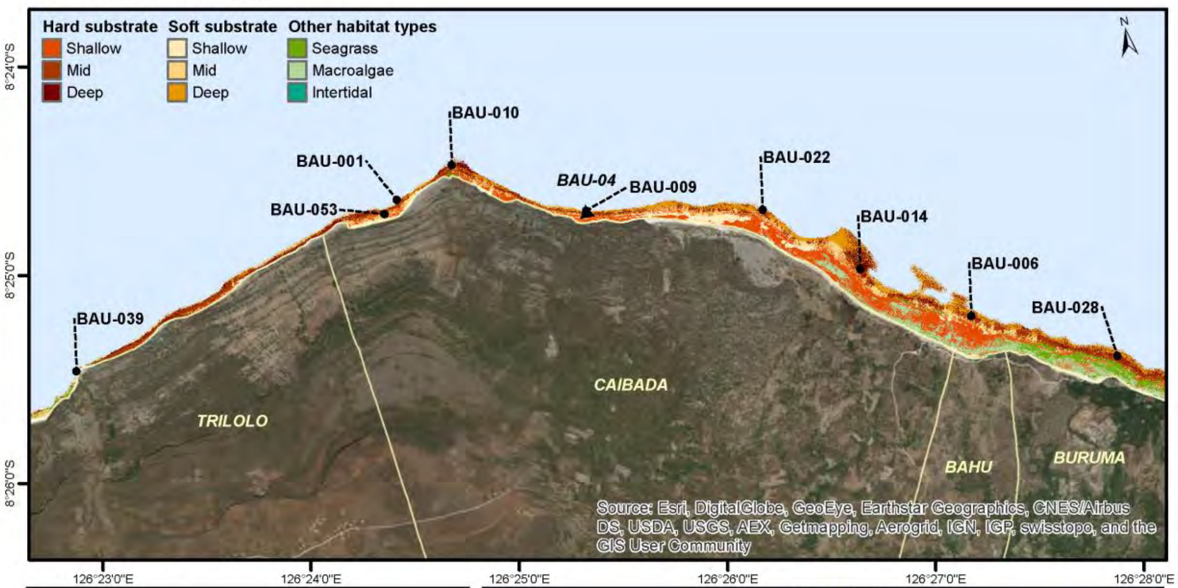

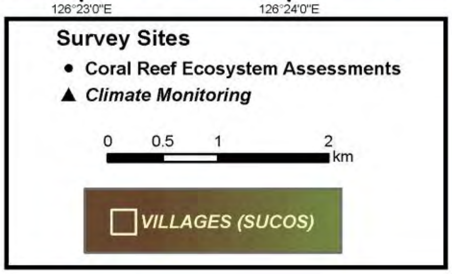

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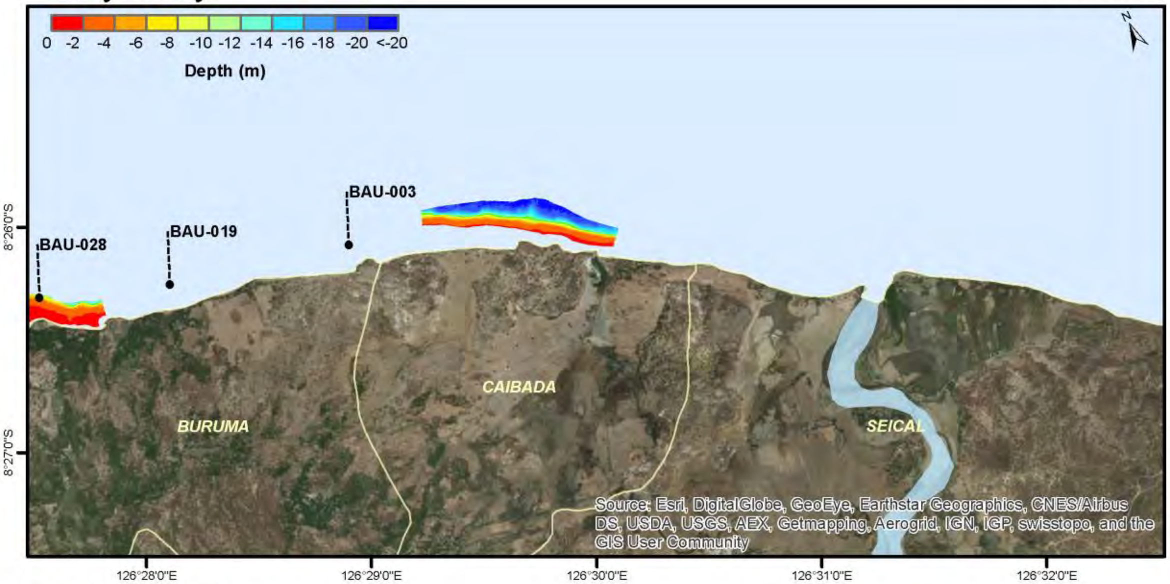
Bathymetry



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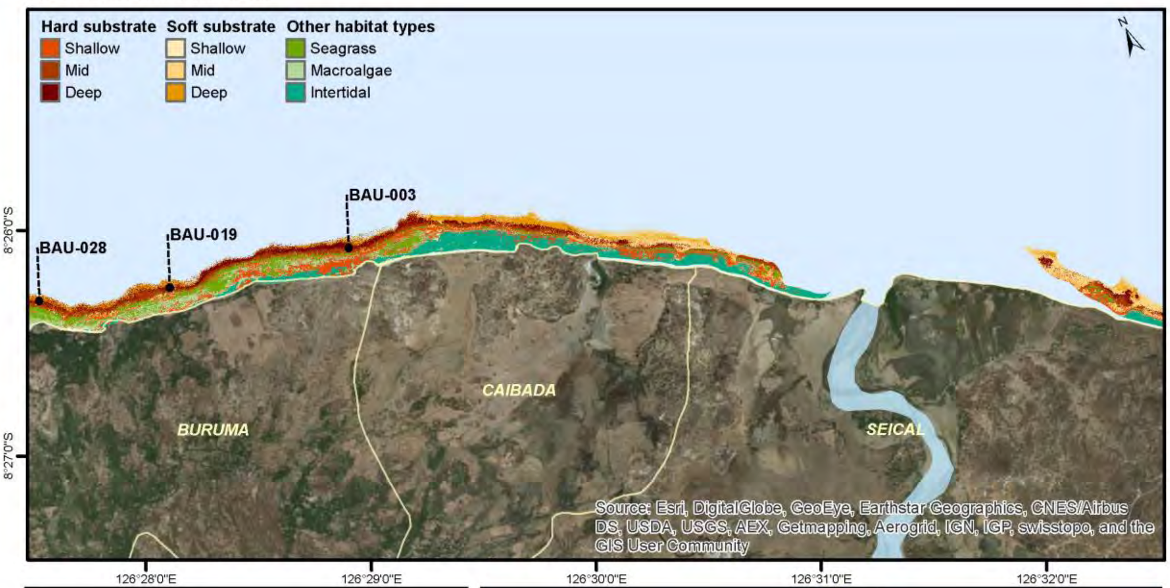

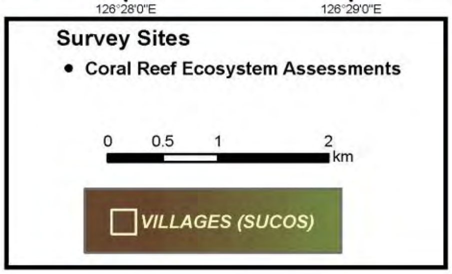

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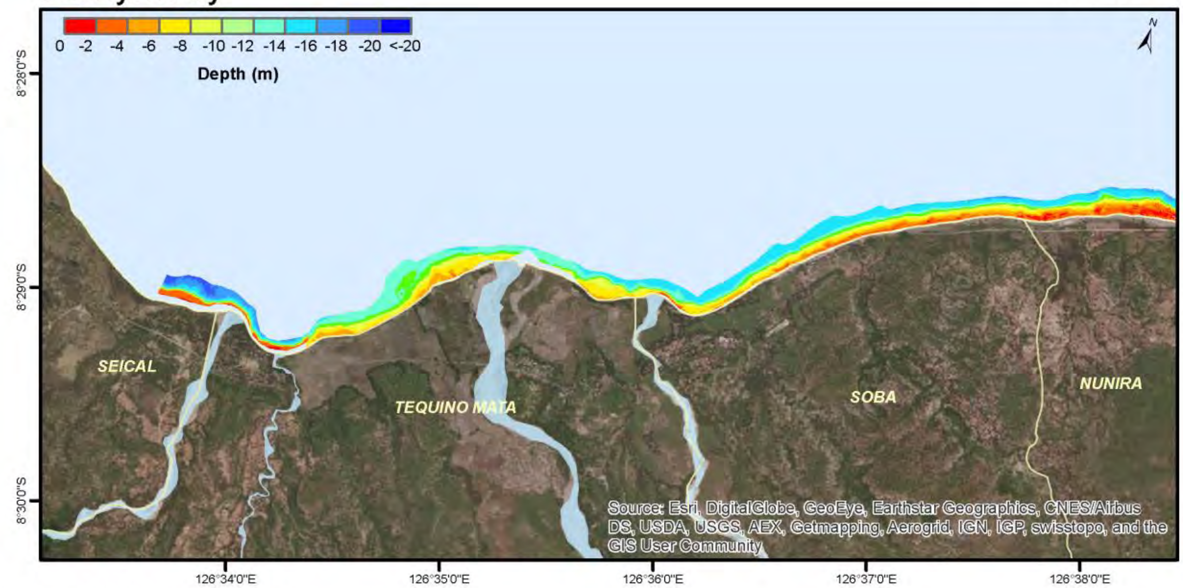

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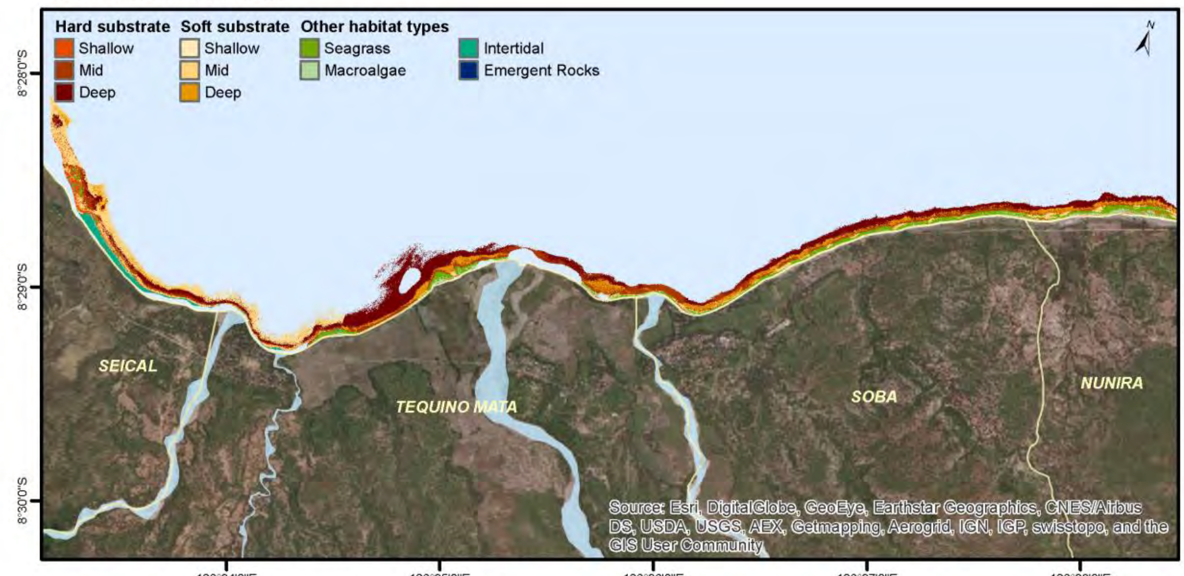

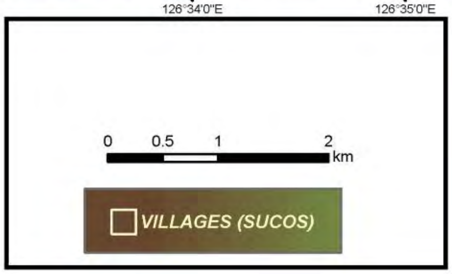

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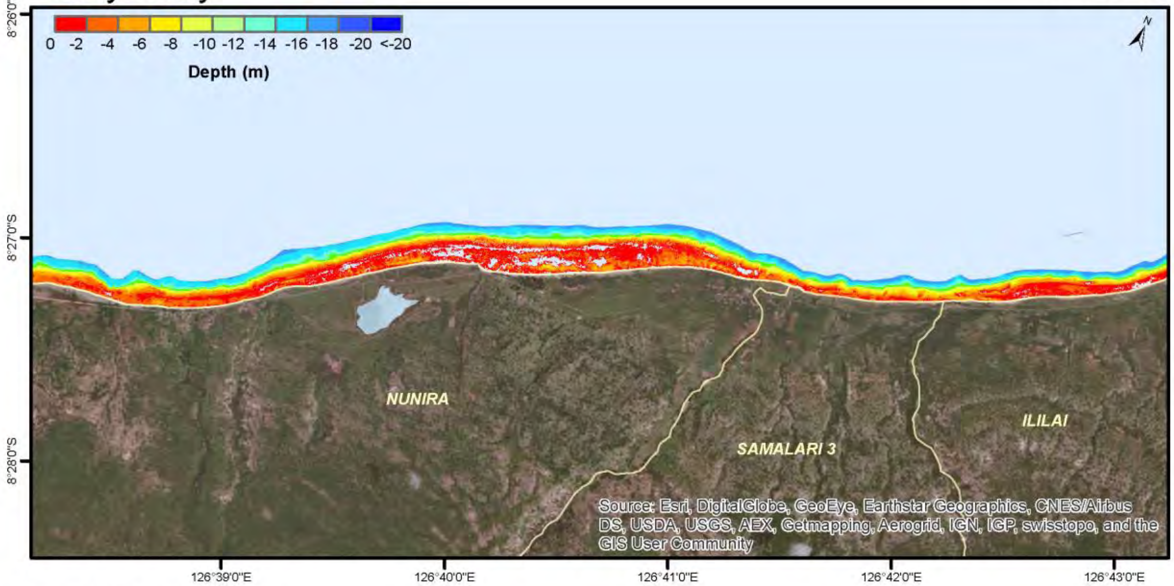
Bathymetry



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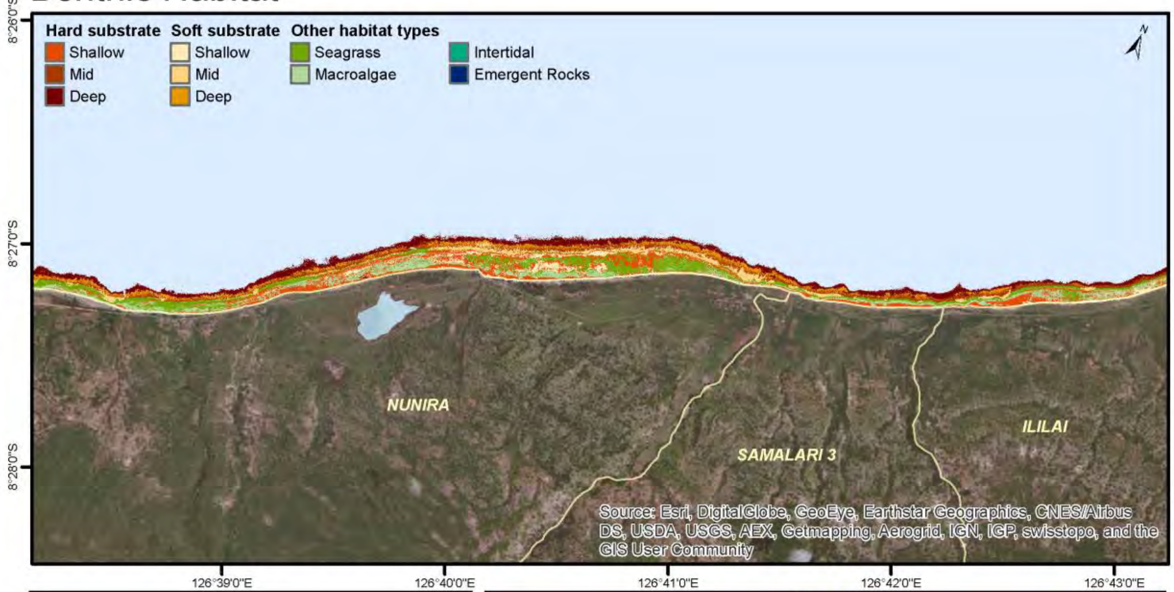

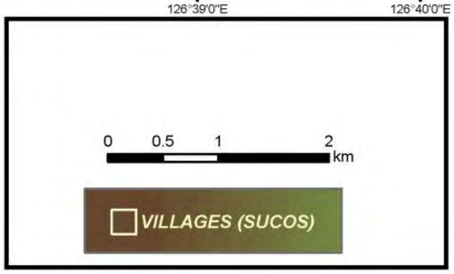

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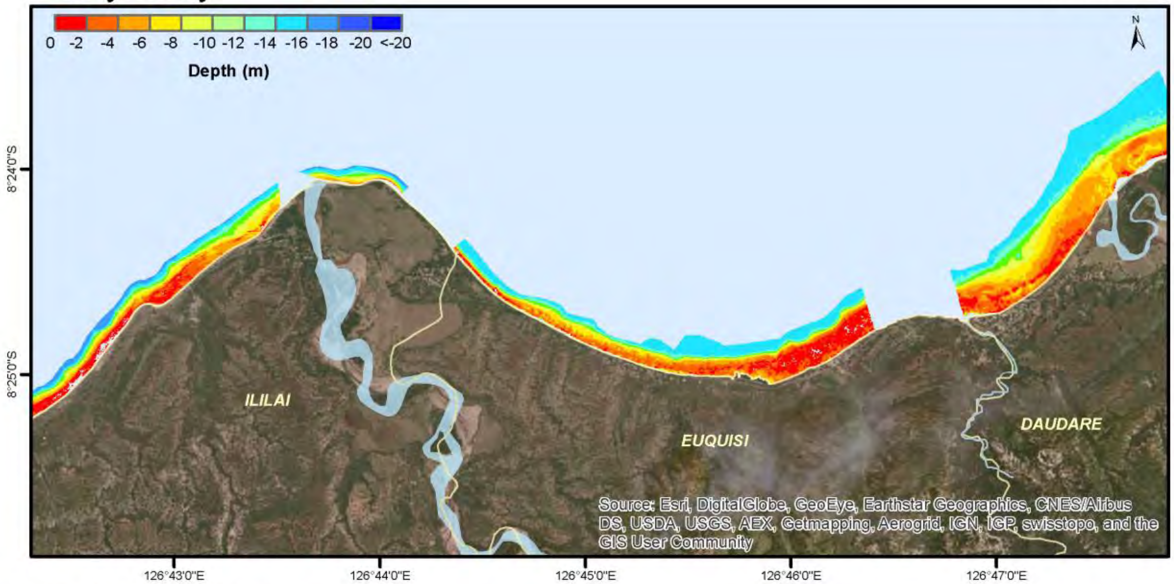

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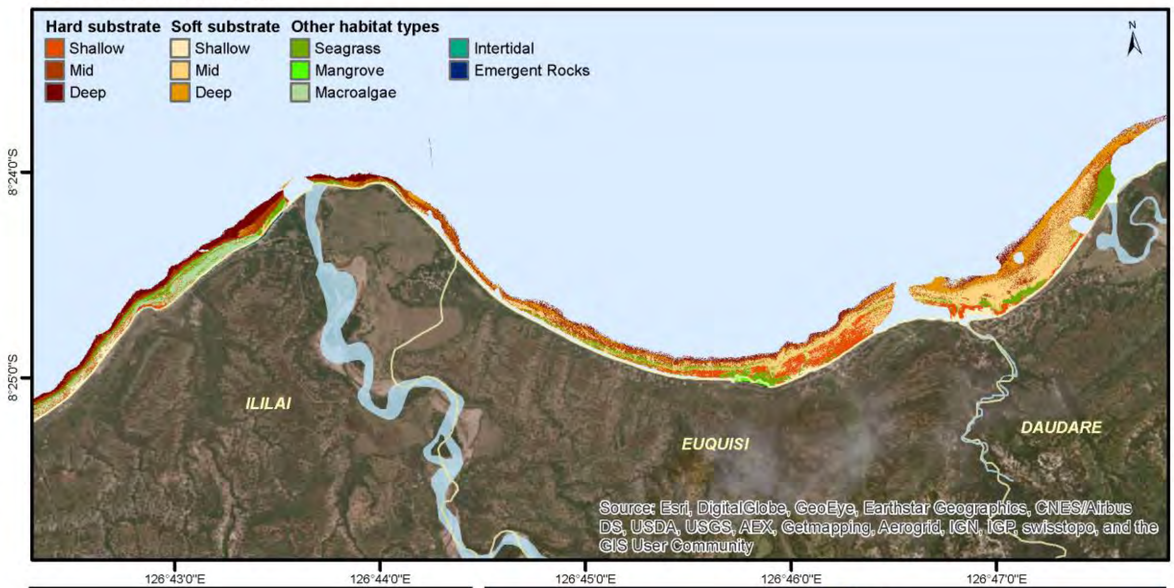

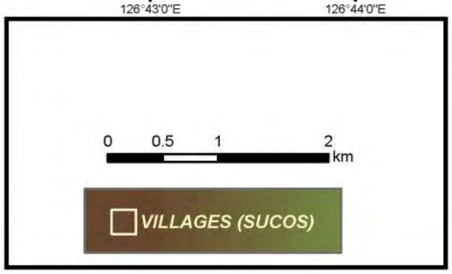

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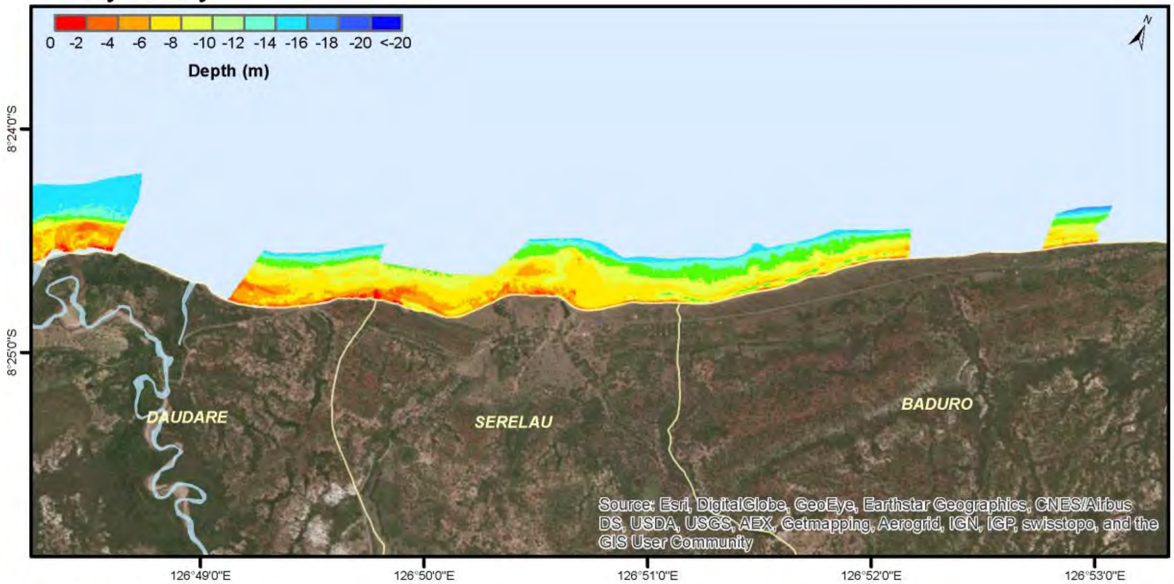

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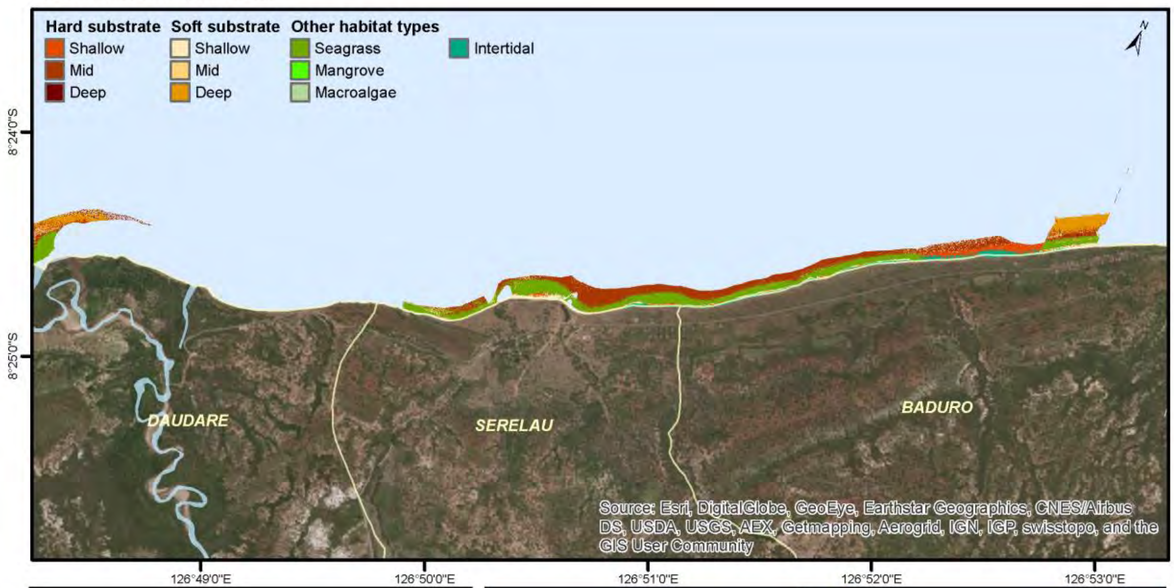

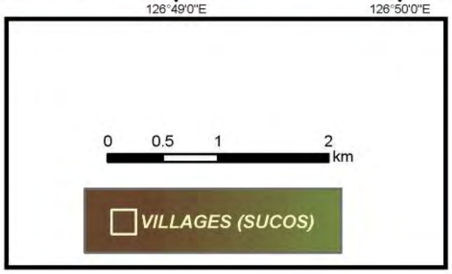

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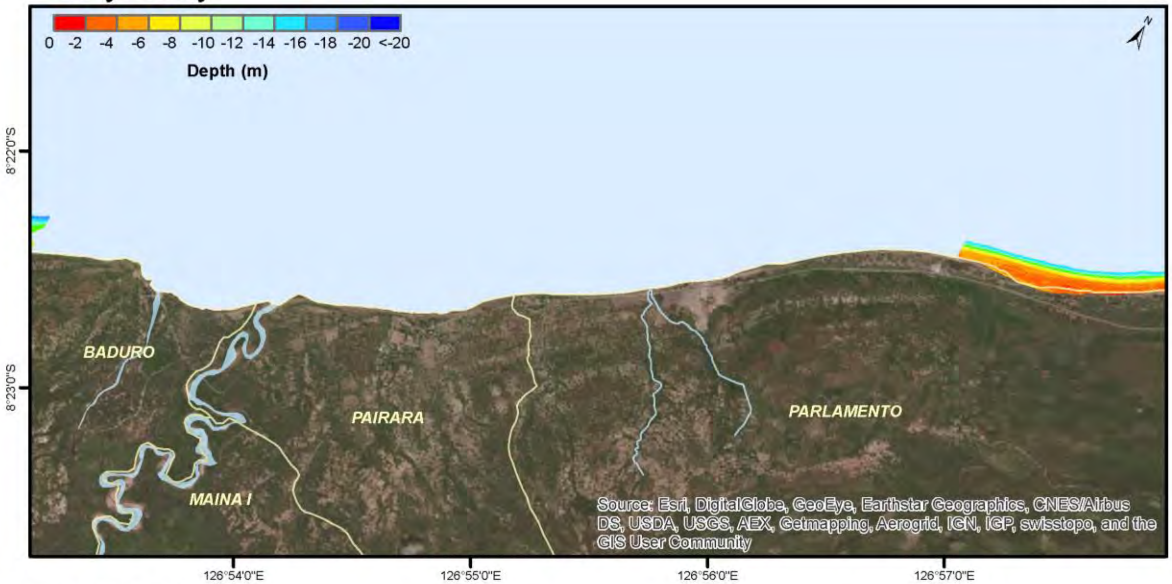
Bathymetry



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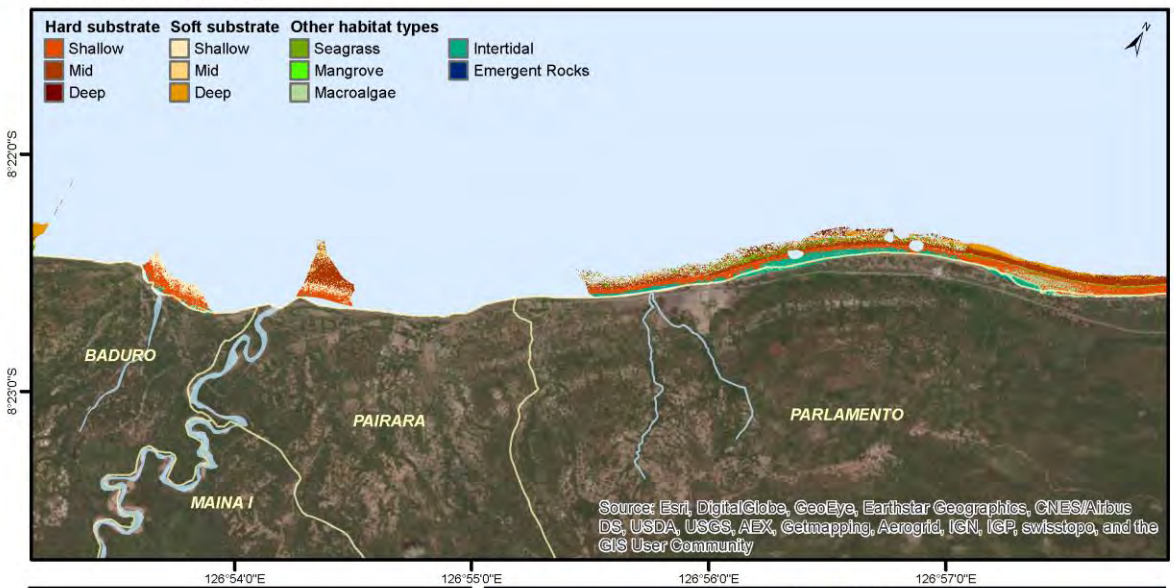

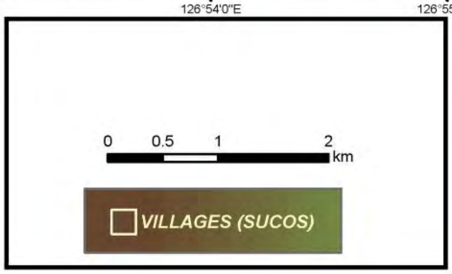

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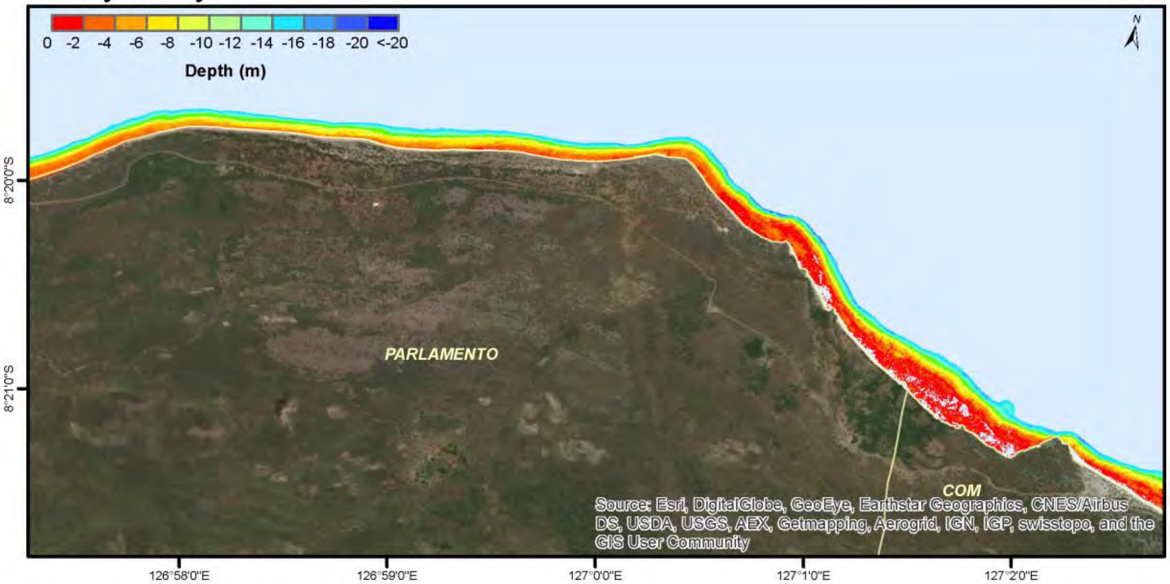

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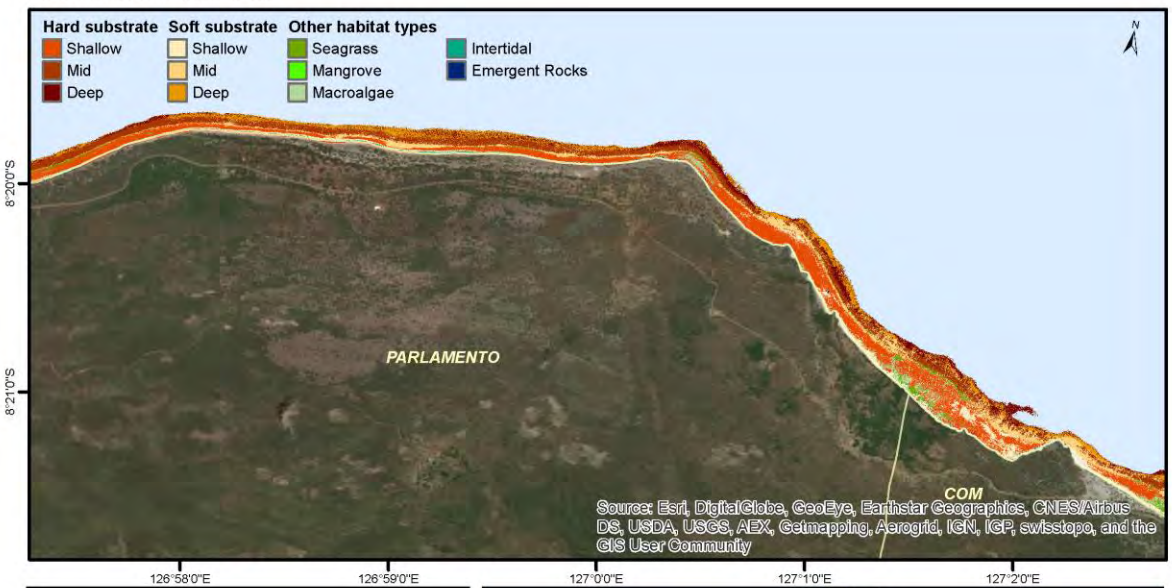

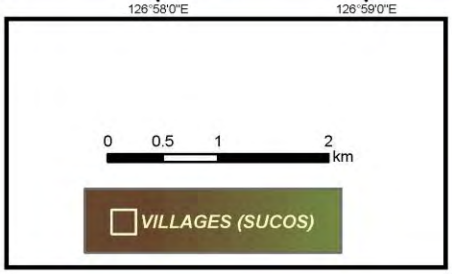

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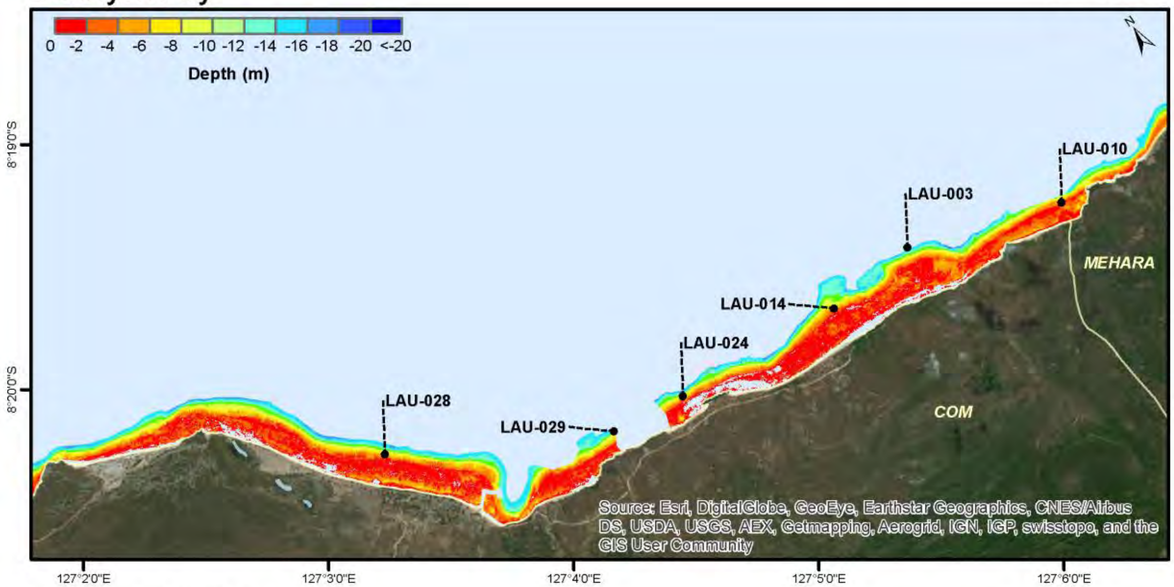
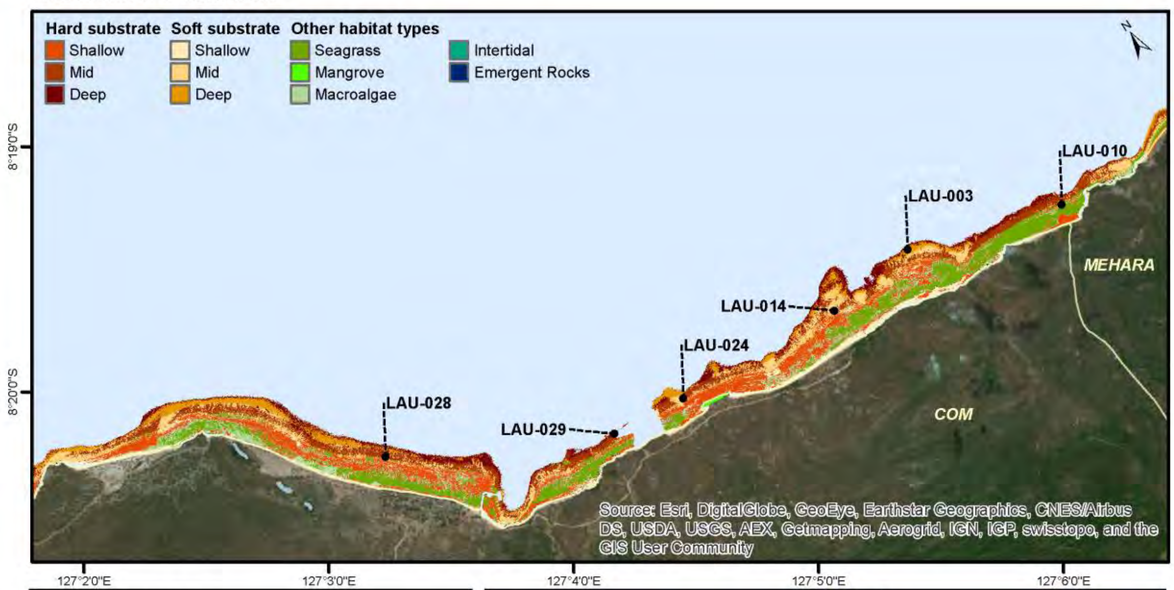
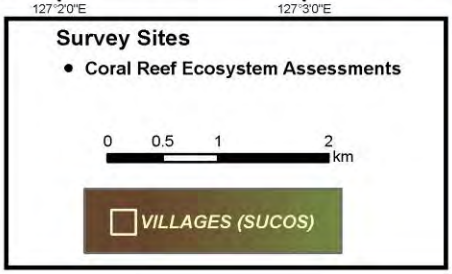
Bathymetry



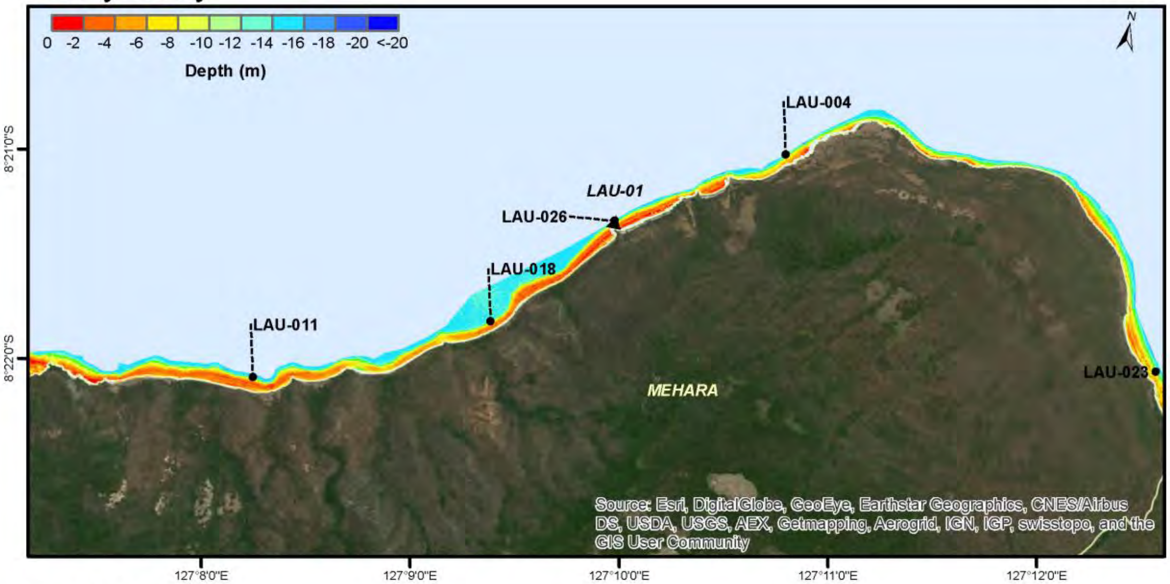
Benthic Habitat



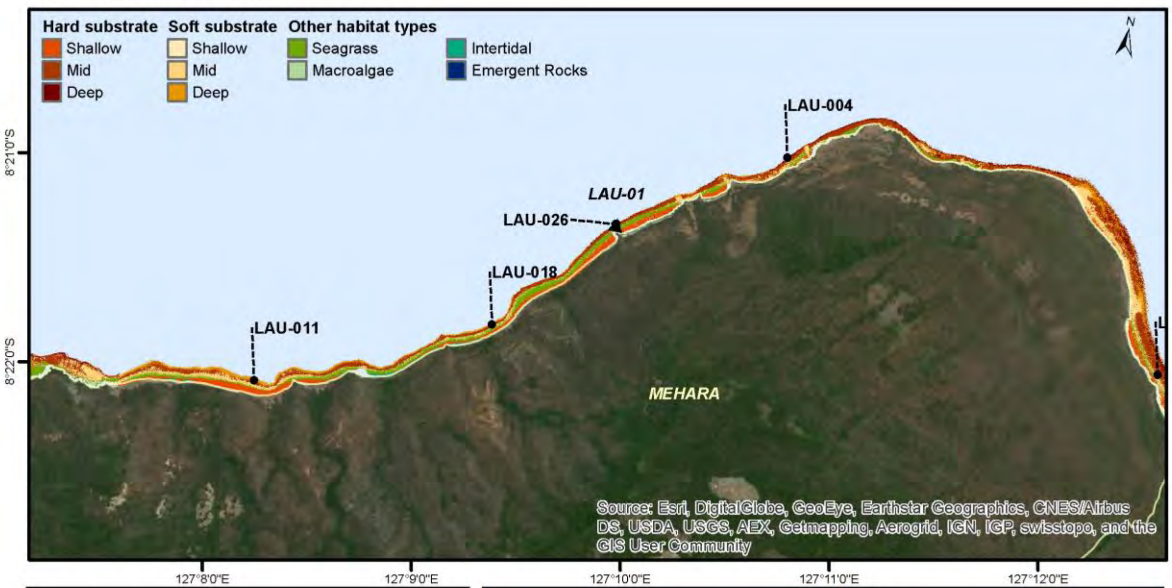


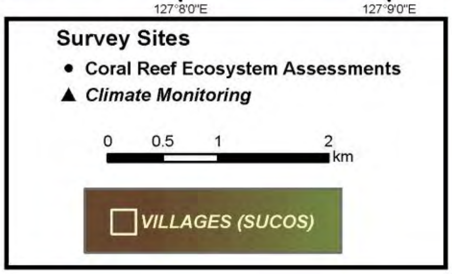
DISTRICT: Lautem
TILE: 41

Bathymetry



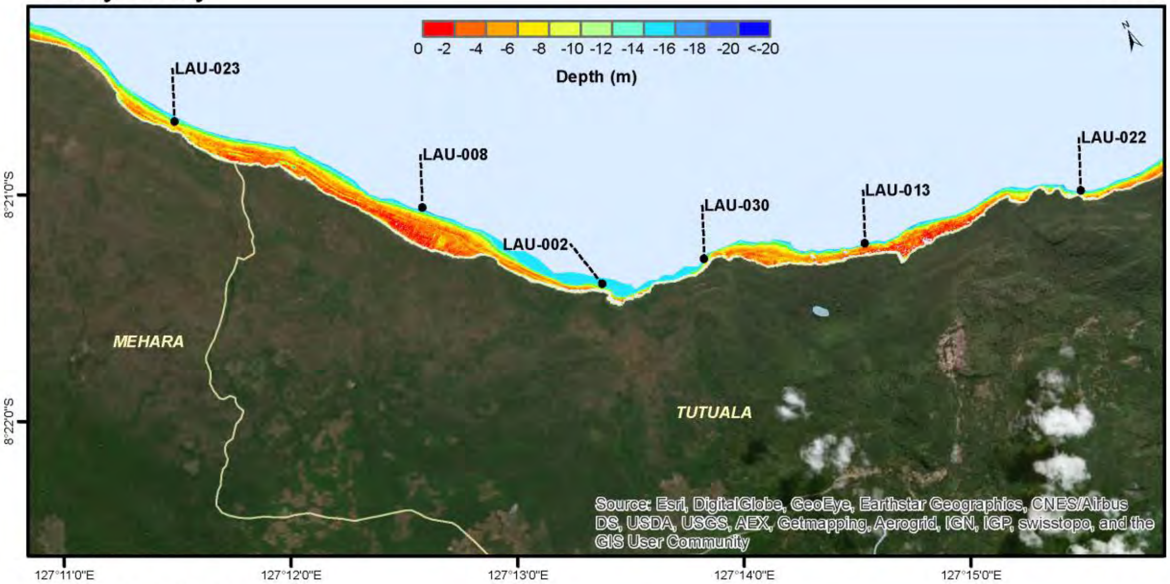
Benthic Habitat



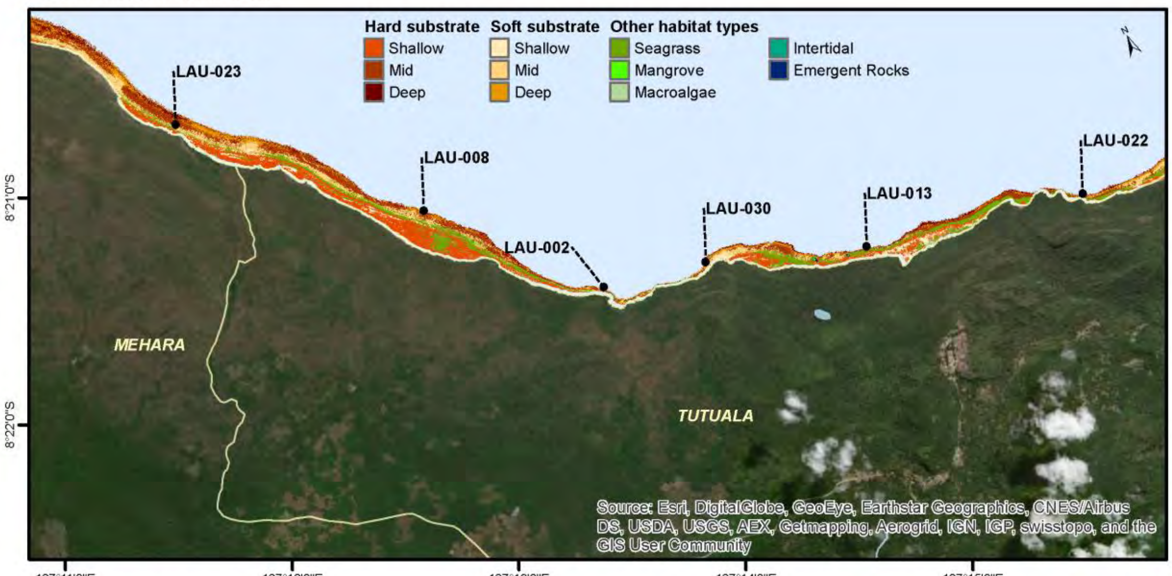


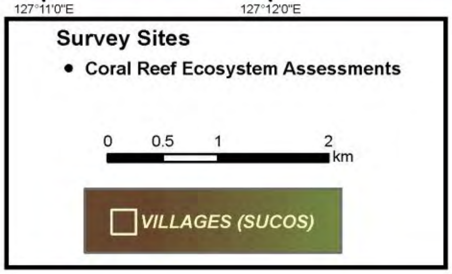
DISTRICT: Lautem
TILE: 42

Bathymetry



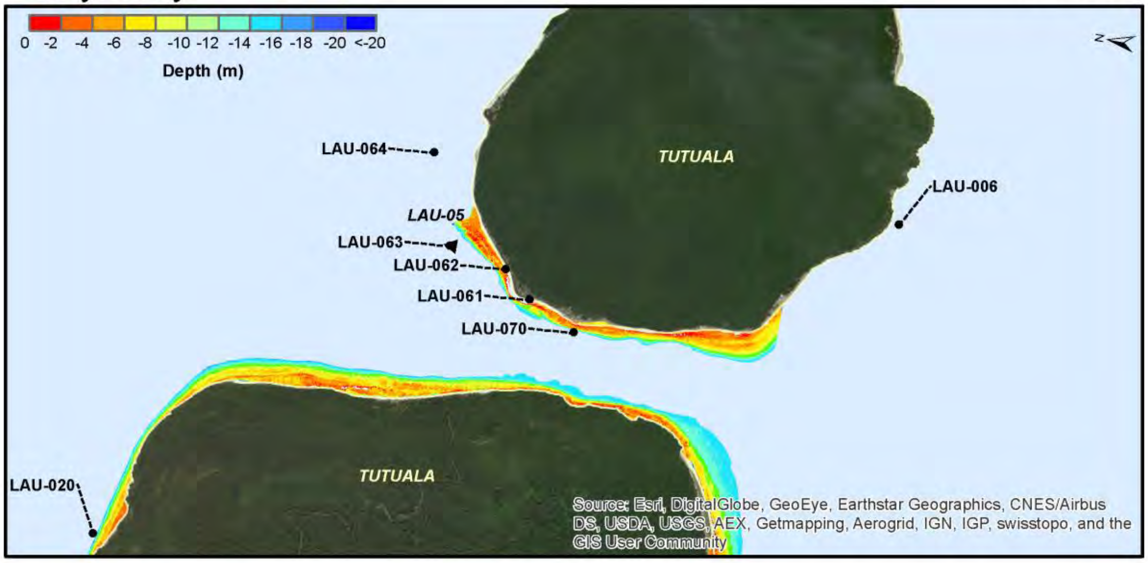
Benthic Habitat



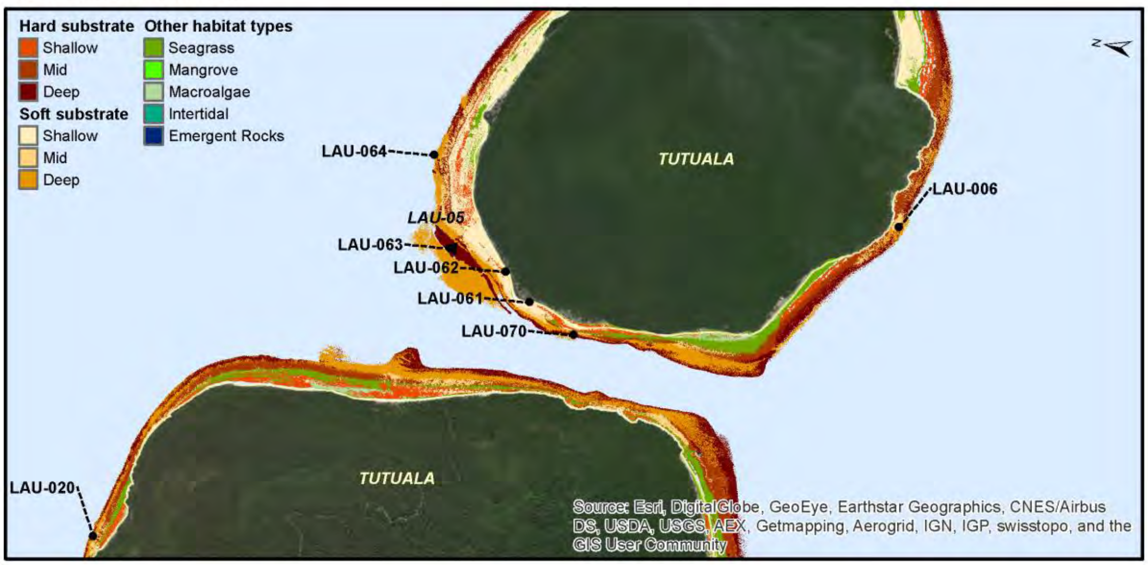


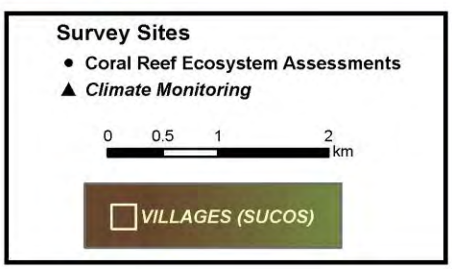
DISTRICT: Lautem
TILE: 43

Bathymetry



Benthic Habitat

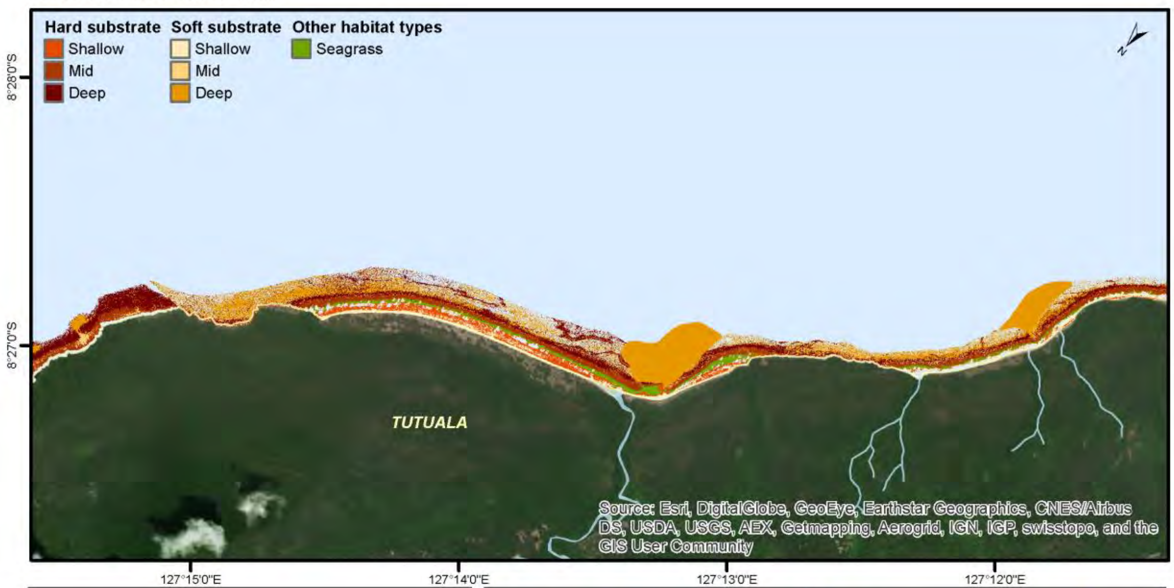


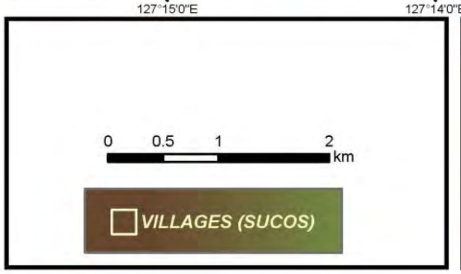


DISTRICT: Lautem
TILE: 44

Bathymetry

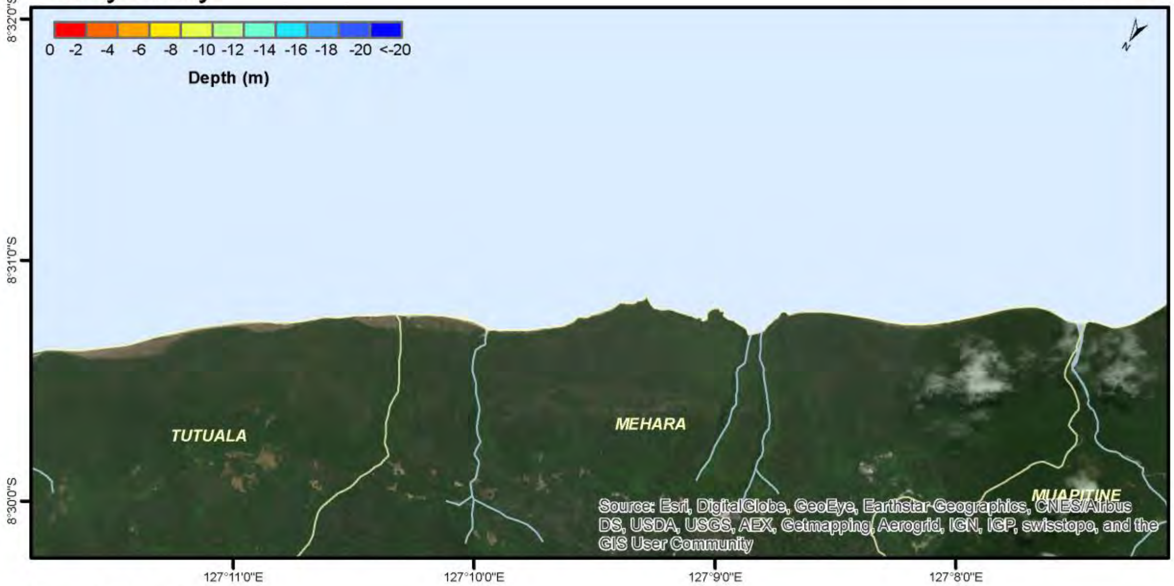
Benthic Habitat



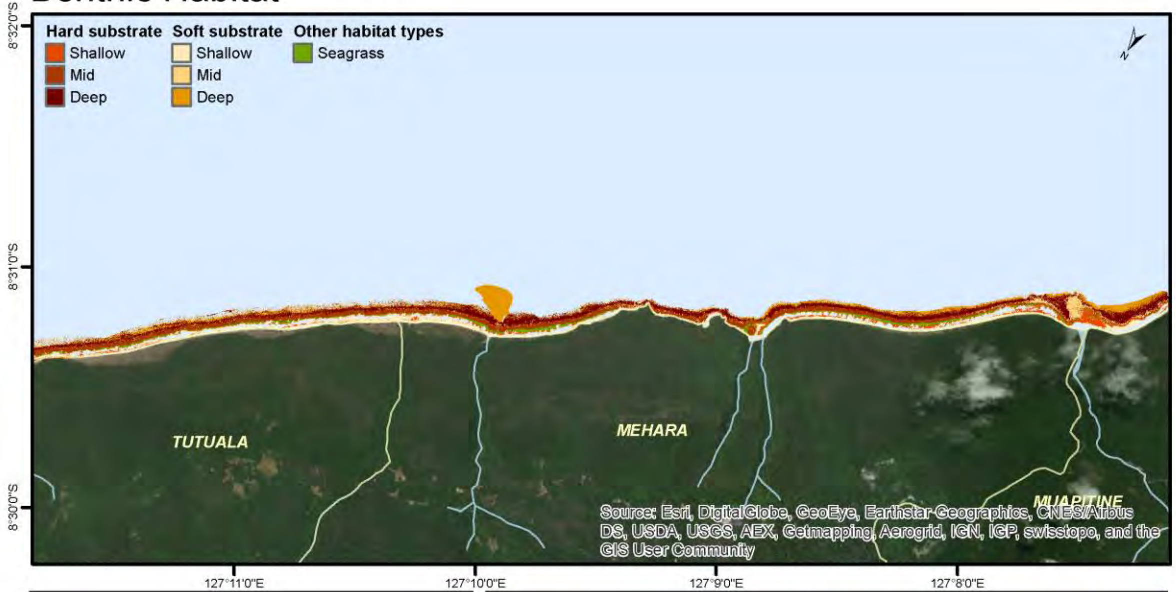


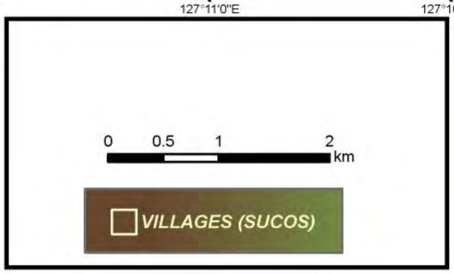
DISTRICT: Lautem
TILE: 45

Bathymetry



Benthic Habitat

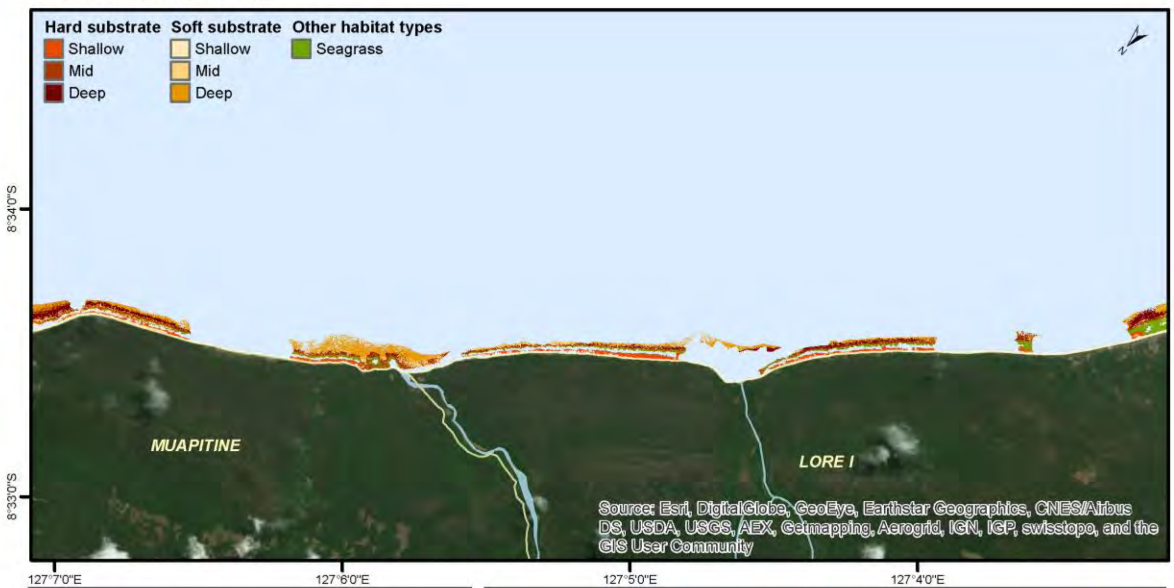


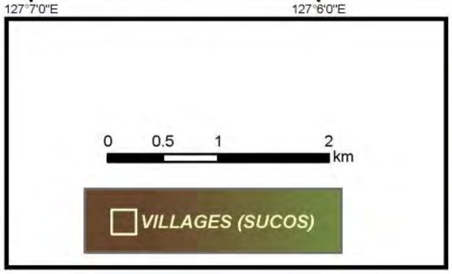


DISTRICT: Lautem
TILE: 46

Bathymetry

Benthic Habitat

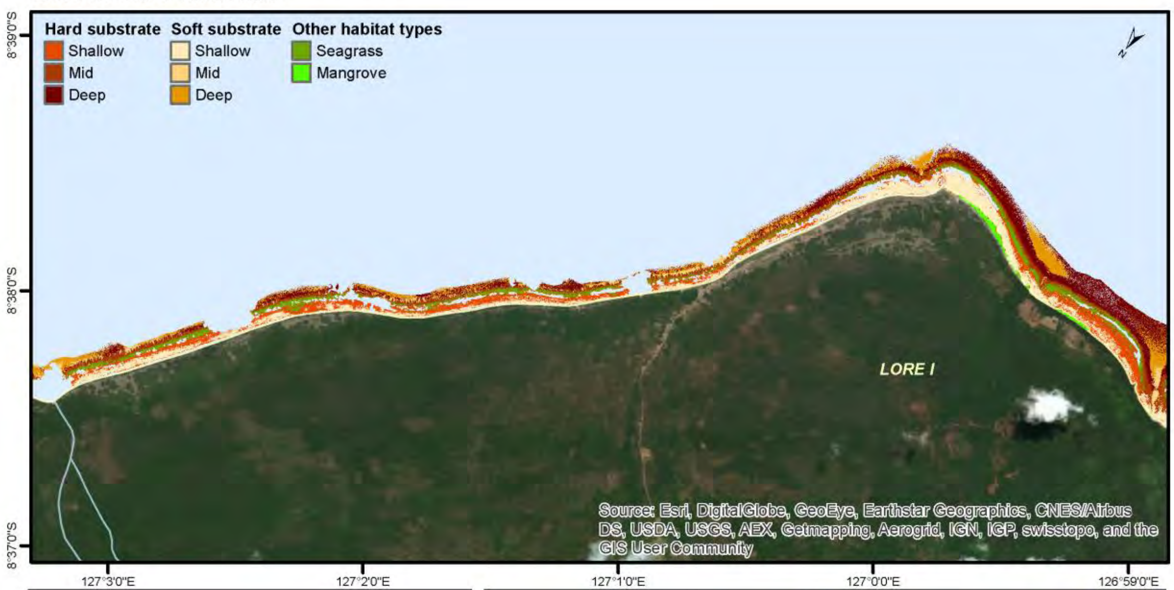


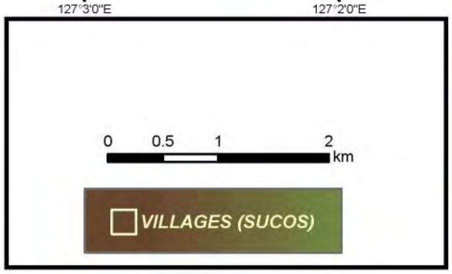


DISTRICT: Lautem
TILE: 47

Bathymetry

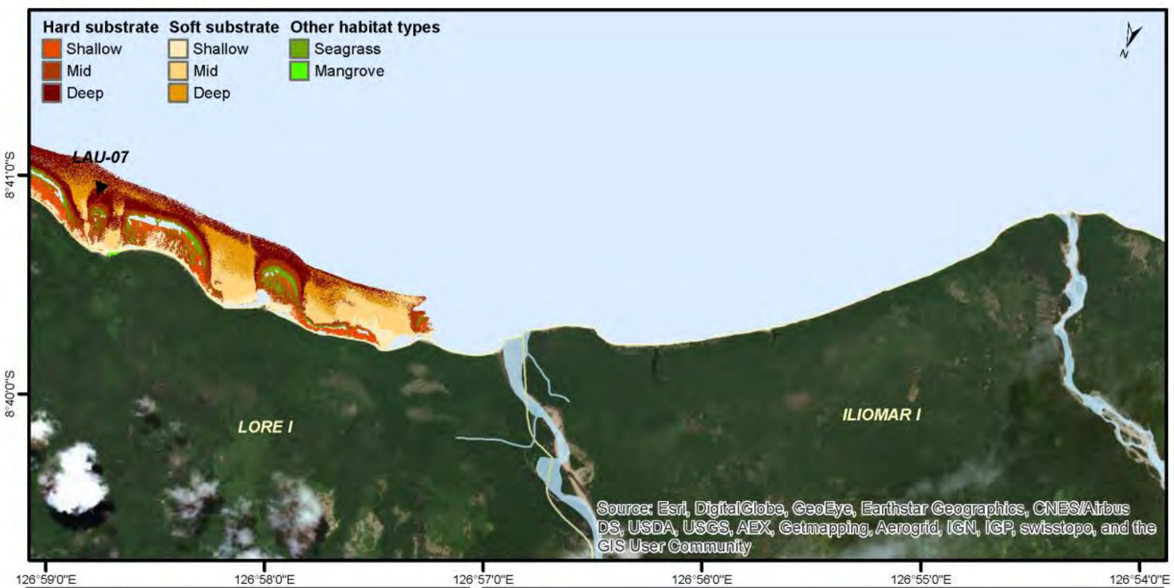
Benthic Habitat

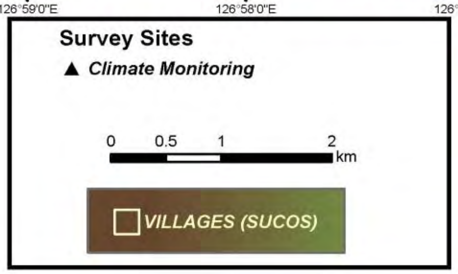




Bathymetry

Benthic Habitat

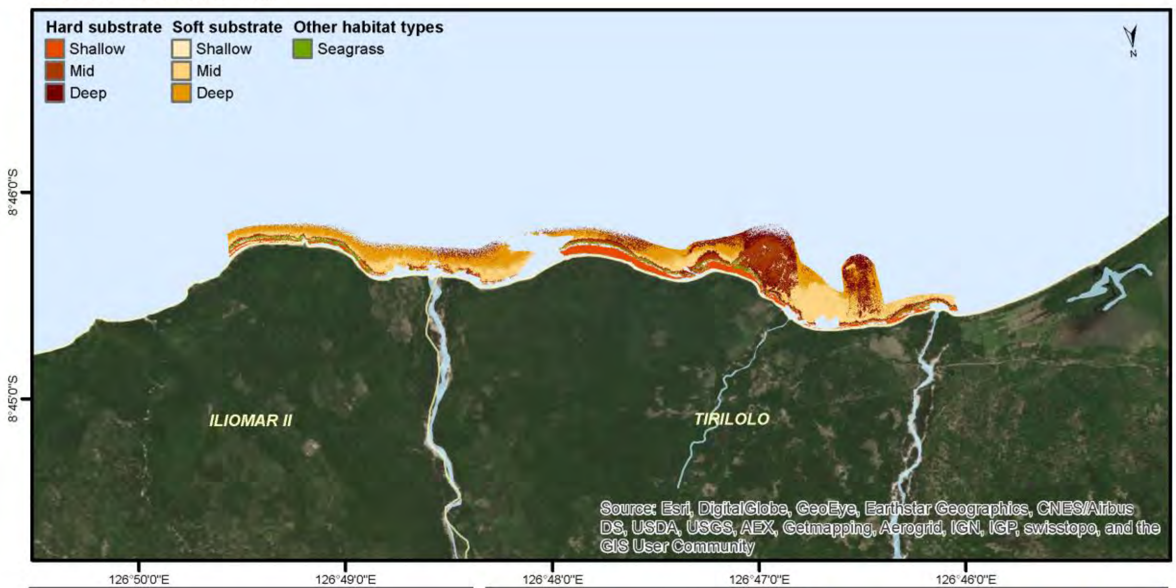


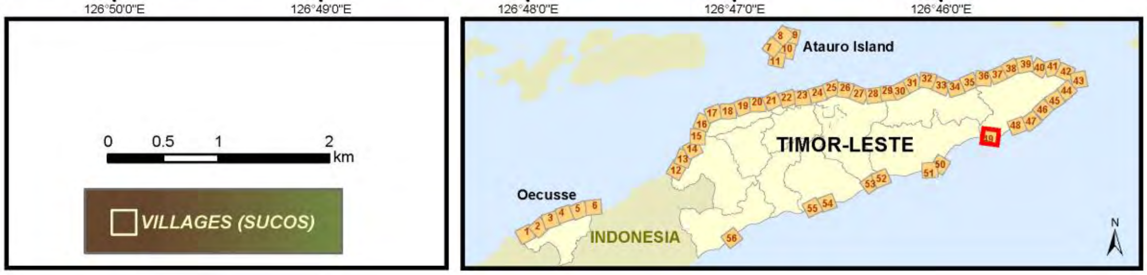


DISTRICT: Lautem
TILE: 49

Bathymetry

Benthic Habitat

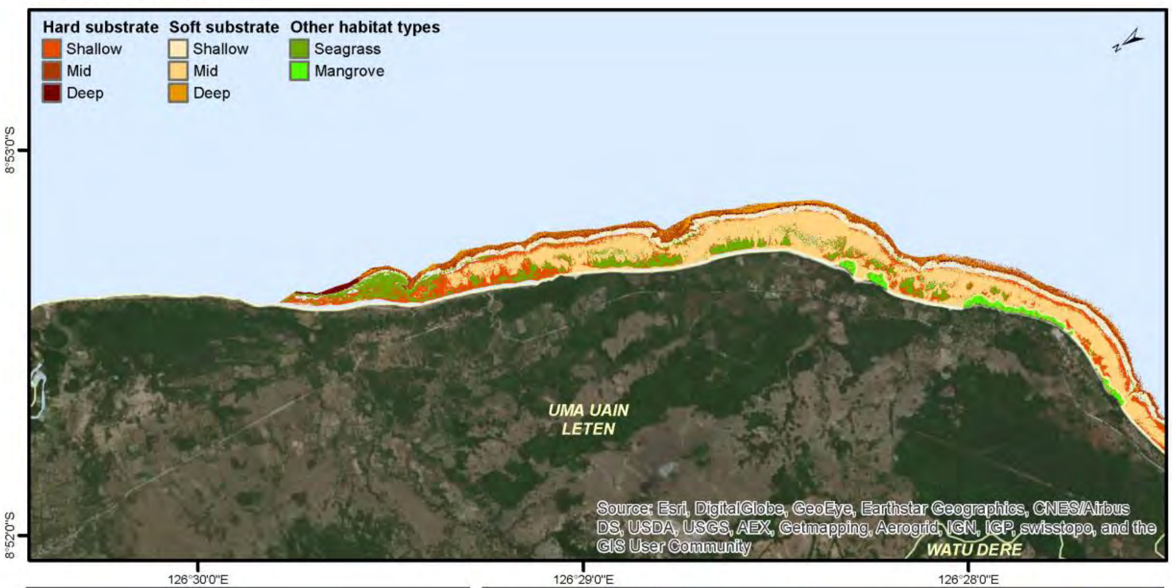


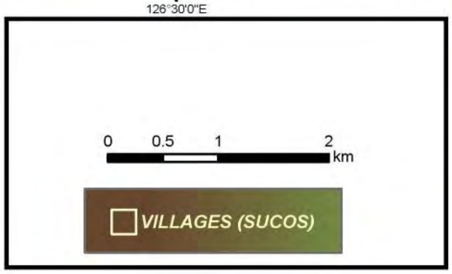


DISTRICT: Viqueque
TILE: 50

Bathymetry

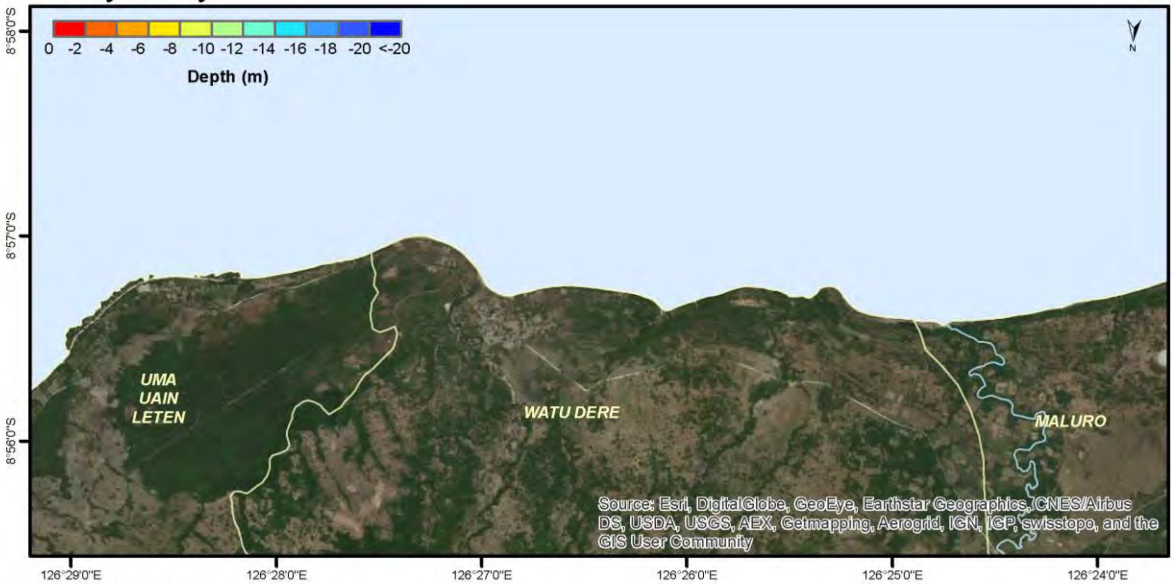
Benthic Habitat



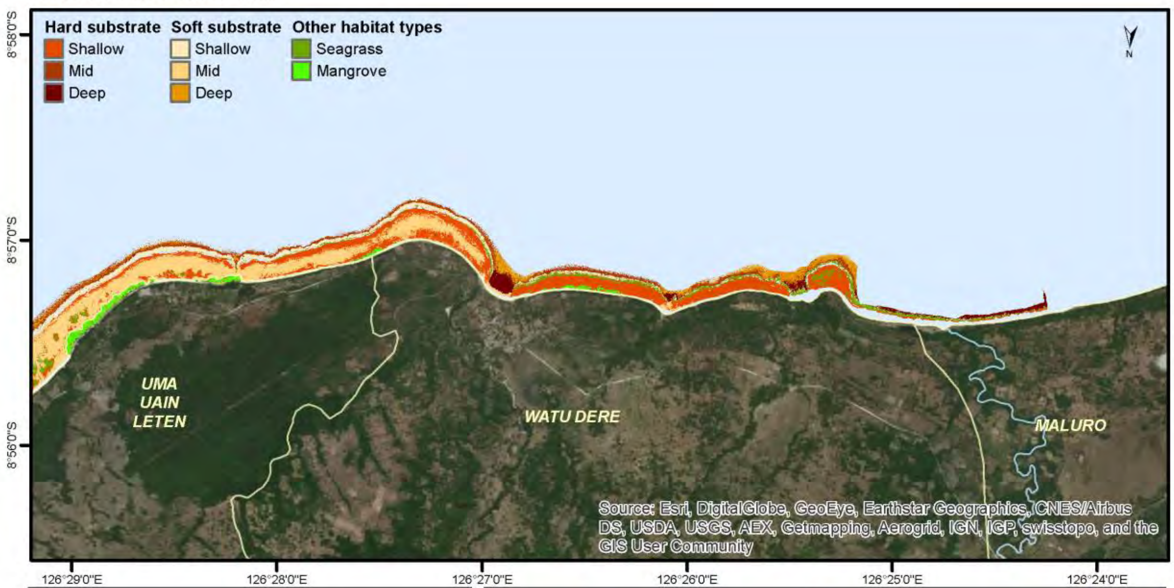


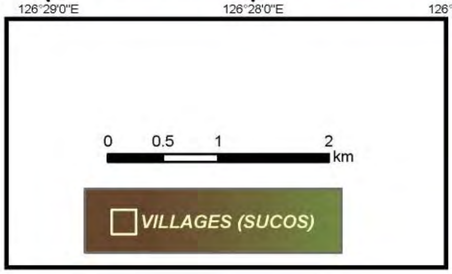
DISTRICT: Viqueque
TILE: 51

Bathymetry

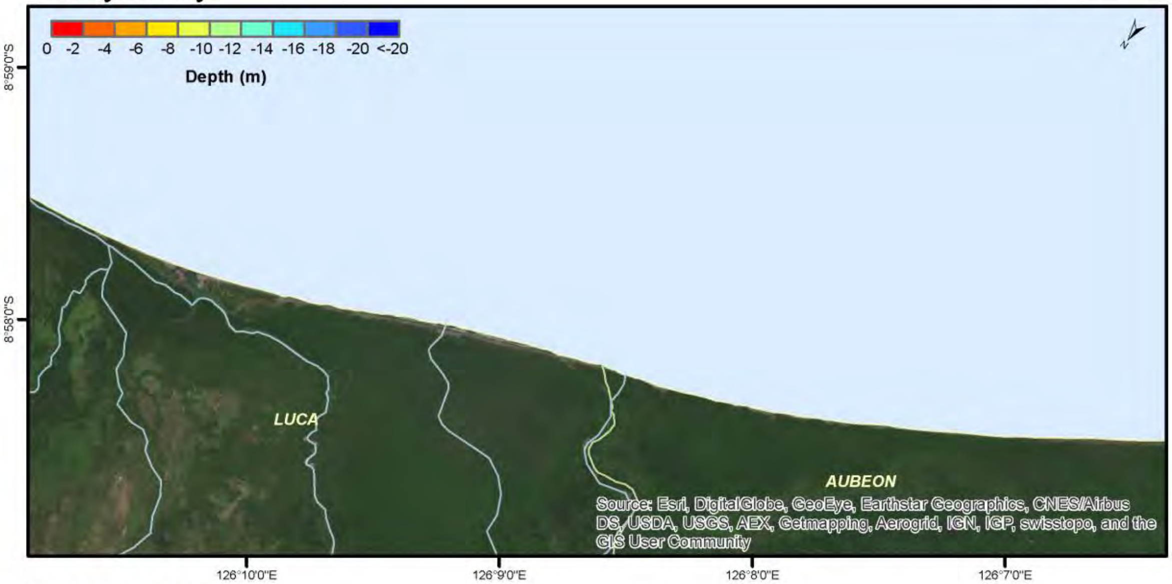


Benthic Habitat

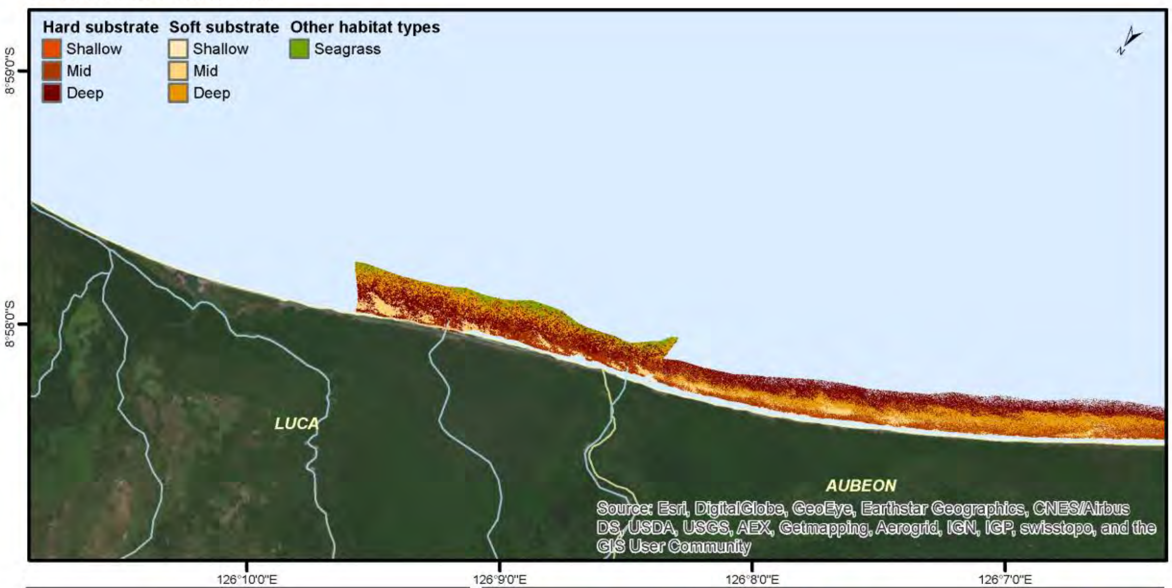


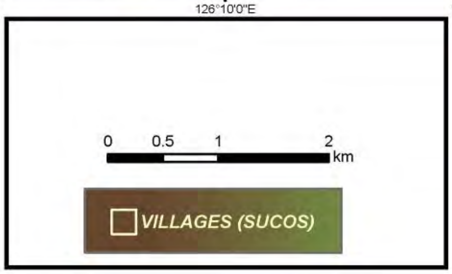


Bathymetry



Benthic Habitat

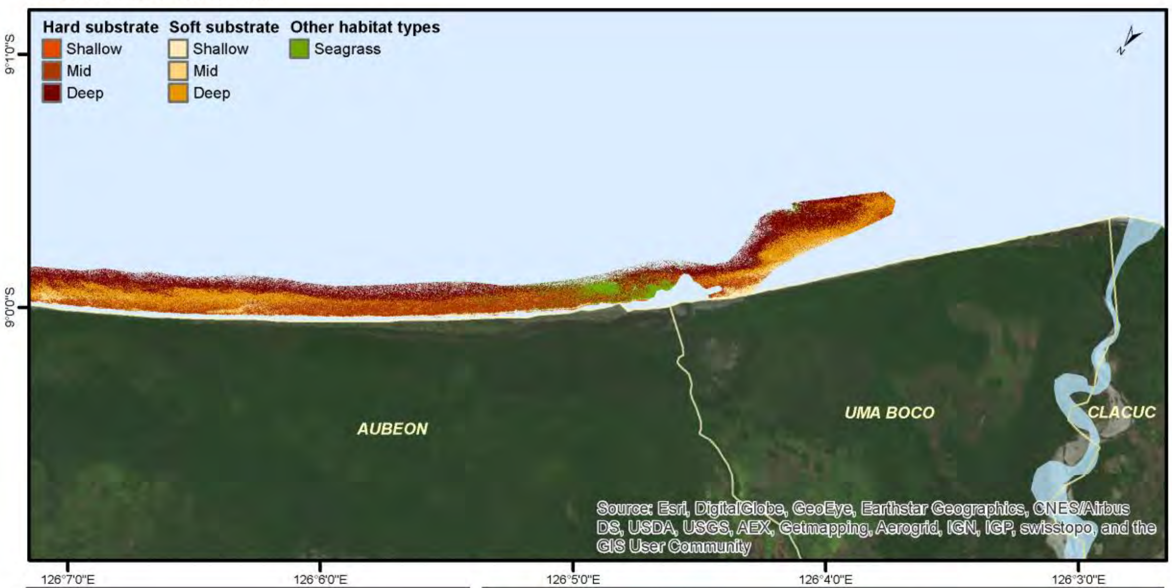


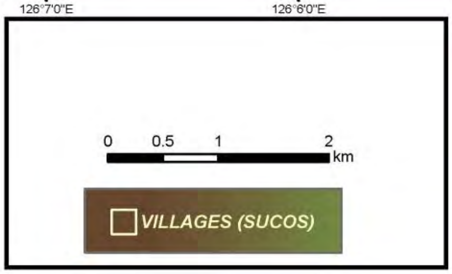


DISTRICT: Manatuto
TILE: 53

Bathymetry

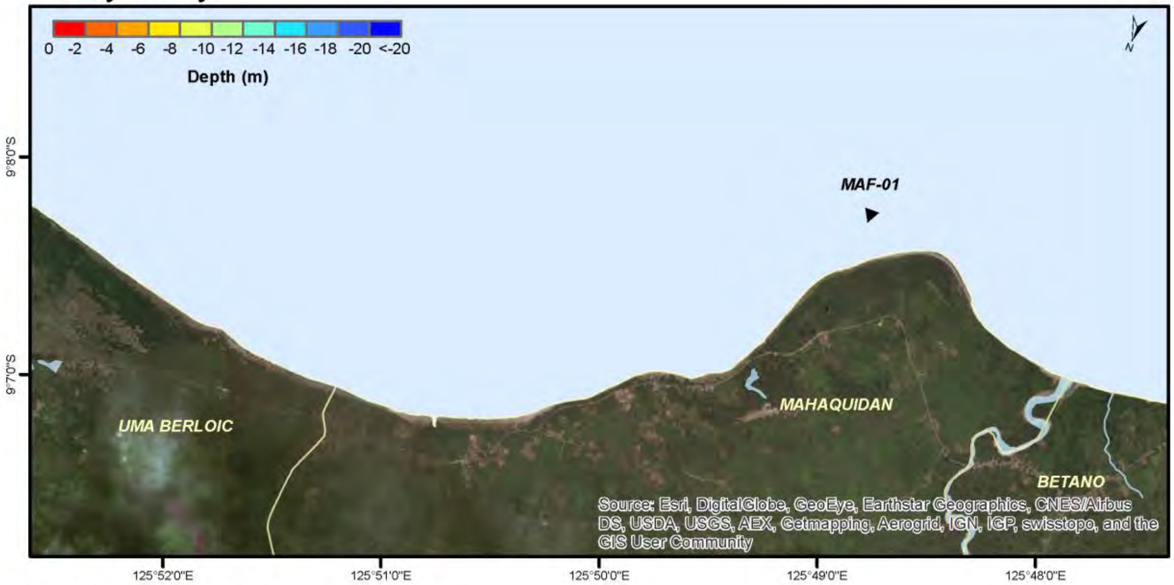
Benthic Habitat



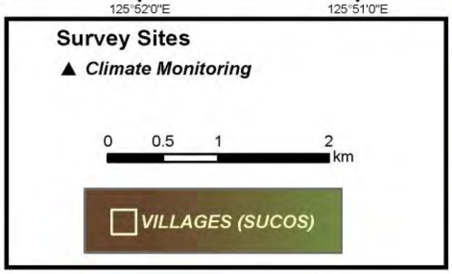


DISTRICT: Manufahi
TILE: 54

Bathymetry

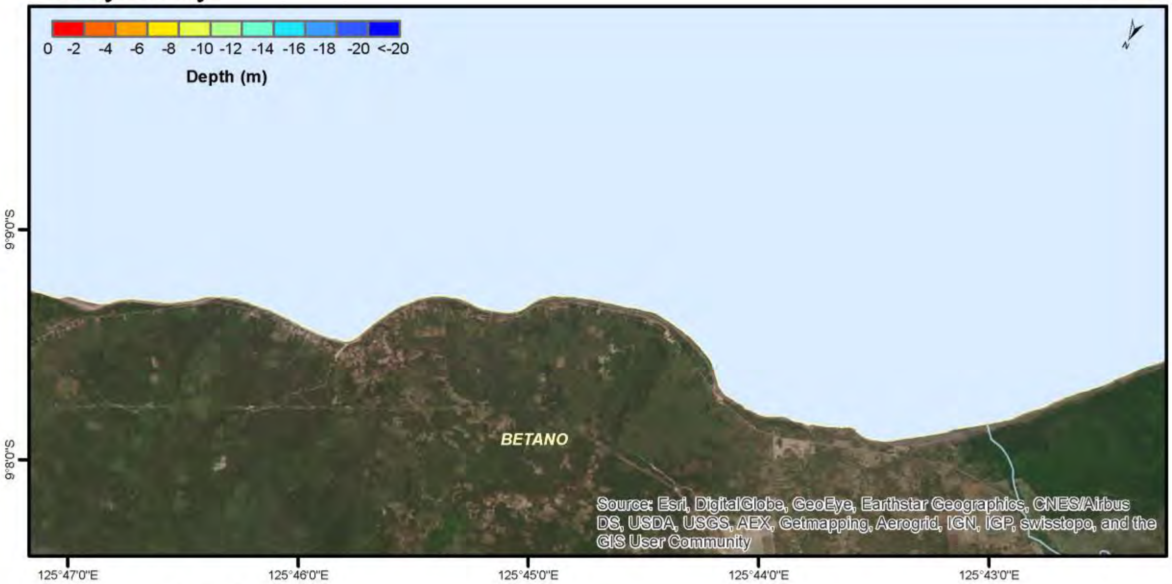


Benthic Habitat

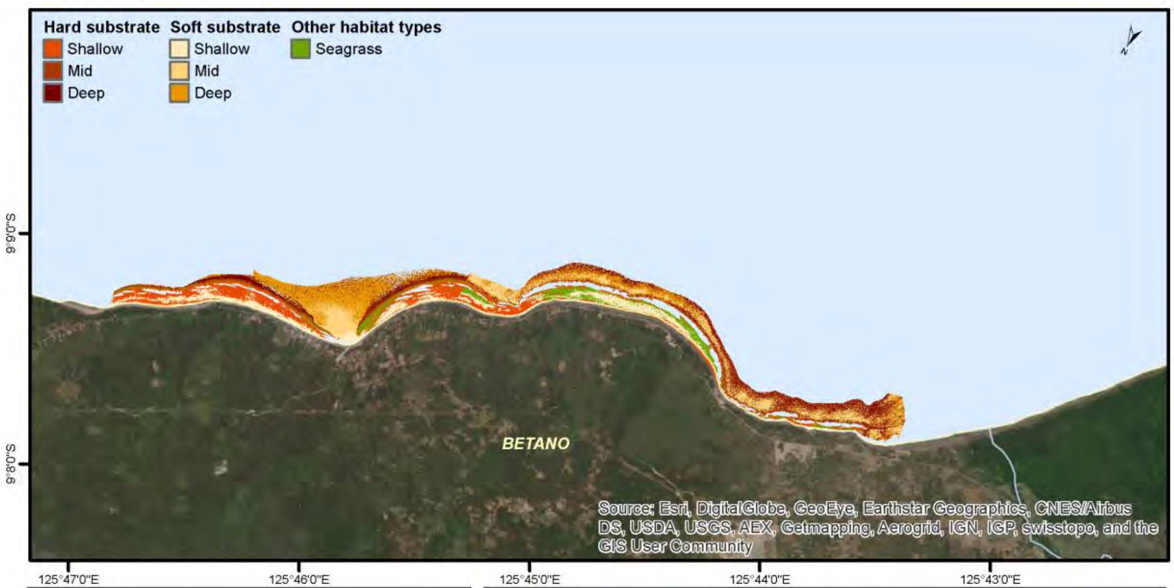


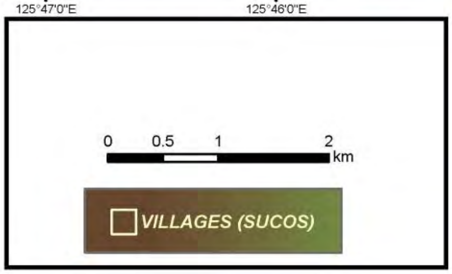
DISTRICT: Manufahi
TILE: 55

Bathymetry



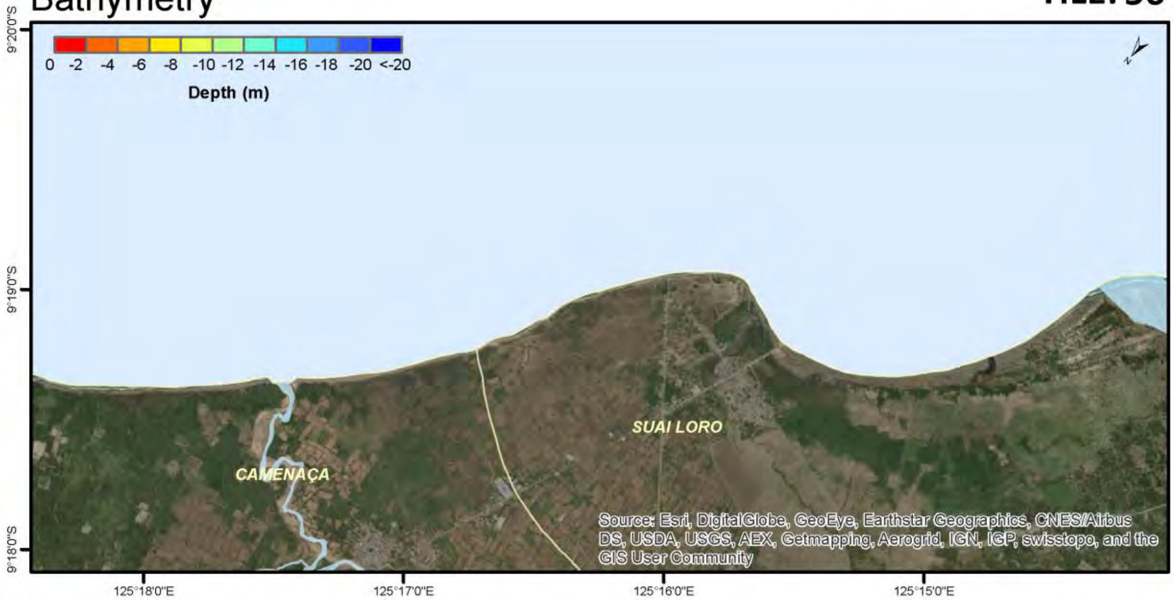
Benthic Habitat



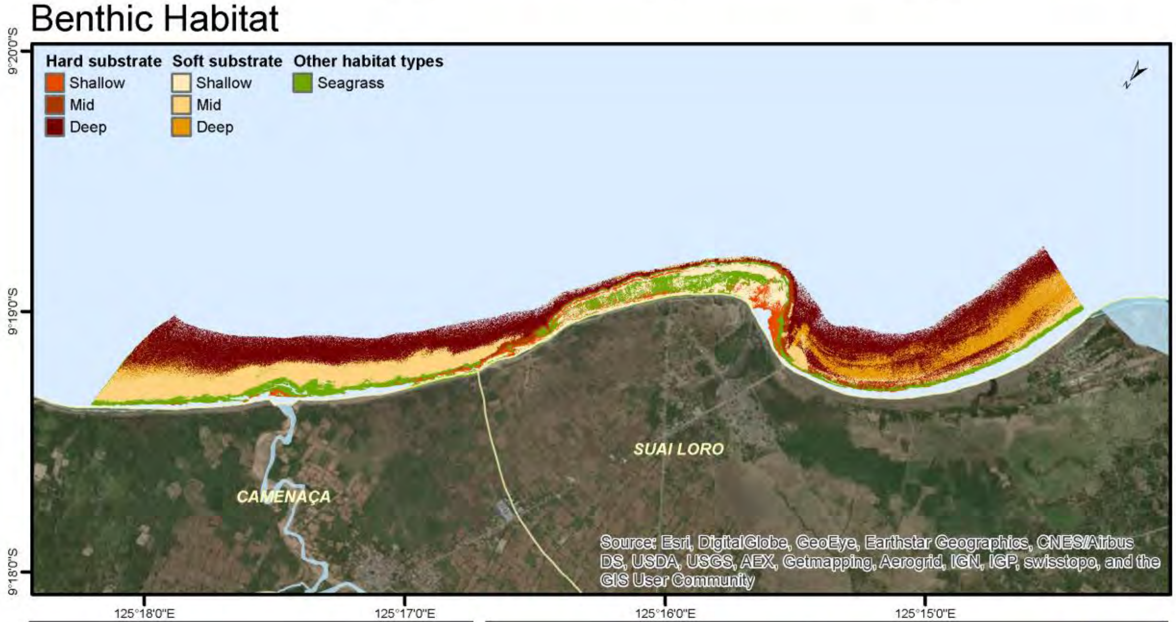


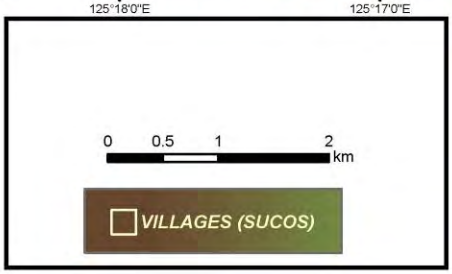
DISTRICT: Cova Lima
TILE: 56

Bathymetry



Benthic Habitat





Appendix E. Climate Monitoring Site Benthic Habitat Characterization

SITE: BOB-02

DEPTH: 14.0m

LOCATION: Batugade, Bobonaro

Figure 65. Landward view of Batugade from site BOB-02.

Figure 66. Underwater views of site BOB-02.

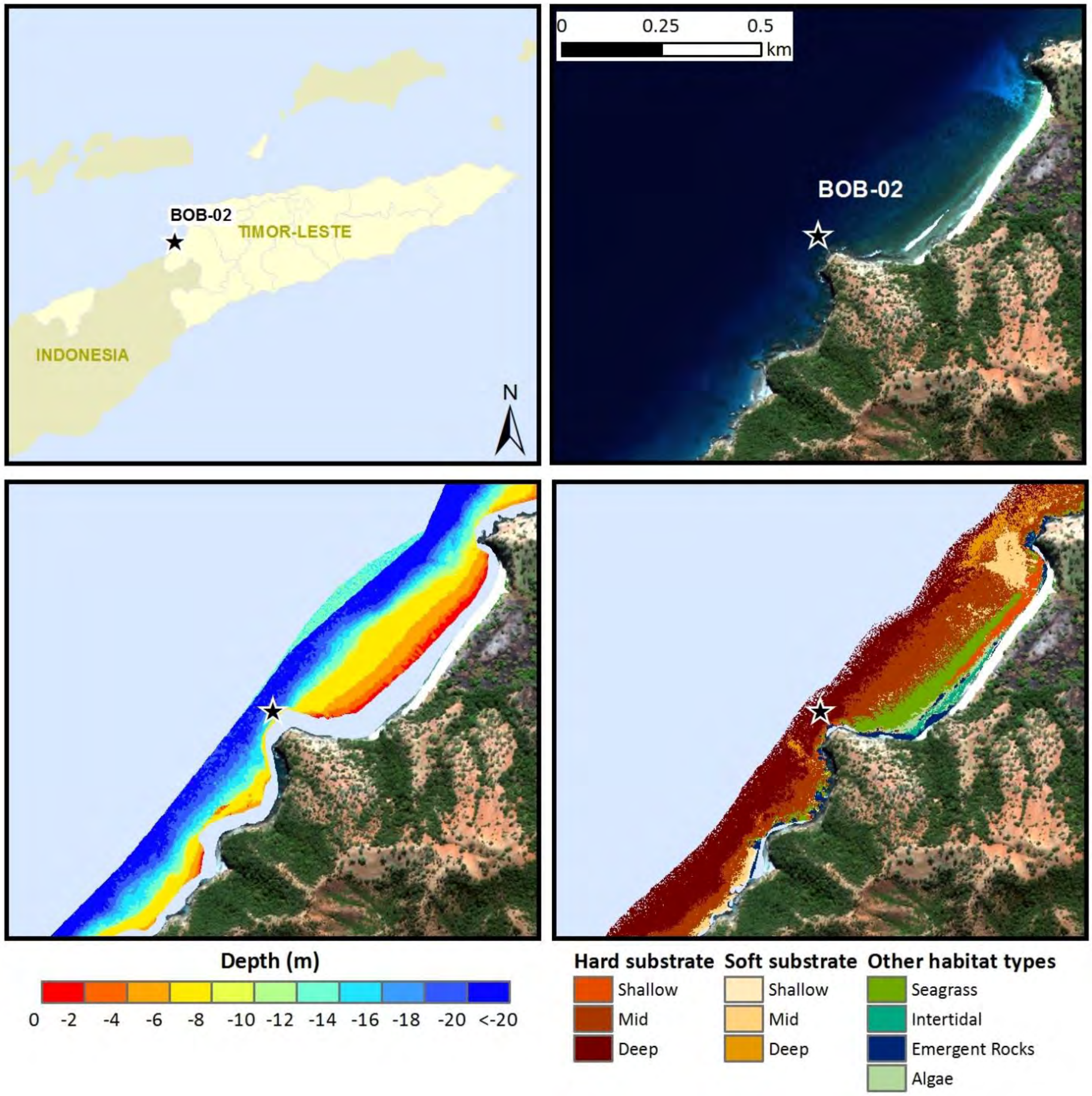


Figure 67. Maps of site BOB-02 (indicated by the black star), including WorldView-2 satellite image (*top right*), bathymetry (*bottom left*) and habitat classes (*bottom right*) derived from satellite imagery, and an overview map showing the location of the site in Timor-Leste (*top left*).

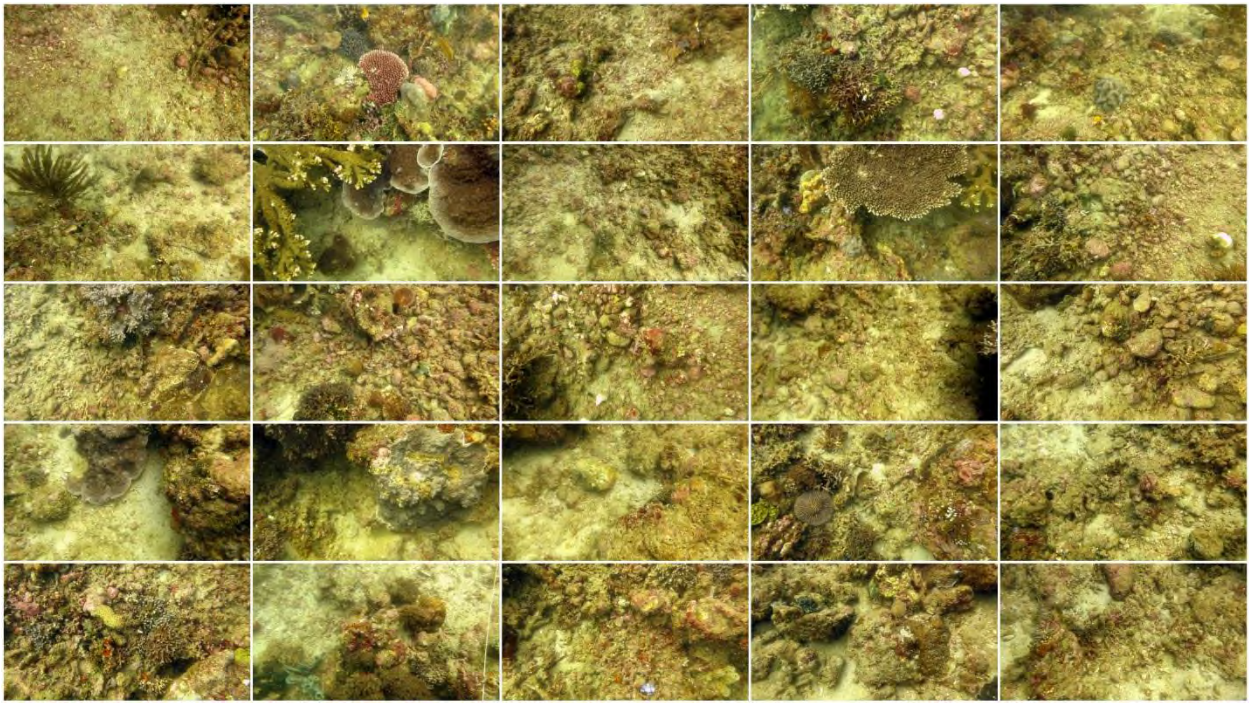


Figure 68. A collage of benthic photographs illustrating the benthic composition at site BOB-02 from the photographs taken around the perimeter in 2014.

Table 15. Benthic composition (i.e., mean percent cover) at site BOB-02. The benthic substrate ratio is the ratio of corals and crustose coralline algae (CCA) to nonaccreting organisms (macroalgae and turf algae), calculated from the mean percent cover.

BENTHIC CATEGORY	COVER (%)
Hard coral	11.6
Soft coral	2.7
CCA	6.6
Macroalgae	5.5
Turf algae	61.7
Invertebrates	2.7
Sand	2.7
Unclassified	6.5
TOTAL	**100.0**
BENTHIC SUBSTRATE RATIO	**0.3**

Figure 69. Photos of the ARMS plates from an ARMS unit recovered from site BOB-02. There are 9 plates per ARMS unit, with the topside and underside of each plate photographed except for the bottom plate that had only the topside photographed since the underside was resting on the base plate, for a total of 17 photos per ARMS unit. ARMS plate photos are displayed starting from the top plate in the upper left corner moving in a left to right direction for each row of photos. The photos with the cross hatches represent semi-closed layers.

SITE: **DIL-02**

DEPTH: **13.1m**

LOCATION: **Dili Rock, Manatuto**

Figure 70. Landward view of Dili from site DIL-02.

Figure 71. Underwater views of site DIL-02.

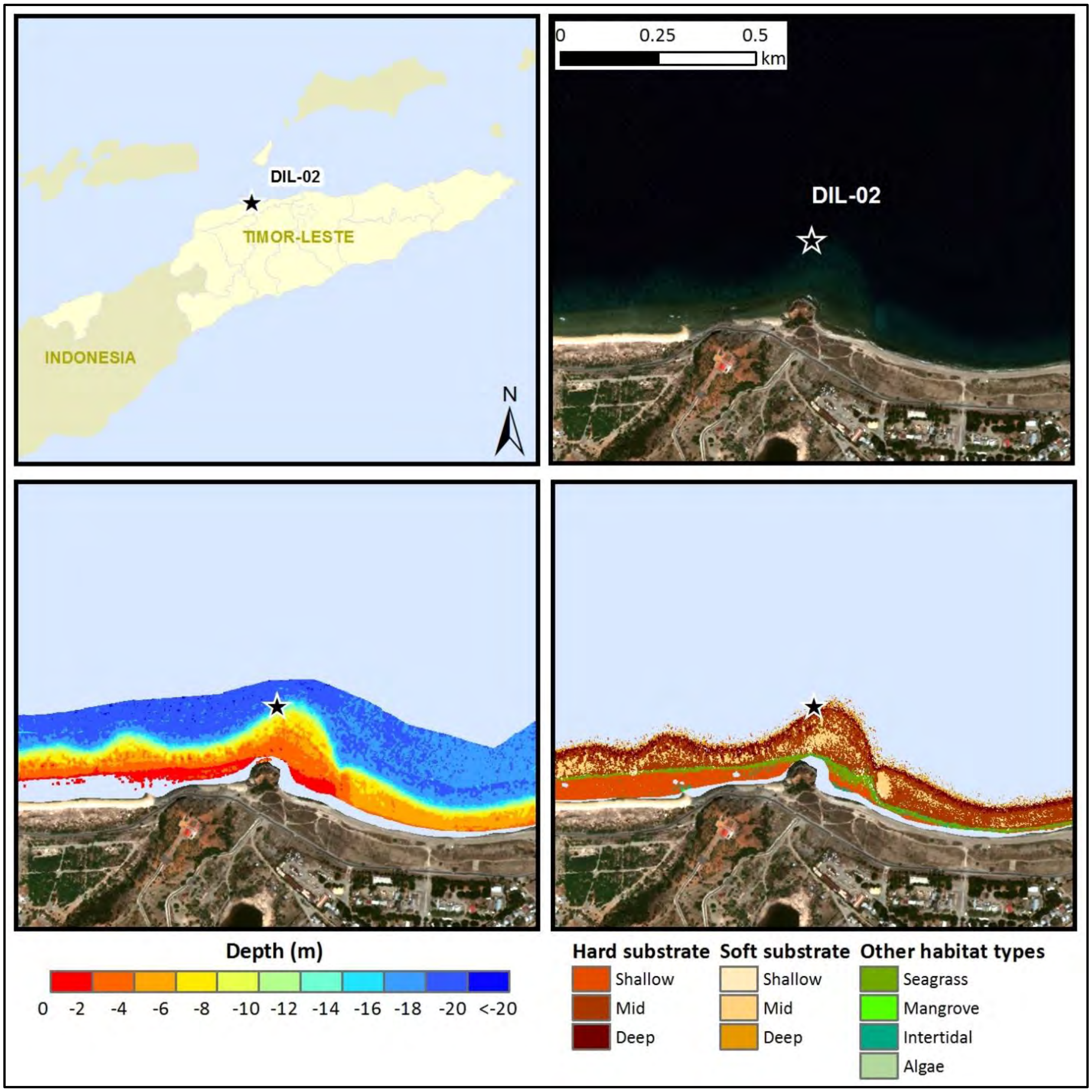


Figure 72. Maps of site DIL-02 (indicated by the black star), including WorldView-2 satellite image (*top right*), bathymetry (*bottom left*) and habitat classes (*bottom right*) derived from satellite imagery, and an overview map showing the location of the site in Timor-Leste (*top left*).

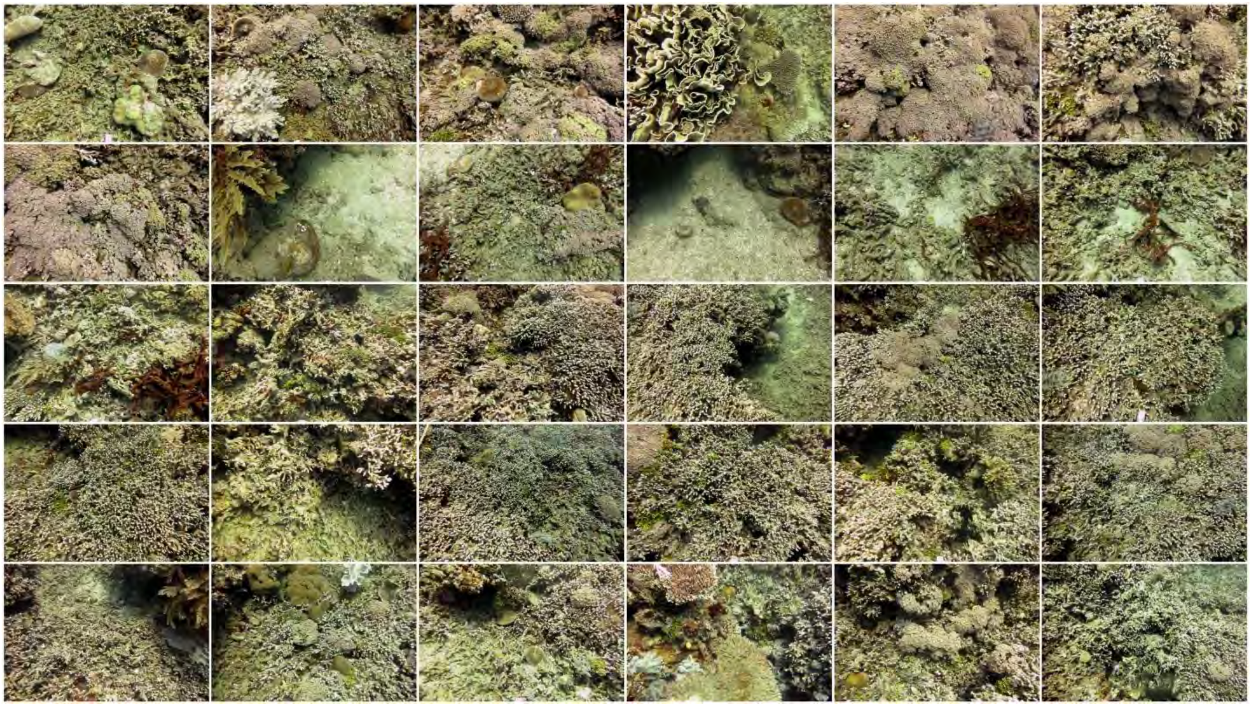


Figure 73. A collage of benthic photographs illustrating the benthic composition at site DIL-02 from the photographs taken around the perimeter in 2014.

Table 16. Benthic composition (i.e., mean percent cover) at site DIL-02. The benthic substrate ratio is the ratio of corals and crustose coralline algae (CCA) to nonaccreting organisms (macroalgae and turf algae), calculated from the mean percent cover.

BENTHIC CATEGORY	COVER (%)
Hard coral	21.6
Soft coral	17.5
CCA	1.7
Macroalgae	4.0
Turf algae	26.7
Invertebrates	4.3
Sand	4.0
Unclassified	20.1
TOTAL	**100.0**
BENTHIC SUBSTRATE RATIO	**1.3**

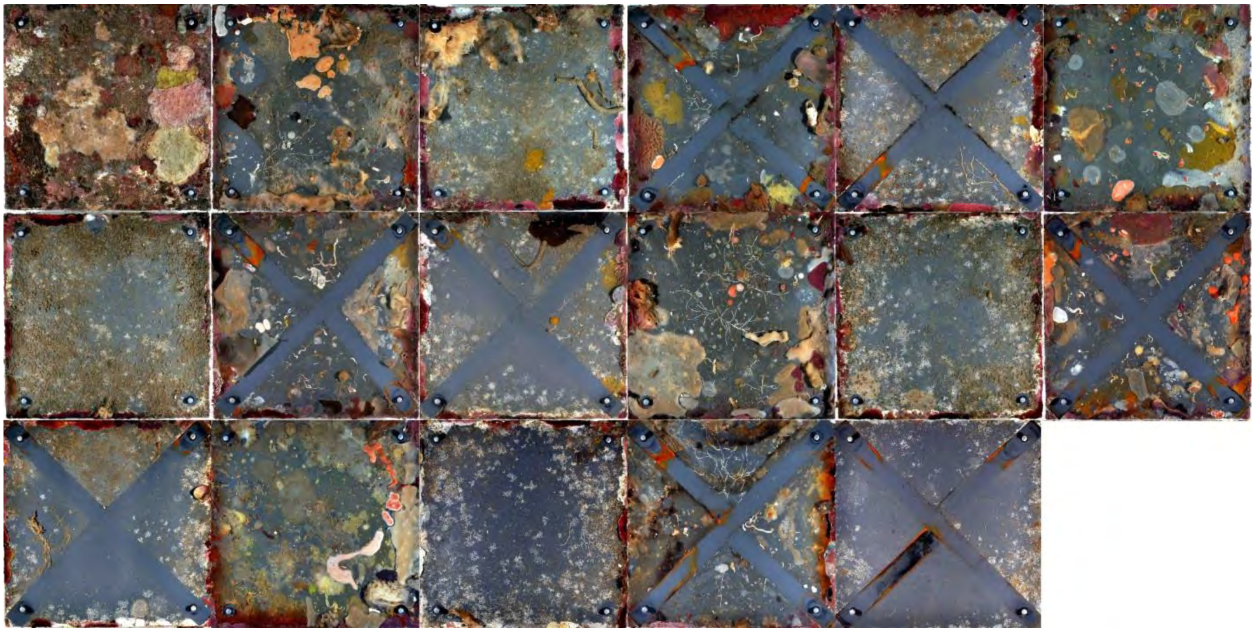


Figure 74. Photos of the ARMS plates from an ARMS unit recovered from site DIL-02. There are 9 plates per ARMS unit, with the topside and underside of each plate photographed except for the bottom plate that had only the topside photographed since the underside was resting on the base plate, for a total of 17 photos per ARMS unit. ARMS plate photos are displayed starting from the top plate in the upper left corner moving in a left to right direction for each row of photos. The photos with the cross hatches represent semi-closed layers.

SITE: VIL-03
DEPTH: 14.3m
LOCATION: South Atauro Island, Dili

Figure 75. Landward view of the east coast of Atauro Island from site VIL-03.

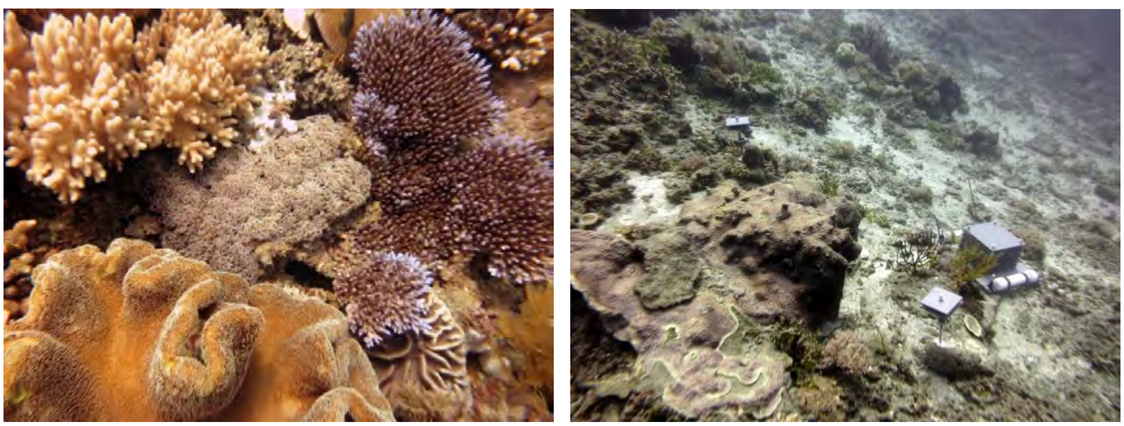


Figure 76. Underwater views of site VIL-03.

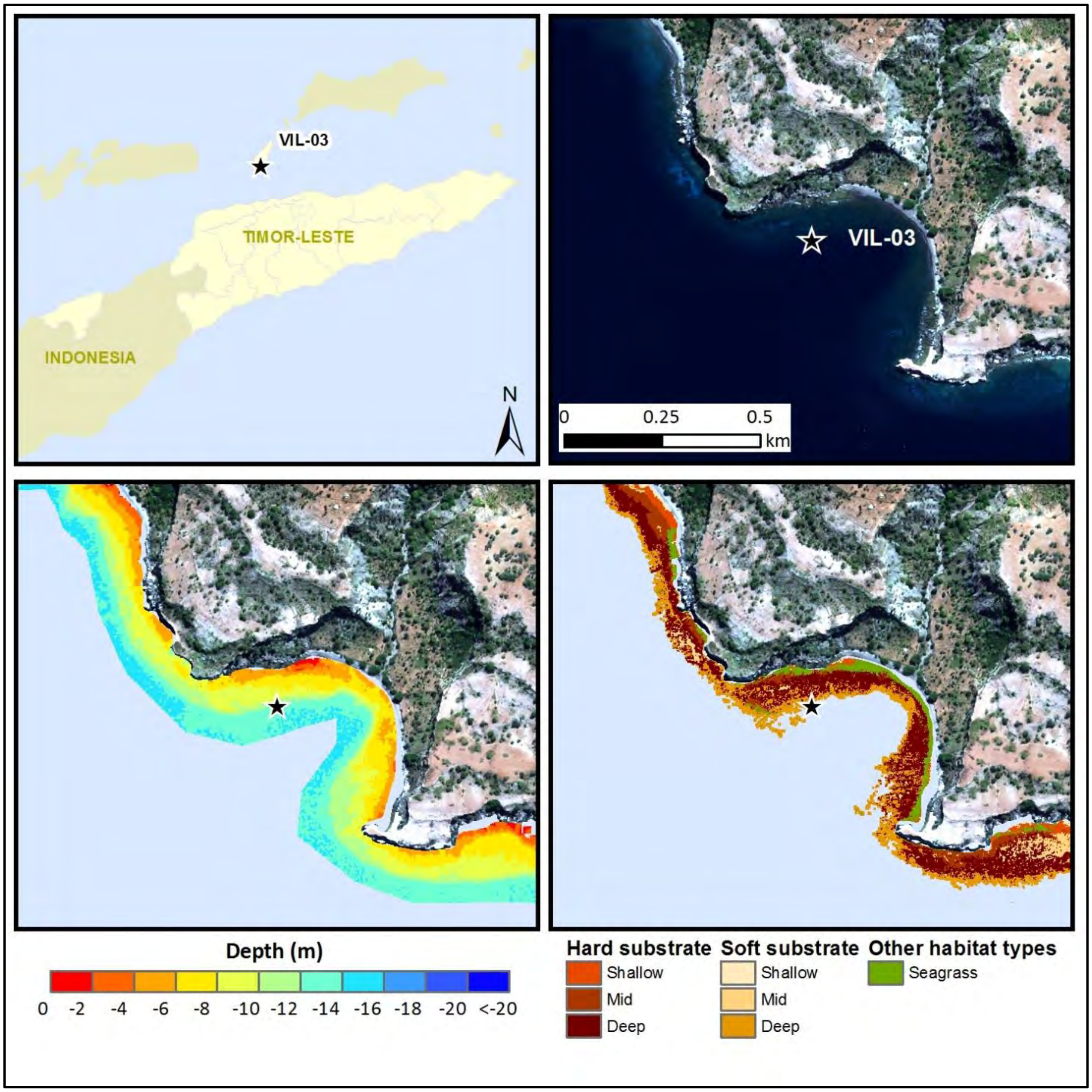


Figure 77. Maps of site VIL-03 (indicated by the black star), including WorldView-2 satellite image (*top right*), bathymetry (*bottom left*) and habitat classes (*bottom right*) derived from satellite imagery, and an overview map showing the location of the site in Timor-Leste (*top left*).

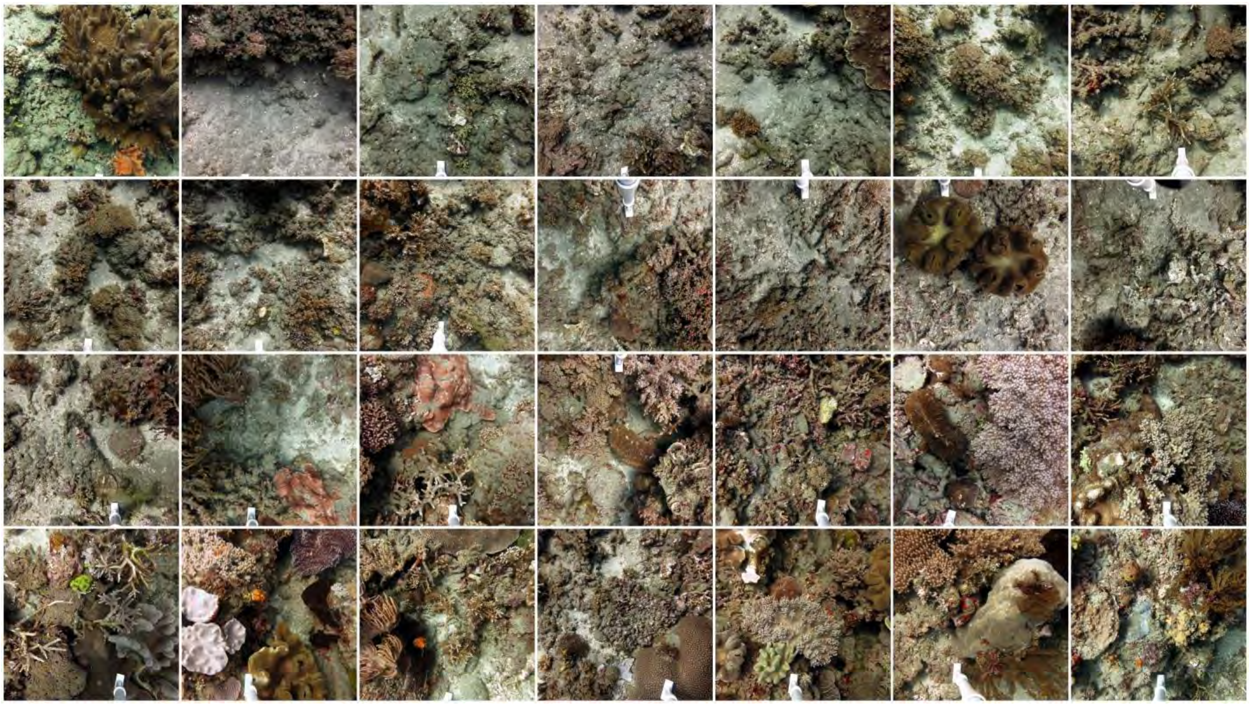


Figure 78. A collage of benthic photographs illustrating the benthic composition at site VIL-03 from the photographs taken around the perimeter in 2014.

Table 17. Benthic composition (i.e., mean percent cover) at site VIL-03. The benthic substrate ratio is the ratio of corals and crustose coralline algae (CCA) to nonaccreting organisms (macroalgae and turf algae), calculated from the mean percent cover.

BENTHIC CATEGORY	COVER (%)
Hard coral	9.7
Soft coral	16.5
CCA	2.5
Macroalgae	1.4
Turf algae	55.0
Invertebrates	2.8
Sand	9.3
Unclassified	2.8
TOTAL	**100.0**
BENTHIC SUBSTRATE RATIO	**0.5**

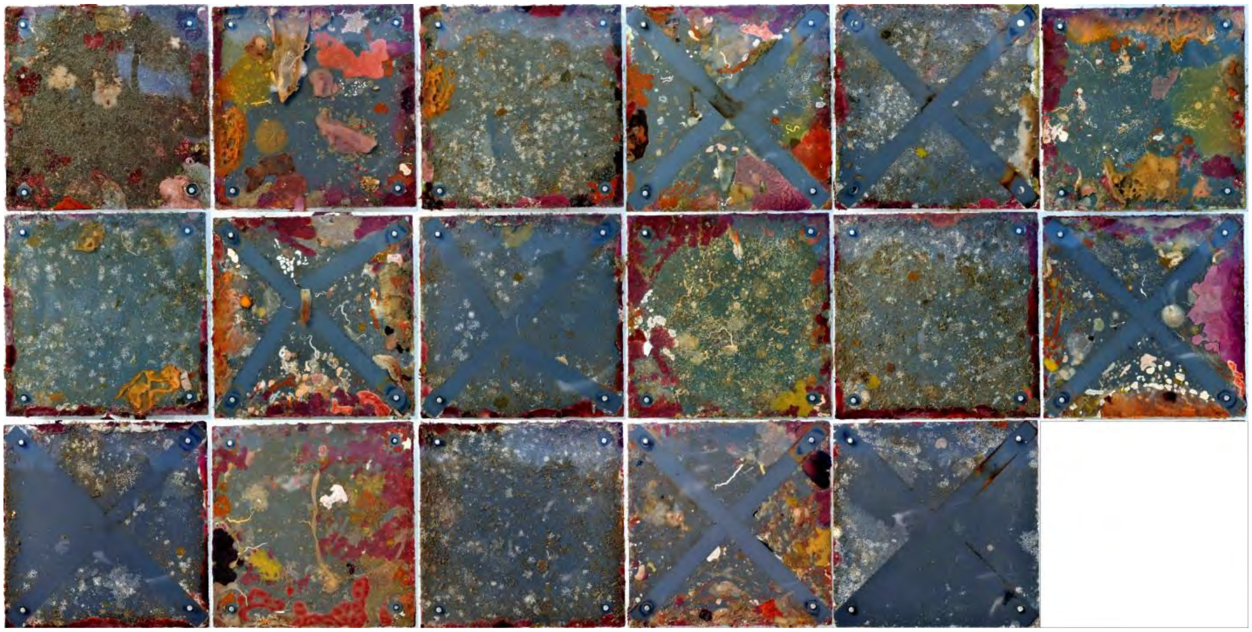


Figure 79. Photos of the ARMS plates from an ARMS unit recovered from site VIL-03. There are 9 plates per ARMS unit, with the topside and underside of each plate photographed except for the bottom plate that had only the topside photographed since the underside was resting on the base plate, for a total of 17 photos per ARMS unit. ARMS plate photos are displayed starting from the top plate in the upper left corner moving in a left to right direction for each row of photos. The photos with the cross hatches represent semi-closed layers.

SITE: VIL-10

DEPTH: 13.1m

LOCATION: East Atauro Island, Dili

Figure 80. Underwater views of site VIL-10.

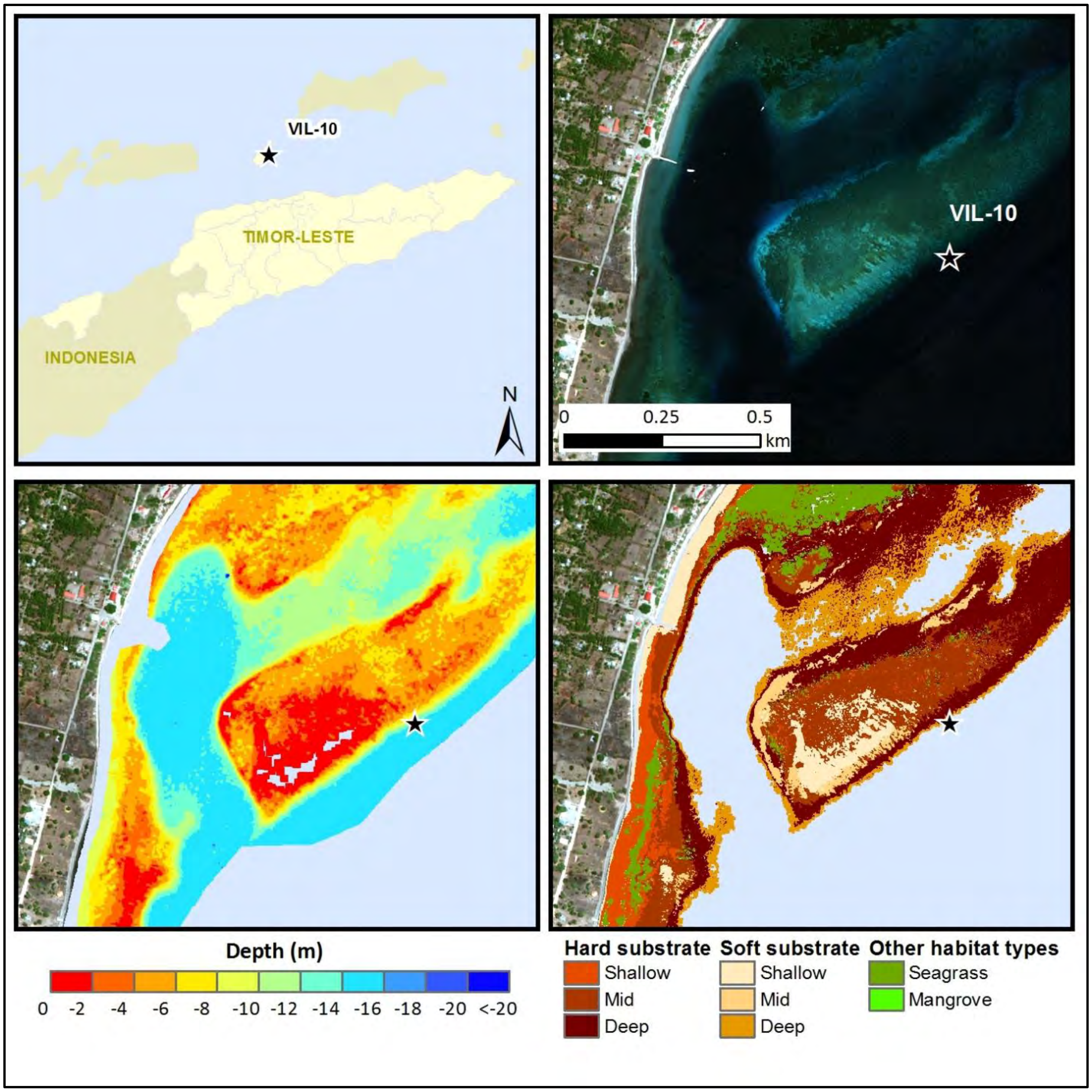


Figure 81. Maps of site VIL-10 (indicated by the black star), including WorldView-2 satellite image (*top right*), bathymetry (*bottom left*) and habitat classes (*bottom right*) derived from satellite imagery, and an overview map showing the location of the site in Timor-Leste (*top left*).

Figure 82. A collage of benthic photographs illustrating the benthic composition at site VIL-10 from the photographs taken around the perimeter in 2014.

Figure 83. Benthic composition (i.e., mean percent cover) at site VIL-10. The benthic substrate ratio is the ratio of corals and crustose coralline algae (CCA) to nonaccreting organisms (macroalgae and turf algae), calculated from the mean percent cover.

BENTHIC CATEGORY	COVER (%)
Hard coral	38.1
Soft coral	12.8
CCA	5.7
Macroalgae	11.1
Turf algae	11.4
Invertebrates	7.7
Sand	0.7
Unclassified	12.6
TOTAL	**100.0**
BENTHIC SUBSTRATE RATIO	**2.5**

Figure 84. Photos of the ARMS plates from an ARMS unit recovered from site VIL-10. There are 9 plates per ARMS unit, with the topside and underside of each plate photographed except for the bottom plate that had only the topside photographed since the underside was resting on the base plate, for a total of 17 photos per ARMS unit. ARMS plate photos are displayed starting from the top plate in the upper left corner moving in a left to right direction for each row of photos. The photos with the cross hatches represent semi-closed layers.

SITE: MAF-01

DEPTH: 14.6m

LOCATION: Betano, Manufahi

Figure 85. Underwater views of site MAF-01.

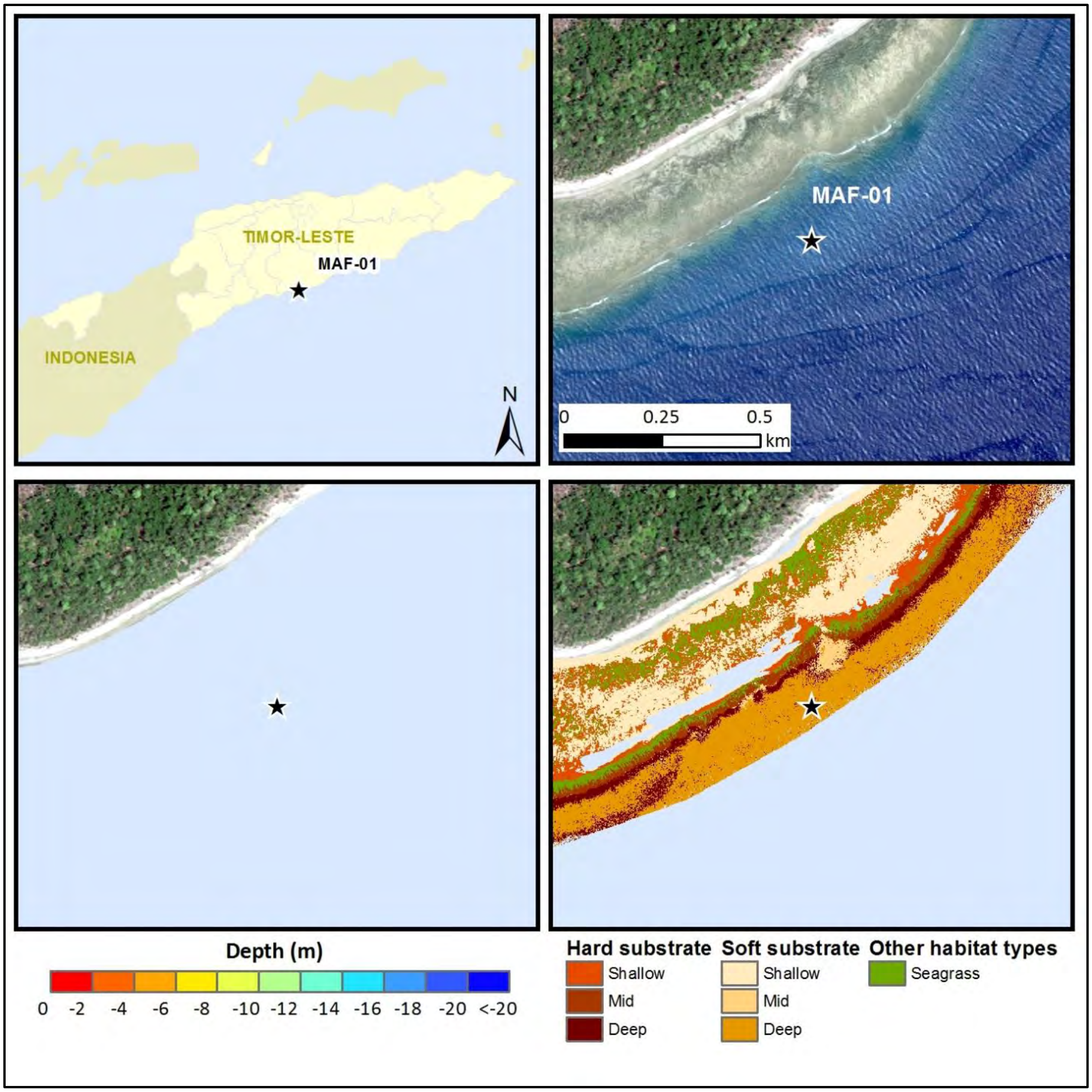


Figure 86. Maps of site MAF-01 (indicated by the black star), including WorldView-2 satellite image (*top right*), and habitat classes (*bottom right*) derived from satellite imagery, and an overview map showing the location of the site in Timor-Leste (*top left*). Bathymetry data was not generated for the south shore (*bottom left*).

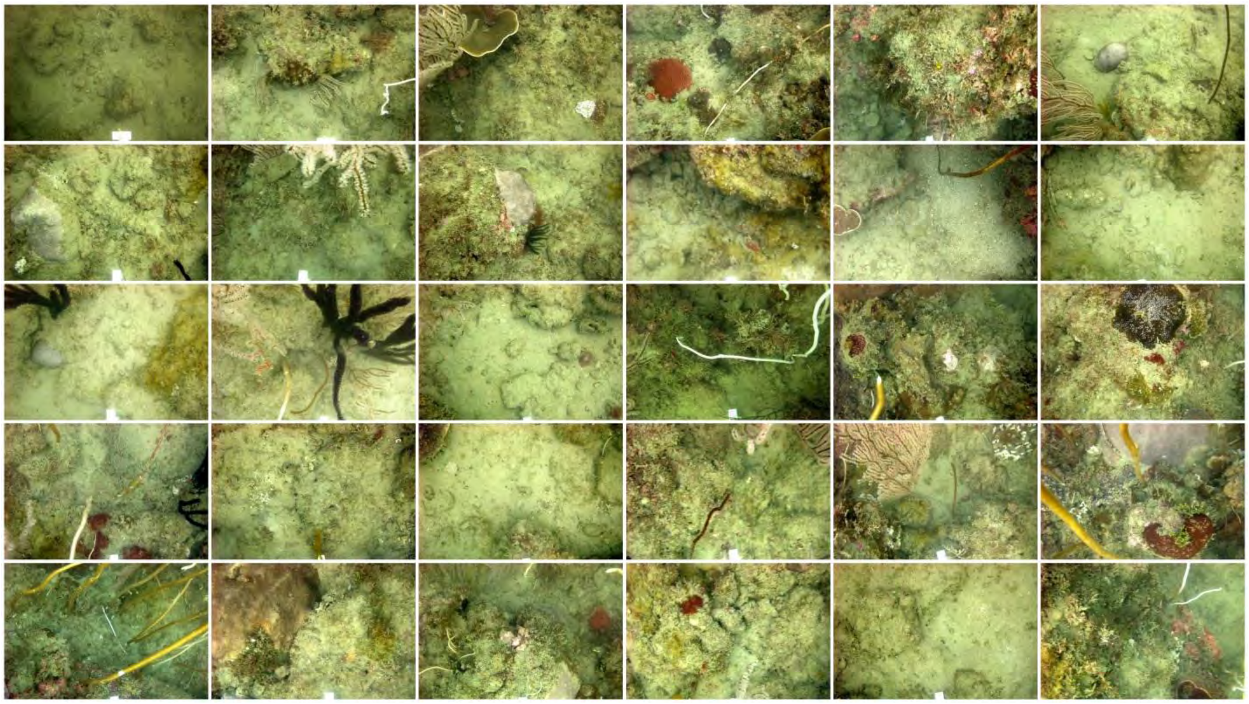


Figure 87. A collage of benthic photographs illustrating the benthic composition at site MAF-01 from the photographs taken around the perimeter in 2012.

There are no benthic composition data or ARMS plate photos for site MAF-01 since it was not revisited in 2014. Photographs collected in 2012 were not analyzed for benthic cover.

SITE: **MAN-09**
DEPTH: **14.6m**
LOCATION: **Ilimano, Manatuto**

Figure 88. Underwater views of site MAN-09.

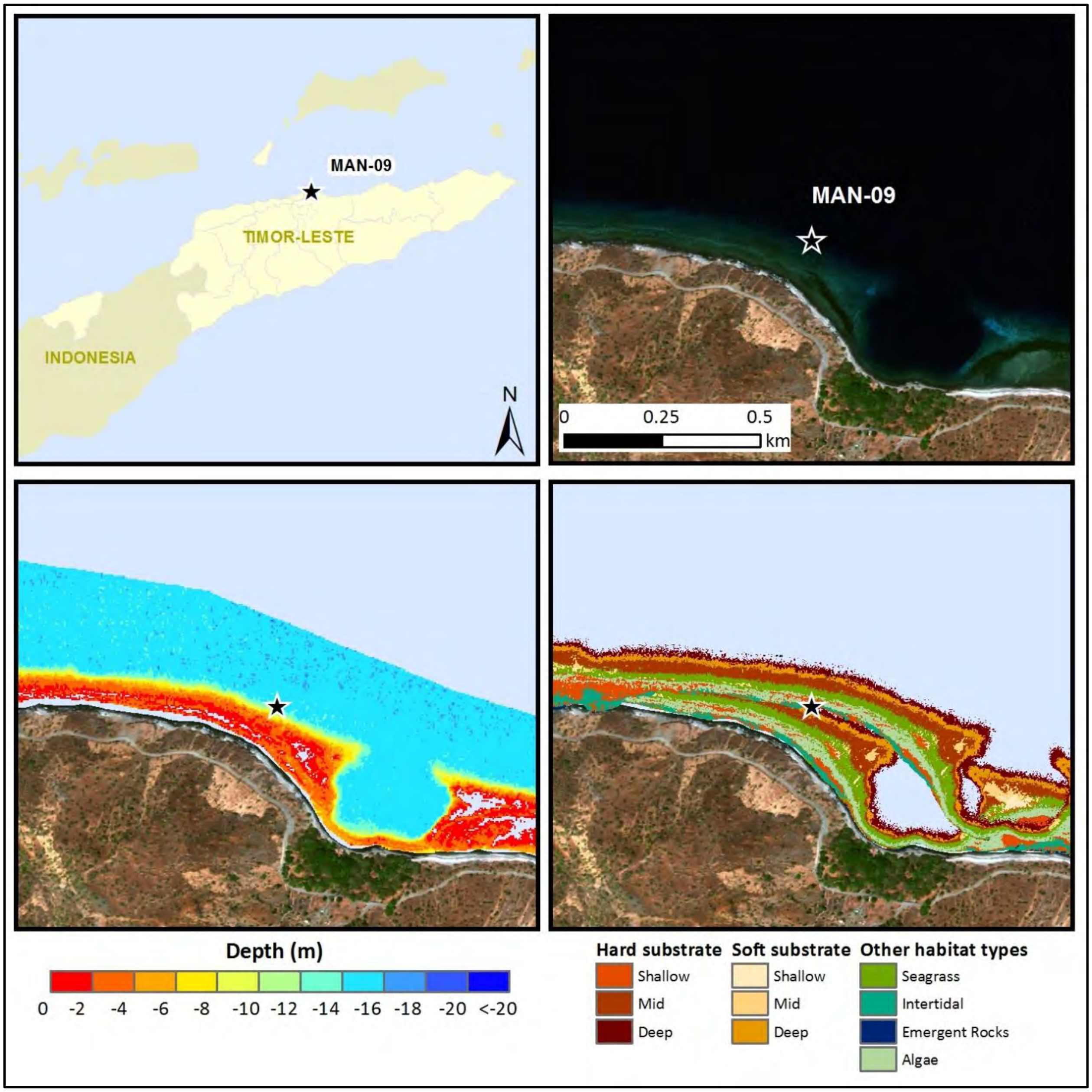


Figure 89. Maps of site MAN-09 (indicated by the black star), including WorldView-2 satellite image (*top right*), bathymetry (*bottom left*) and habitat classes (*bottom right*) derived from satellite imagery, and an overview map showing the location of the site in Timor-Leste (*top left*).

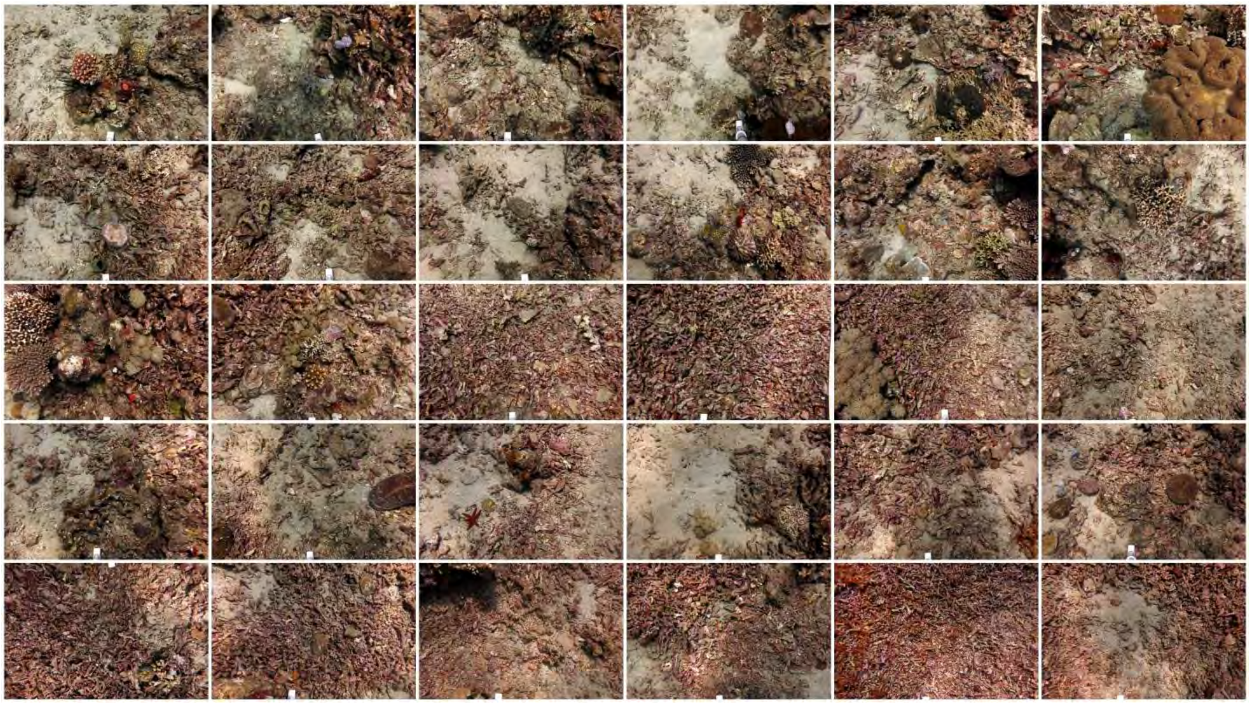


Figure 90. A collage of benthic photographs illustrating the benthic composition at site MAN-09 from the photographs taken around the perimeter in 2014.

Table 18. Benthic composition (i.e., mean percent cover) at site MAN-09. The benthic substrate ratio is the ratio of corals and crustose coralline algae (CCA) to nonaccreting organisms (macroalgae and turf algae), calculated from the mean percent cover.

BENTHIC CATEGORY	COVER (%)
Hard coral	6.4
Soft coral	2.0
CCA	10.4
Macroalgae	7.1
Turf algae	59.6
Invertebrates	1.3
Sand	11.9
Unclassified	1.3
TOTAL	**100.0**
BENTHIC SUBSTRATE RATIO	**0.3**

Figure 91. Photos of the ARMS plates from an ARMS unit recovered from site MAN-09. There are 9 plates per ARMS unit, with the topside and underside of each plate photographed except for the bottom plate that had only the topside photographed since the underside was resting on the base plate, for a total of 17 photos per ARMS unit. ARMS plate photos are displayed starting from the top plate in the upper left corner moving in a left to right direction for each row of photos. The photos with the cross hatches represent semi-closed layers.

SITE: BAU-04
DEPTH: 13.7m
LOCATION: Baucau

Figure 92. Landward view of Baucau from site BAU-04.

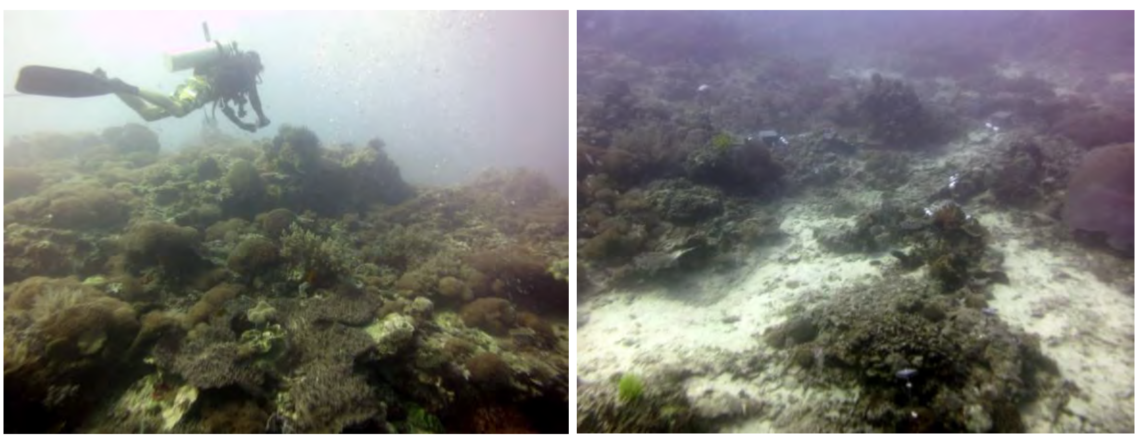


Figure 93. Underwater views of site BAU-04.

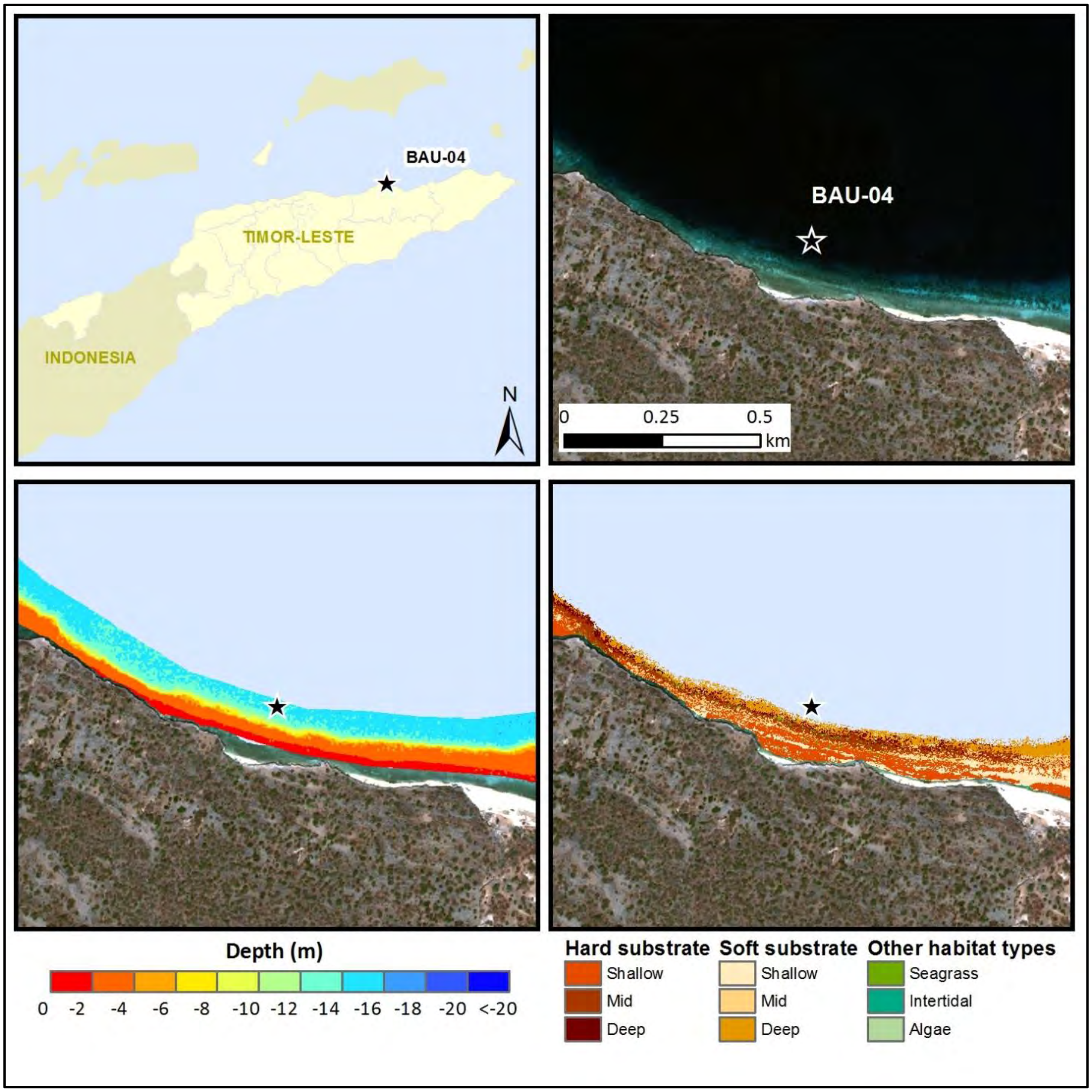


Figure 94. Maps of site BAU-04 (indicated by the black star), including WorldView-2 satellite image (*top right*), bathymetry (*bottom left*) and habitat classes (*bottom right*) derived from satellite imagery, and an overview map showing the location of the site in Timor-Leste (*top left*).

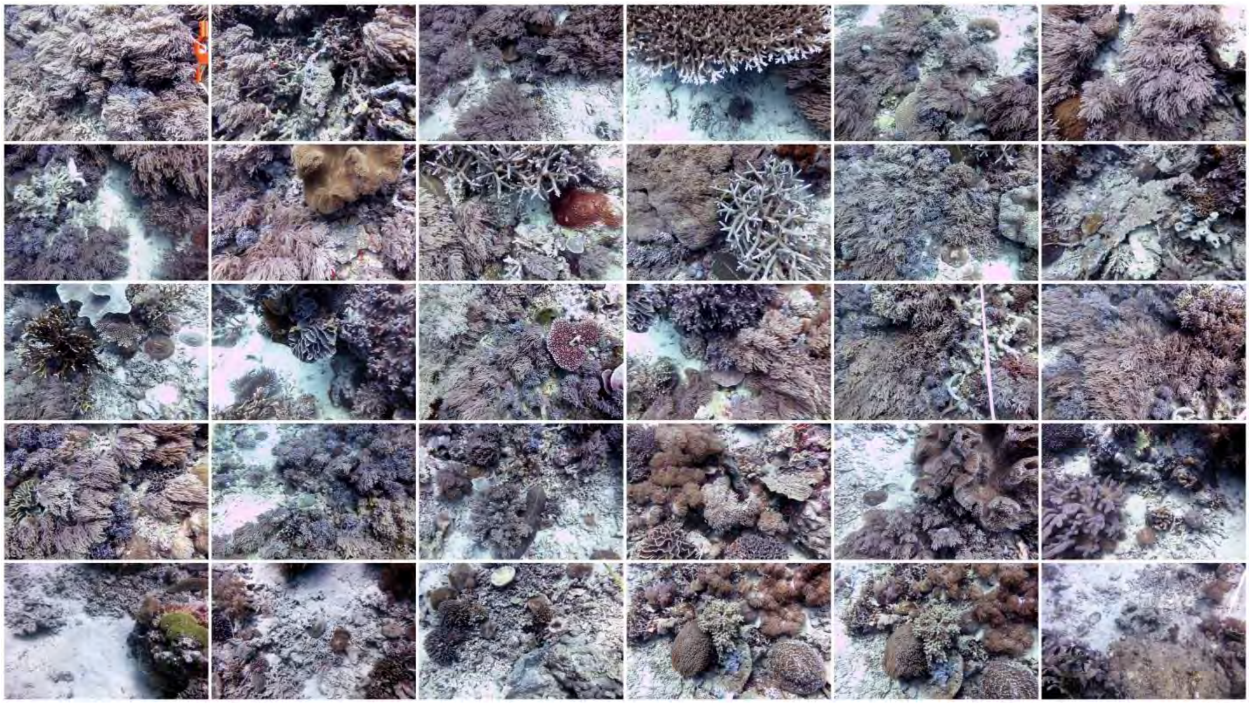


Figure 95. A collage of benthic photographs illustrating the benthic composition at site BAU-04 from the photographs taken around the perimeter in 2014.

Table 19. Benthic composition (i.e., mean percent cover) at site BAU-04. The benthic substrate ratio is the ratio of corals and crustose coralline algae (CCA) to nonaccreting organisms (macroalgae and turf algae), calculated from the mean percent cover.

BENTHIC CATEGORY	COVER (%)
Hard coral	17.0
Soft coral	41.3
CCA	1.7
Macroalgae	0.0
Turf algae	22.3
Invertebrates	4.3
Sand	9.7
Unclassified	3.7
TOTAL	**100.0**
BENTHIC SUBSTRATE RATIO	**2.7**

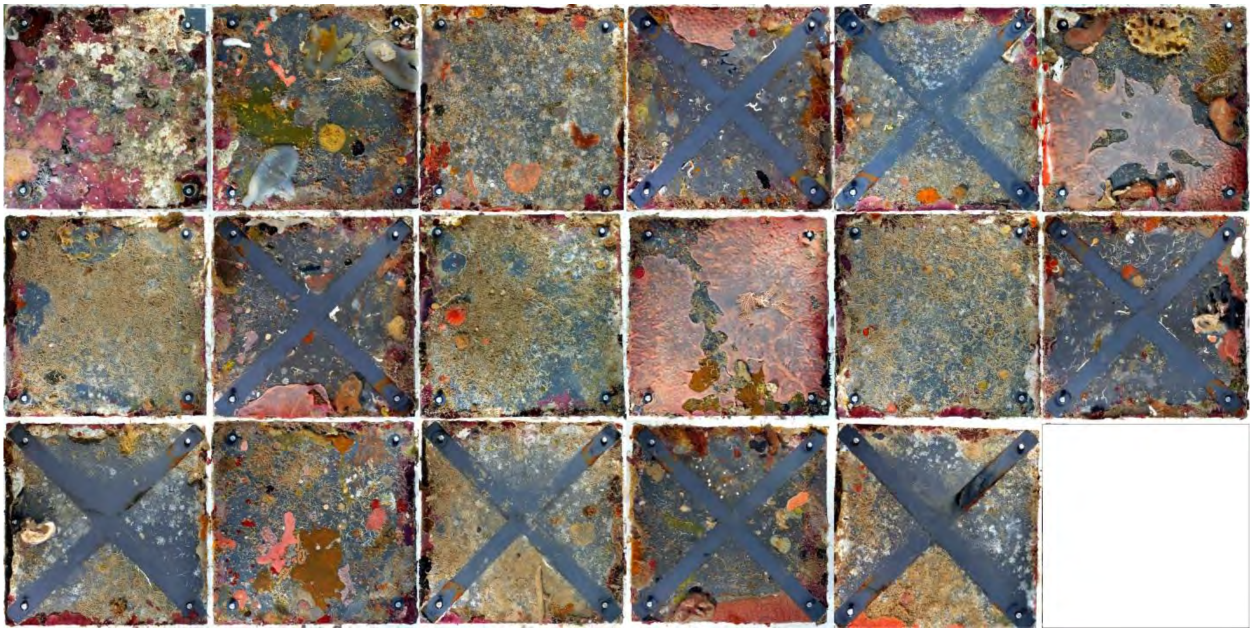


Figure 96. Photos of the ARMS plates from an ARMS unit recovered from site BAU-04. There are 9 plates per ARMS unit, with the topside and underside of each plate photographed except for the bottom plate that had only the topside photographed since the underside was resting on the base plate, for a total of 17 photos per ARMS unit. ARMS plate photos are displayed starting from the top plate in the upper left corner moving in a left to right direction for each row of photos. The photos with the cross hatches represent semi-closed layers.

SITE: LAU-07

DEPTH: 11.0 m

LOCATION: Lore, Lautem

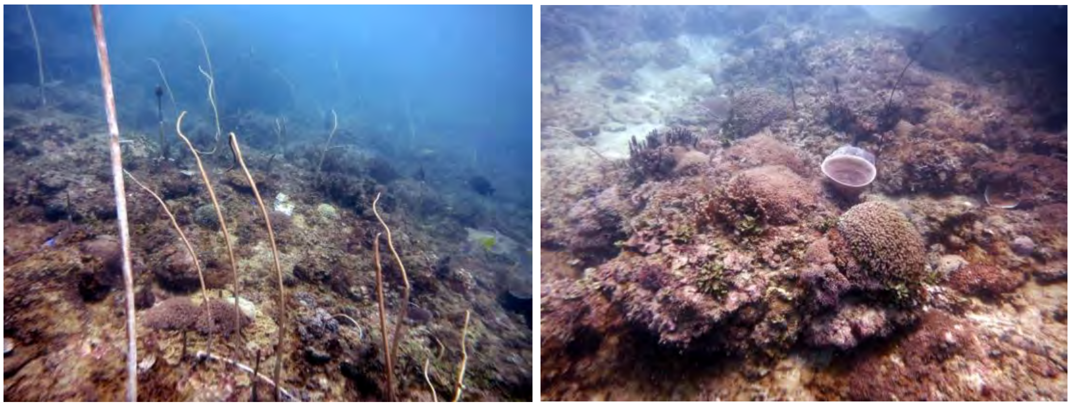


Figure 97. Underwater views of site LAU-07.

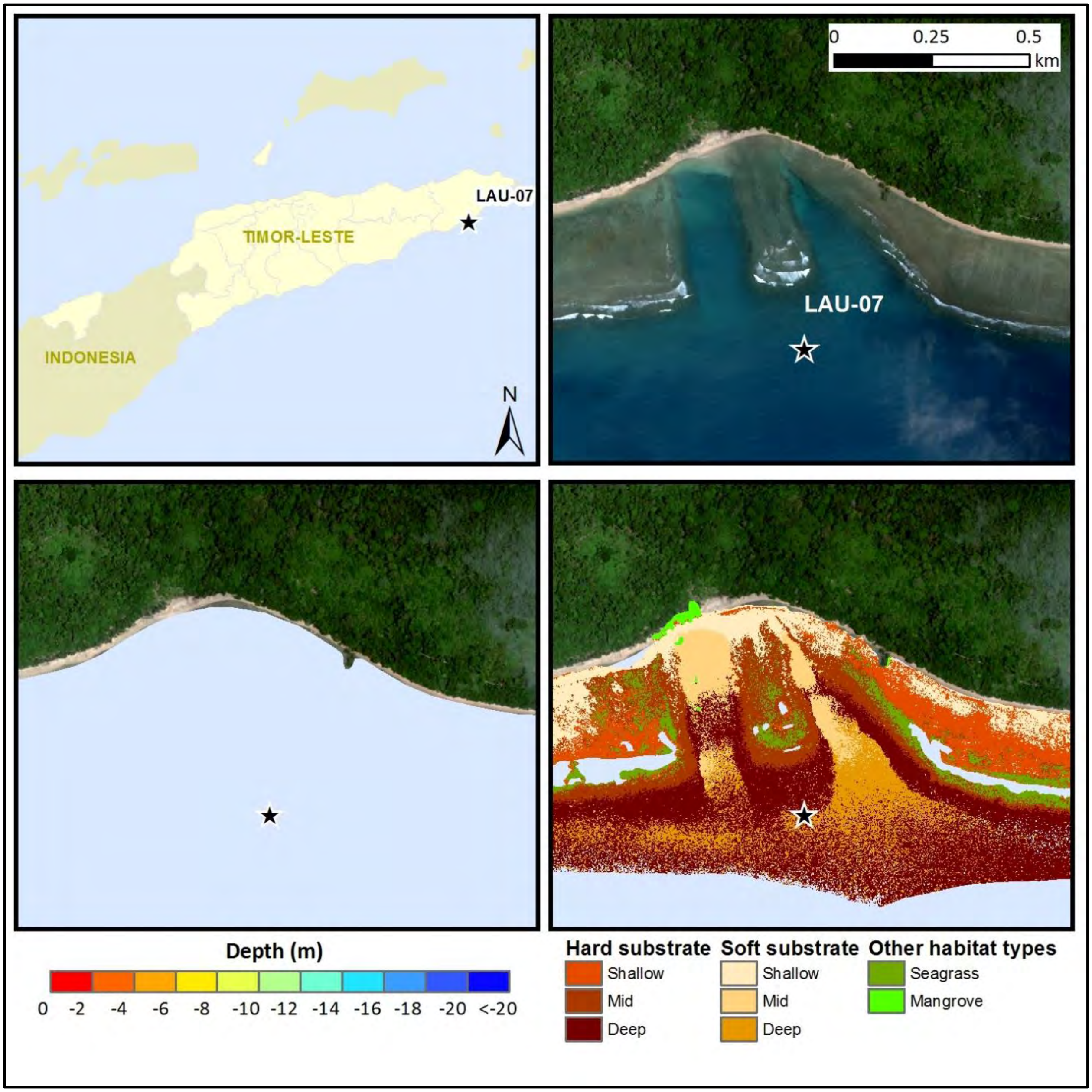


Figure 98. Maps of site LAU-07 (indicated by the black star), including WorldView-2 satellite image (*top right*), and habitat classes (*bottom right*) derived from satellite imagery, and an overview map showing the location of the site in Timor-Leste (*top left*). Bathymetry data was not generated for the south shore (*bottom left*).

Figure 99. A collage of benthic photographs illustrating the benthic composition at site LAU-07 from the photographs taken around the perimeter in 2014.

There are no benthic composition data or ARMS plate photos for site LAU-07 since it was not revisited in 2014. Photographs collected in 2012 were not analyzed for benthic cover.

SITE: LAU-01

DEPTH: 14.6m

LOCATION: Com, Lautem

Figure 100. Landward view of Com from site LAU-01.

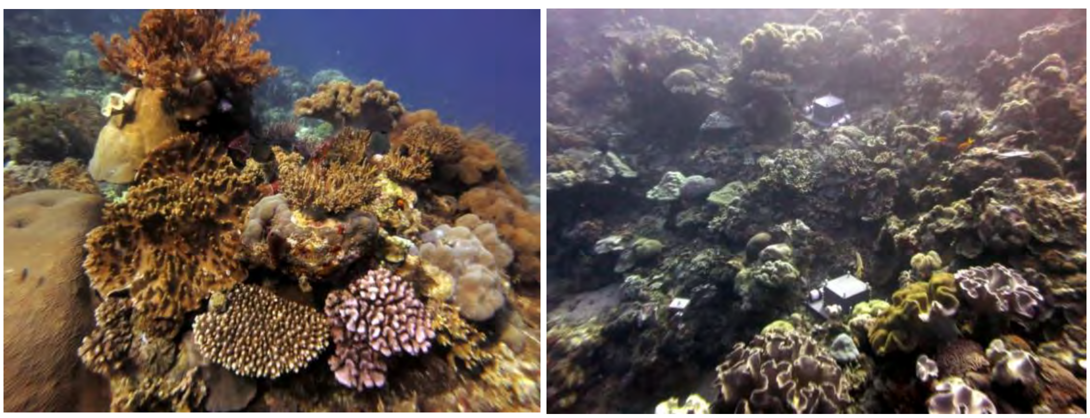


Figure 101. Underwater views of site LAU-01.

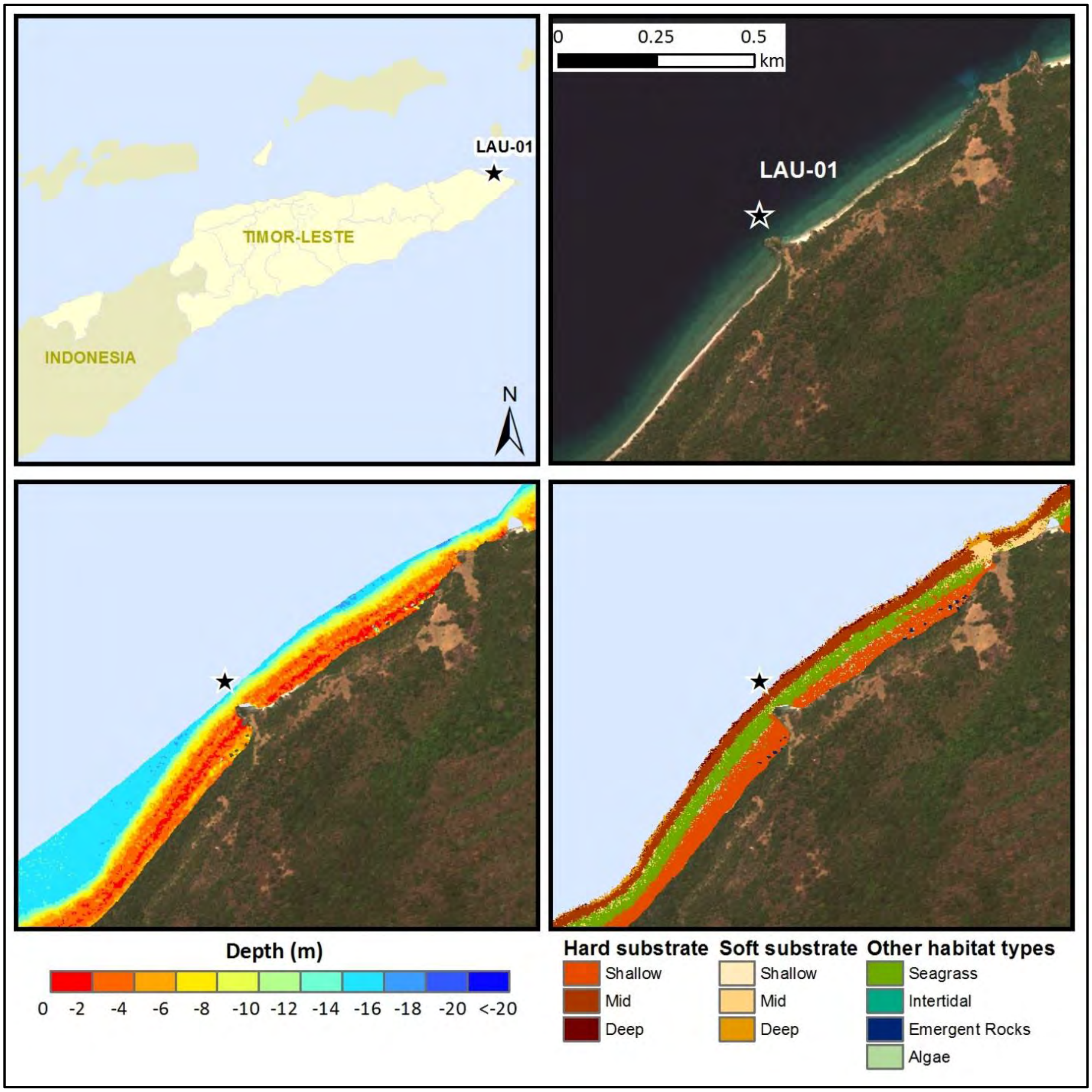


Figure 102. Maps of site LAU-01 (indicated by the black star), including WorldView-2 satellite image (*top right*), bathymetry (*bottom left*) and habitat classes (*bottom right*) derived from satellite imagery, and an overview map showing the location of the site in Timor-Leste (*top left*).

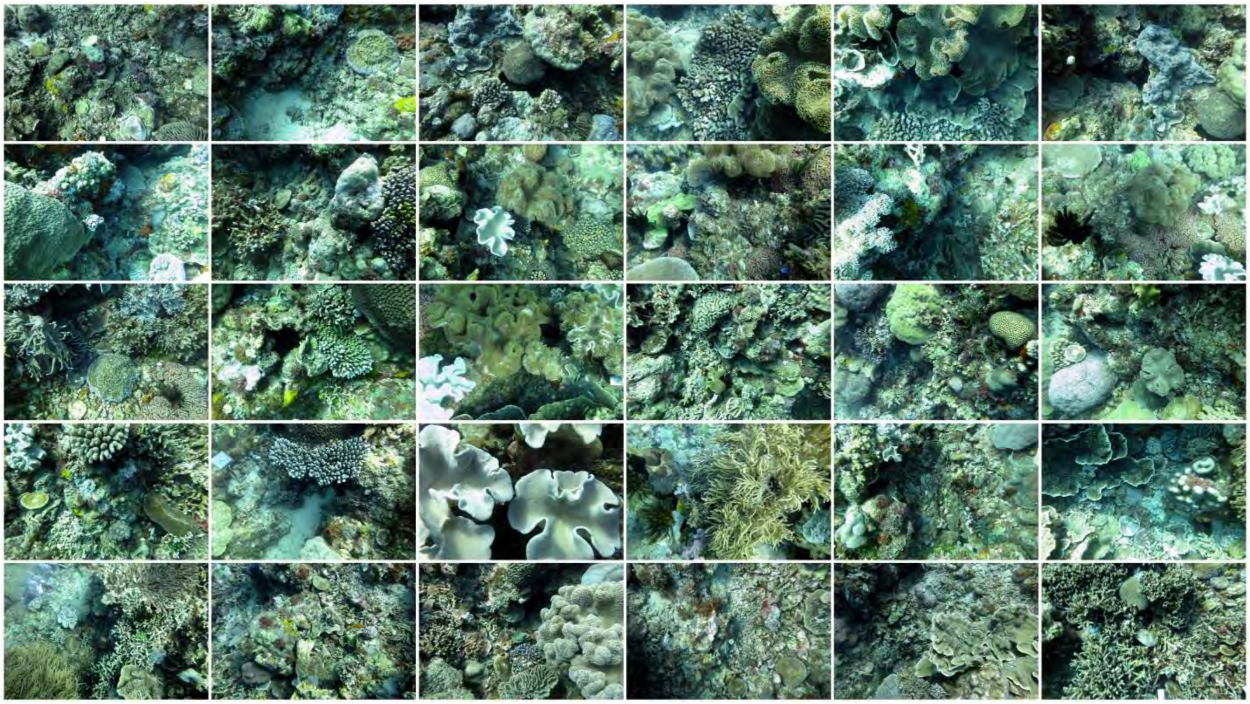


Figure 103. A collage of benthic photographs illustrating the benthic composition at site LAU-01 from the photographs taken around the perimeter in 2014.

Table 20. Benthic composition (i.e., mean percent cover) at site LAU-01. The benthic substrate ratio is the ratio of corals and crustose coralline algae (CCA) to nonaccreting organisms (macroalgae and turf algae), calculated from the mean percent cover.

BENTHIC CATEGORY	COVER (%)
Hard coral	40.1
Soft coral	14.6
CCA	3.0
Macroalgae	7.1
Turf algae	22.5
Invertebrates	4.7
Sand	0.3
Unclassified	7.7
TOTAL	**100.0**
BENTHIC SUBSTRATE RATIO	**2.0**

Figure 104. Photos of the ARMS plates from an ARMS unit recovered from site LAU-01. There are 9 plates per ARMS unit, with the topside and underside of each plate photographed except for the bottom plate that had only the topside photographed since the underside was resting on the base plate, for a total of 17 photos per ARMS unit. ARMS plate photos are displayed starting from the top plate in the upper left corner moving in a left to right direction for each row of photos. The photos with the cross hatches represent semi-closed layers.

SITE: **LAU-05**
DEPTH: **14.6m**
LOCATION: **Jaco Island, Lautem**

Figure 105. Landward view of Jaco Island from site LAU-05.

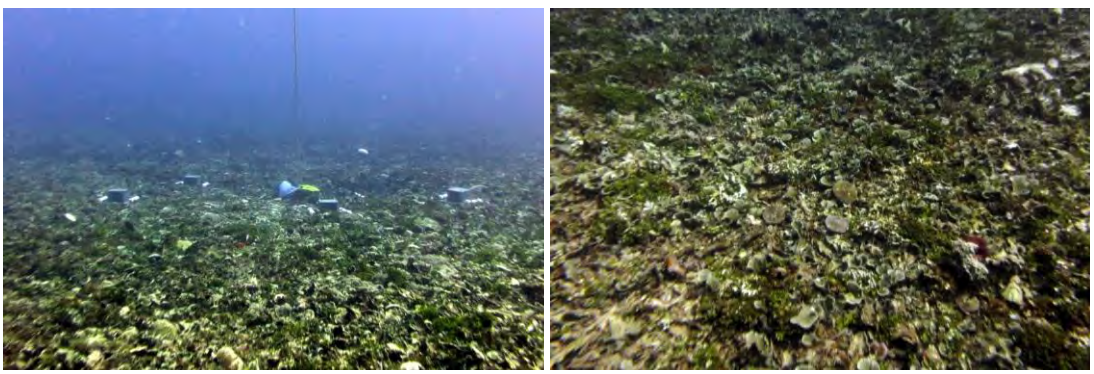


Figure 106. Underwater views of site LAU-05.

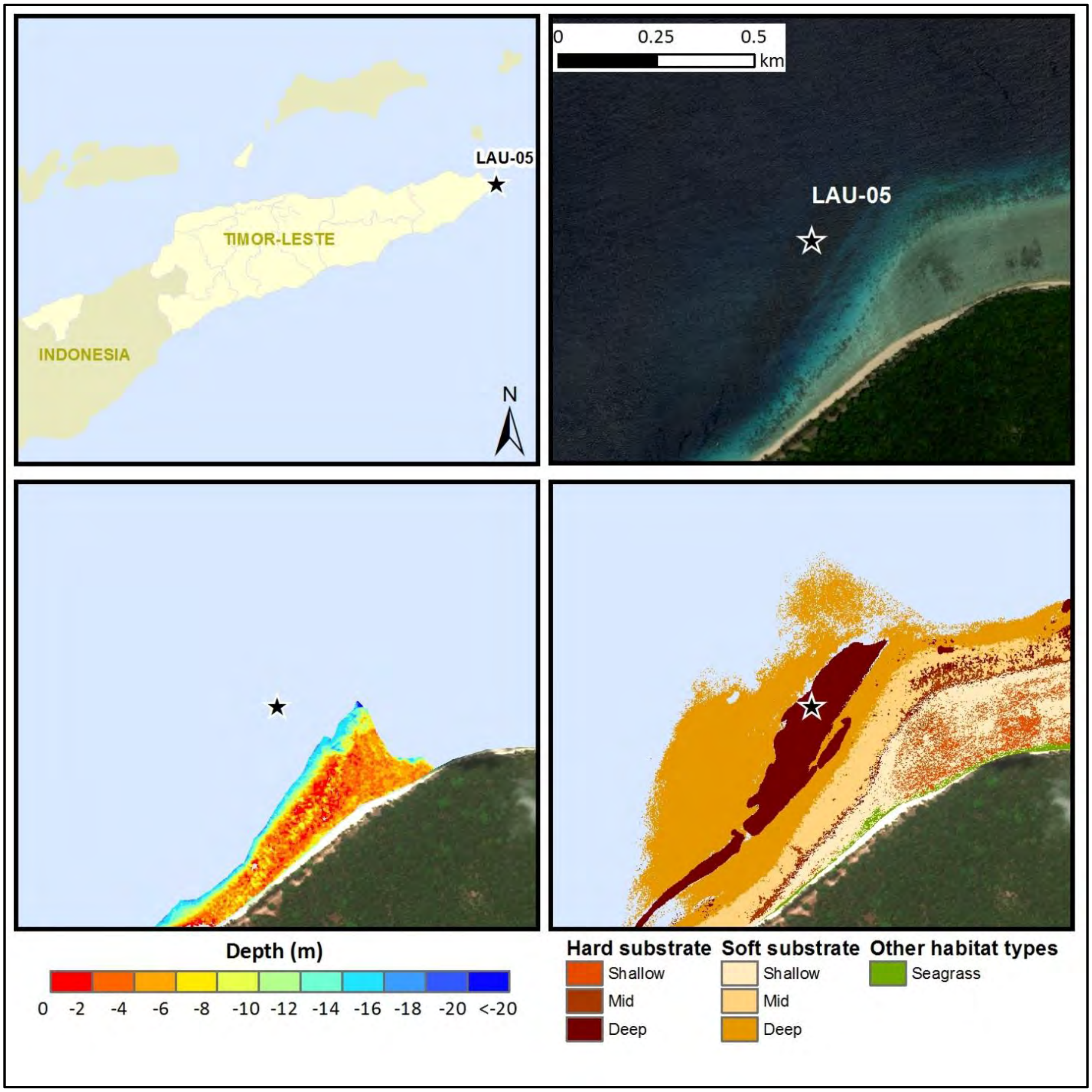


Figure 107. Maps of site LAU-05 (indicated by the black star), including WorldView-2 satellite image (*top right*), bathymetry (*bottom left*) and habitat classes (*bottom right*) derived from satellite imagery, and an overview map showing the location of the site in Timor-Leste (*top left*).

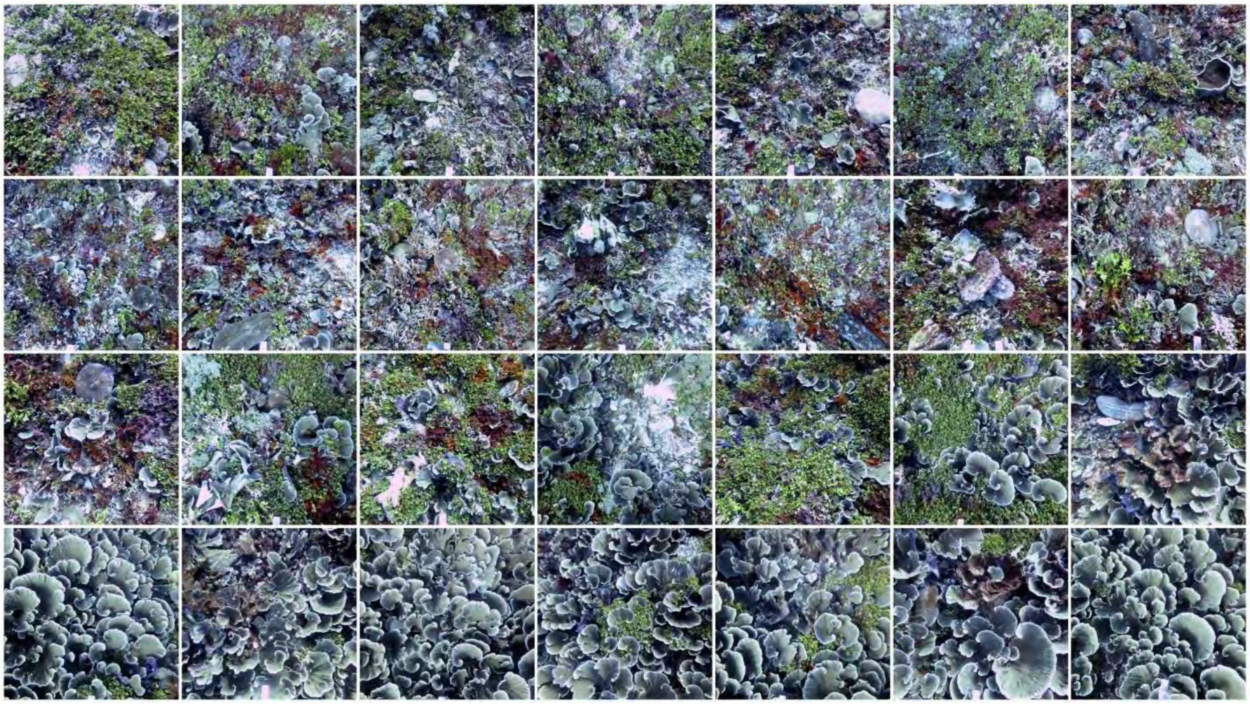


Figure 108. A collage of benthic photographs illustrating the benthic composition at site LAU-05 from the photographs taken around the perimeter in 2014.

Table 21. Benthic composition (i.e., mean percent cover) at site LAU-05. The benthic substrate ratio is the ratio of corals and crustose coralline algae (CCA) to nonaccreting organisms (macroalgae and turf algae), calculated from the mean percent cover.

BENTHIC CATEGORY	COVER (%)
Hard coral	32.1
Soft coral	0.4
CCA	1.5
Macroalgae	40.5
Turf algae	9.6
Invertebrates	3.0
Sand	0.4
Unclassified	12.7
TOTAL	**100.0**
BENTHIC SUBSTRATE RATIO	**0.7**

Figure 109. Photos of the ARMS plates from an ARMS unit recovered from site LAU-05. There are 9 plates per ARMS unit, with the topside and underside of each plate photographed except for the bottom plate that had only the topside photographed since the underside was resting on the base plate, for a total of 17 photos per ARMS unit. ARMS plate photos are displayed starting from the top plate in the upper left corner moving in a left to right direction for each row of photos. The photos with the cross hatches represent semi-closed layers.

Appendix F. Satellite Mapping Poster

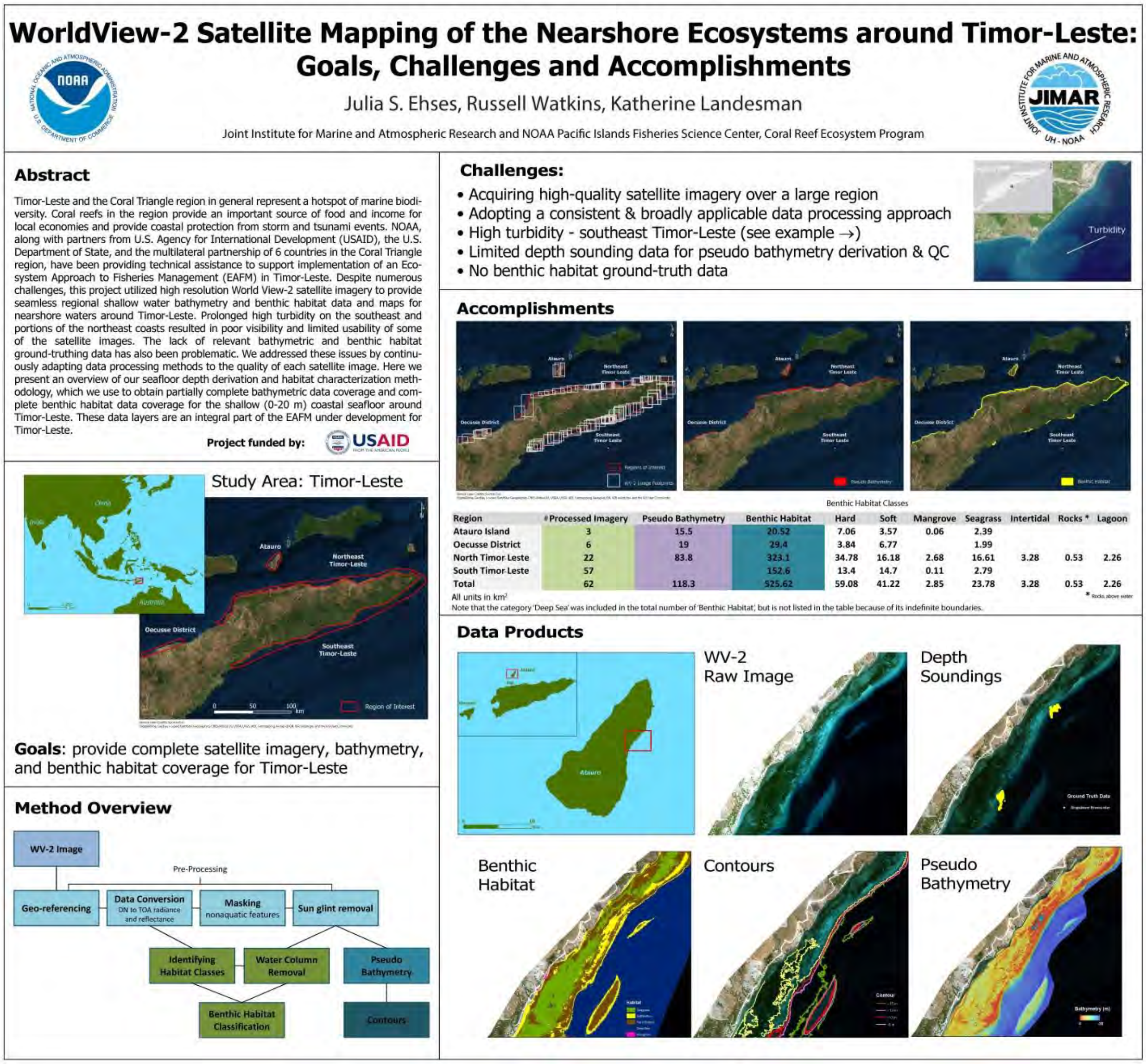


Figure 110. Satellite mapping poster presented at the 13th International Coral Reef Symposium, June 19-24, 2016, Honolulu, HI.

Appendix G. Methods: Coral Reef Ecosystem Assessments

Reef Fish Surveys

Field Method

All sites were surveyed using NOAA-CREP's standard coral reef fish survey method, i.e., stationary point counts (SPC). The SPC protocol closely follows that used by Ault and colleagues (2006) and involves a pair of divers conducting simultaneous counts in adjacent, visually estimated 15 m diameter cylindrical plots extending from the substrate to the limits of vertical visibility (Figure 111).

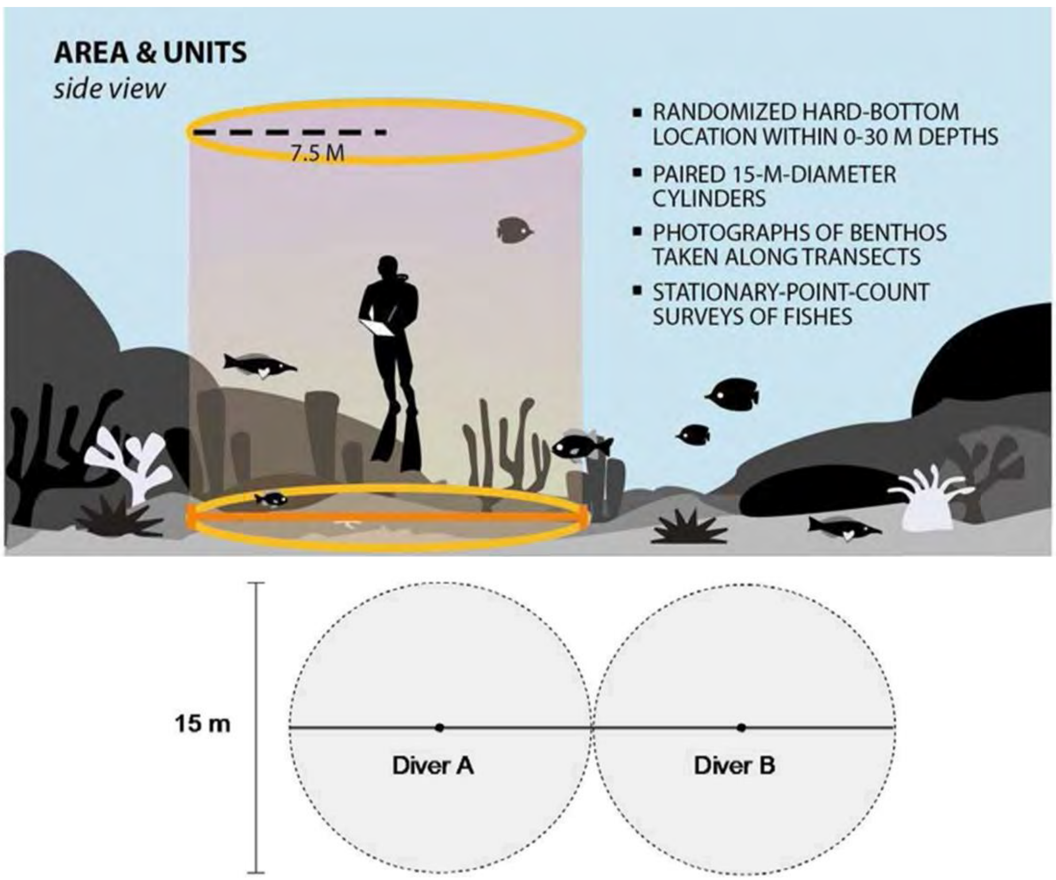


Figure 111. Schematic of NOAA-CREP stationary point count reef fish survey method.

Each count consisted of two components. The first was a 5-minute species enumeration period in which each diver recorded the taxa of all species observed within their respective cylinders (Figure 111). At the end of the 5-minute period, divers began the tallying portion of the count, in which they systematically worked through their list for each species and recorded the number of fish and size (total length, to nearest centimeter) of each individual fish. The tallying portion was conducted as a series of rapid visual sweeps of the plot, with one species-grouping counted per sweep. In cases where a species was observed during the enumeration period but was not present in the cylinder during the tallying period, divers recorded their best estimates of size and number observed in the first encounter during the enumeration period and marked the data record as 'non-instantaneous.' See Ayotte et al. (2011) for the complete fish survey standard operating procedure.

Analysis: Estimation of Biomass by Fish Groupings

Fish biomass was calculated using the following equation to estimate weight (*W*) from length (*L*) measurements: $W = a \times L^b$

The parameter a is a scaling coefficient for the weight and length of the fish species, and the parameter b is a shape parameter for the body form of the fish species. Biomass was calculated for each species at each site by averaging the two divers' estimates.

In estimating fish biomass, species data were pooled into "all fishes" and into several trophic, taxonomic, and size groupings. The four trophic groupings used were: "primary consumers" (herbivores and detritivores); "secondary consumers" (omnivores and benthic invertivores); "planktivores"; and "piscivores". Family-level data on emperors, snappers, breams, parrotfish, and groupers were also presented because of their general importance as fishery targets. Biomass was also pooled into size classes: small- (0–20 cm), medium- (21–50 cm), and large- bodied reef fish (greater than 50 cm).

Total biomass ("TIMOR ALL") and each of the fish groupings from Timor-Leste were compared to averages of reef fish biomass at populated and remote areas across the Pacific Islands where NOAA-CREP has conducted reef fish surveys since 2009 using the same survey methods (Heenan et al. 2014). Data from these remote and populated islands provide context and reference for interpreting fish biomass values from Timor-Leste. While there are other important sources of natural variability among these Pacific reefs, including biogeographic differences, these data from other remote and populated Pacific islands serve as useful reference points for interpreting the Timor-Leste dataset. For example, fish communities observed from Timor-Leste reefs with high human impacts (including fishing activities) are expected to be more similar to the fish communities observed from other populated Pacific reefs. These types of comparisons can help contextualize the baseline datasets NOAA-CREP generated for Timor-Leste's coral reef ecosystems.

Benthic Cover

Field Method

Upon completion of the fish survey, one diver conducted a photoquadrat by photographing the benthos at 1-m intervals along the 30-m transect line between the centers of the two cylinders (30 photographs per site). A 1-m plastic polyvinyl chloride (PVC) pole was used to position a digital camera directly above the substrate to frame a photograph approximately 0.7 m^2 in area (Figure 112).

Figure 112. A fish diver conducting a photoquadrat survey.

Analysis: Benthic Cover Derived from Analysis of Benthic Images Collected during Fish Surveys

For the estimation of benthic cover, each benthic photograph was analyzed using Coral Point Count with Excel Extensions image analysis software (CPCe v.4.12; Kohler and Gill 2006). A photo analyst identified the substrate types under 10 randomly-assigned points overlaid by CPCe on each image.

Benthic organisms and substrate type on the photographs were classified into broad ecological functional groups: hard (scleractinian) coral, soft coral, crustose coralline algae (CCA), macroalgae, turf algae, invertebrate, sediment (sand), and unclassified (the benthos was not clear and/or could not be identified with a high level of confidence). Percent cover estimates for each site were calculated from the photographs as the proportion of the total number of points falling within each functional group divided by the total number of identifiable points for each site (points falling on the transect line or the PVC stick were removed from the total number of points, but unclassified points were retained). Site estimates were averaged for each sector.

Photographs were analyzed for benthic cover implementing CPCe following the same Tier-2 classification and approach as in Lozada-Misa et al . (2017).

From the categorical estimates, a benthic substrate ratio was calculated as the sum of the percent cover of hard coral, soft coral, and CCA divided by the sum of the percent cover of macroalgae and turf algae.

Appendix H. Sites Surveyed for Reef Fishes and Benthic Community Composition

Table 22. Sites by sector surveyed for reef fishes and benthic community composition (visual estimates), and the subset of those sites that have benthic cover data derived from the analysis of benthic photographs (BENTHIC COVER = Y).

SITE ID	LATITUDE	LONGITUDE	DEPTH BIN	BENTHIC COVER
Oecusse				
OEC-02	-9.2337	124.2389	Shallow	Y
OEC-07	-9.2923	124.1588	Mid	Y
OEC-11	-9.2590	124.1802	Shallow	Y
OEC-12	-9.3119	124.1085	Shallow	Y
OEC-16	-9.2988	124.1338	Mid	Y
OEC-19	-9.2844	124.1665	Mid	Y
OEC-21	-9.2960	124.1490	Shallow	Y
OEC-22	-9.3098	124.1162	Mid	Y
OEC-24	-9.3084	124.1237	Shallow	Y
OEC-30	-9.2361	124.2295	Mid	Y
OEC-32	-9.1882	124.3890	Shallow	Y
OEC-43	-9.1956	124.3726	Mid	Y
OEC-45	-9.2266	124.2600	Shallow	Y
OEC-52	-9.1979	124.3207	Mid	Y
OEC-56	-9.1975	124.3614	Shallow	Y
OEC-58	-9.1918	124.3853	Mid	Y
Bobonaro				
BOB-03	-8.8402	125.0264	Mid	Y
BOB-05	-8.8487	125.0176	Mid	Y
BOB-07	-8.8058	125.0871	Mid	Y
BOB-11	-8.8364	125.0321	Mid	Y
BOB-14	-8.8561	125.0118	Shallow	Y
BOB-17	-8.8623	125.0066	Shallow	Y
BOB-19	-8.8585	125.0100	Shallow	Y
BOB-20	-8.8441	125.0222	Mid	Y
BOB-23	-8.8319	125.0353	Shallow	Y
BOB-80	-8.8214	125.0684	Shallow	Y
BOB-82	-8.8158	125.0779	Mid	Y
BOB-86	-8.8275	125.0532	Mid	Y
BOB-87	-8.8262	125.0460	Mid	Y
BOB-88	-8.8239	125.0581	Shallow	Y
BOB-92	-8.8250	125.0561	Shallow	Y
BOB-99	-8.8100	125.0829	Mid	Y
Liquica				
LIQ-01	-8.5663	125.3840	Shallow	Y
LIQ-07	-8.5597	125.4225	Mid	Y
LIQ-08	-8.5740	125.3705	Shallow	Y
LIQ-12	-8.5597	125.4495	Shallow	Y
LIQ-14	-8.6022	125.2861	Mid	Y

SITE ID	LATITUDE	LONGITUDE	DEPTH BIN	BENTHIC COVER
LIQ-15	-8.5846	125.3294	Mid	Y
LIQ-28	-8.6021	125.2933	Shallow	Y
LIQ-30	-8.5632	125.3917	Mid	Y
LIQ-33	-8.6387	125.1294	Shallow	Y
LIQ-35	-8.6044	125.2722	Mid	Y
LIQ-36	-8.6121	125.1910	Mid	Y
LIQ-39	-8.6256	125.1573	Mid	Y
LIQ-40	-8.6929	125.0988	Shallow	Y
LIQ-41	-8.6047	125.2193	Shallow	Y
LIQ-42	-8.6628	125.1105	Shallow	Y
LIQ-43	-8.6031	125.2574	Mid	Y
LIQ-44	-8.6447	125.1213	Mid	Y
LIQ-45	-8.6068	125.2076	Shallow	Y
LIQ-46	-8.6695	125.1068	Mid	Y
LIQ-47	-8.6808	125.1018	Mid	Y
LIQ-57	-8.6349	125.1392	Mid	Y
LIQ-58	-8.6035	125.2329	Mid	–
LIQ-59	-8.6100	125.2006	Mid	Y
LIQ-60	-8.6214	125.1680	Shallow	Y
LIQ-61	-8.6506	125.1152	Mid	Y
LIQ-62	-8.6299	125.1503	Shallow	Y
LIQ-63	-8.6170	125.1790	Shallow	Y
West Atauro				
ATA-53	-8.2268	125.5241	Mid	Y
ATA-58	-8.2208	125.5462	Shallow	Y
ATA-62	-8.1530	125.6024	Mid	Y
ATA-63	-8.1965	125.5627	Shallow	Y
ATA-66	-8.2197	125.5340	Mid	Y
ATA-70	-8.2139	125.5513	Mid	Y
ATA-74	-8.1782	125.5810	Shallow	Y
ATA-75	-8.1721	125.5865	Shallow	Y
ATA-76	-8.1849	125.5737	Mid	Y
ATA-77	-8.1597	125.5941	Shallow	Y
East Atauro				
VIL-04	-8.1822	125.6389	Shallow	Y
VIL-05	-8.1359	125.6426	Shallow	Y
VIL-06	-8.2142	125.6205	Mid	Y
VIL-12	-8.3075	125.5794	Mid	Y
VIL-15	-8.2018	125.6281	Shallow	Y
VIL-17	-8.2364	125.6140	Shallow	Y

SITE ID	LATITUDE	LONGITUDE	DEPTH BIN	BENTHIC COVER
VIL-26	-8.1494	125.6431	Mid	Y
VIL-32	-8.2633	125.6103	Mid	Y
VIL-34	-8.2927	125.5932	Mid	Y
VIL-35	-8.2796	125.6014	Shallow	Y
VIL-40	-8.3066	125.5636	Shallow	Y
VIL-44	-8.1690	125.6453	Mid	Y
Dili				
DIL-01	-8.4951	125.8126	Shallow	Y
DIL-04	-8.4990	125.7803	Mid	Y
DIL-05	-8.4987	125.7932	Shallow	Y
DIL-07	-8.5225	125.6077	Shallow	Y
DIL-08	-8.5127	125.7466	Mid	Y
DIL-10	-8.5242	125.6794	Mid	Y
DIL-12	-8.5127	125.7440	Mid	Y
DIL-18	-8.5202	125.6125	Shallow	Y
DIL-21	-8.4838	125.8335	Shallow	Y
DIL-22	-8.5239	125.6967	Shallow	Y
DIL-23	-8.5222	125.6473	Shallow	–
DIL-24	-8.5184	125.6212	Mid	Y
DIL-26	-8.4845	125.8182	Mid	Y
DIL-31	-8.4994	125.7915	Shallow	Y
DIL-32	-8.5004	125.7754	Mid	Y
MAN-01	-8.5113	126.0479	Mid	Y
MAN-07	-8.4856	125.9759	Mid	Y
MAN-34	-8.4735	125.8603	Mid	Y
MAN-36	-8.4783	125.9511	Mid	Y
MAN-37	-8.4749	125.8491	Shallow	Y
MAN-46	-8.4814	125.9543	Shallow	Y
MAN-47	-8.4789	125.9277	Shallow	Y
MAN-51	-8.4781	125.9103	Shallow	Y
MAN-52	-8.4738	125.8945	Mid	Y
MAN-53	-8.4742	125.8731	Mid	Y
MAN-55	-8.4773	125.9334	Mid	Y
MAN-58	-8.4850	125.9630	Shallow	Y
MAN-59	-8.4816	125.8375	Mid	–
MAN-64	-8.4764	125.9394	Shallow	Y
Baucau				
BAU-01	-8.4160	126.4121	Mid	Y
BAU-03	-8.4455	126.4922	Shallow	Y

SITE ID	LATITUDE	LONGITUDE	DEPTH BIN	BENTHIC COVER
BAU-06	-8.4336	126.4564	Mid	Y
BAU-09	-8.4196	126.4271	Mid	Y
BAU-10	-8.4140	126.4170	Mid	–
BAU-14	-8.4282	126.4482	Shallow	–
BAU-19	-8.4424	126.4776	Shallow	Y
BAU-22	-8.4221	126.4412	Mid	Y
BAU-28	-8.4390	126.4675	Shallow	Y
BAU-32	-8.4224	126.3717	Shallow	Y
BAU-34	-8.4410	126.3445	Mid	Y
BAU-39	-8.4251	126.3840	Mid	Y
BAU-48	-8.4496	126.3292	Shallow	Y
BAU-53	-8.4169	126.4109	Shallow	Y
BAU-59	-8.4259	126.3601	Mid	Y
Lautem				
LAU-02	-8.3766	127.2324	Mid	Y
LAU-03	-8.3628	127.1033	Mid	–
LAU-04	-8.3383	127.1736	Mid	Y
LAU-06	-8.4465	127.3203	Mid	Y
LAU-08	-8.3647	127.2218	Mid	Y
LAU-09	-8.3870	127.2784	Shallow	Y
LAU-10	-8.3666	127.1158	Shallow	Y
LAU-11	-8.3646	127.1346	Mid	Y
LAU-13	-8.3828	127.2531	Shallow	Y
LAU-14	-8.3637	127.0956	Shallow	–
LAU-18	-8.3564	127.1527	Shallow	Y
LAU-20	-8.3864	127.2840	Mid	–
LAU-22	-8.3865	127.2708	Mid	Y
LAU-23	-8.3497	127.2066	Shallow	–
LAU-24	-8.3629	127.0814	Shallow	Y
LAU-26	-8.3463	127.1610	Mid	Y
LAU-28	-8.3535	127.0586	Shallow	–
LAU-29	-8.3622	127.0752	Mid	Y
LAU-30	-8.3783	127.2408	Mid	Y
LAU-61	-8.4180	127.3090	Shallow	Y
LAU-62	-8.4156	127.3111	Shallow	Y
LAU-63	-8.4108	127.3122	Mid	Y
LAU-64	-8.4082	127.3194	Mid	Y
LAU-70	-8.4220	127.3070	Mid	–
LAU-71	-8.4445	127.3414	Mid	Y

Appendix I. Methods: Ecological Baselines for Climate Change

At each Climate Monitoring site, one subsurface temperature recorder (STR), five Calcification Accretion Units (CAUs) and three Autonomous Reef Monitoring Structures (ARMS) were typically deployed (Figure 113). In 2012, 10 Climate Monitoring sites were established; in 2014, eight Climate Monitoring sites were revisited and instruments were recovered.

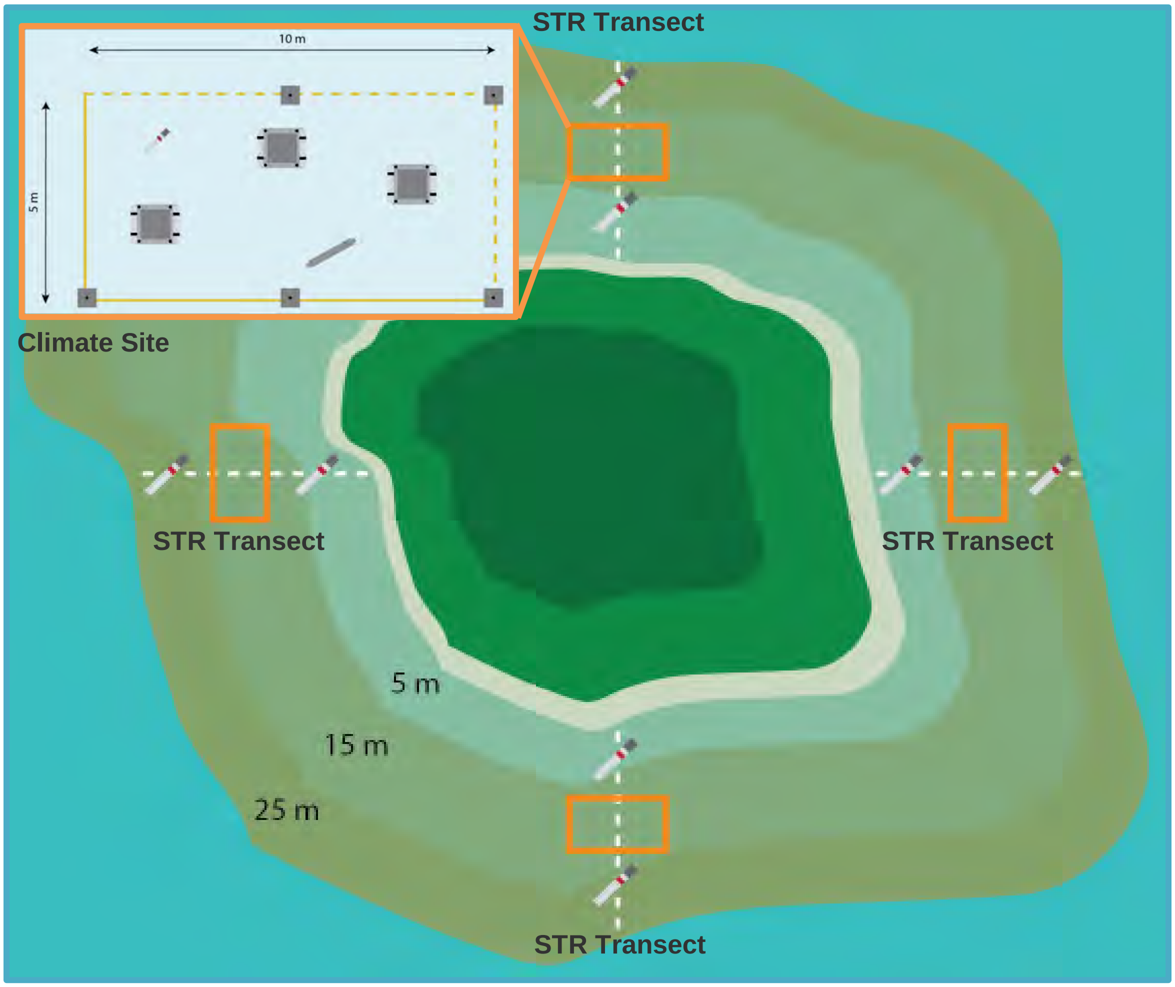


Figure 113. Schematic of Climate Monitoring sites (orange boxes) and STR transects (dashed white lines) around an island. A STR transect includes 1 STR deployed in the shallow (0–6 m), mid (6–18 m), and deep (18–30 m) water at each site, and the mid-depth STR is deployed within the Climate Monitoring site. Inset shows details of the Climate Monitoring site with the deployment of three ARMS (large grey squares), five CAUs (small grey squares), one STR (top left), one water sample (bottom middle), and the photoquad (dashed orange line).

Temperature (STRs)

Field Method

Temperature data were collected using high-accuracy, subsurface temperature recorders (STRs) made by Sea-Bird Electronics (model no. 39), which sampled at a rate of 1 temperature measurement every 60 minutes throughout the 2-year deployment. STRs were attached to a mounting bracket with weights and then strapped to reef substrate at the benthos using large cable ties. At each of the Climate Monitoring sites, one STR was deployed in the mid-depth range (6–18 m)in close proximity to the other instruments. Additionally, STR transects (Figure 113) were established at 4 of the sites in 2012, with a second STR deployed in the shallow depth range (0–6 m), and a third STR deployed in the deep water range (18–30 m) at 3 of those 4 sites. See Table 23 for a complete list of STRs deployed and recovered.

Remote Sensing Method

To serve as a comparison to the STR data, we extracted the NOAA ¼° daily Optimum Interpolation Sea Surface Temperature (OISST) for the northern Timor-Leste region. The OISST is an analysis constructed by combining temperature observations from different platforms (satellites, ships, and buoys) on a regular global grid (Reynolds et al. 2002).

Analysis

For each STR, there are two versions of the data files with .ASC and .CDP extensions. Data downloaded from the instruments were saved as an ASC file and include the header information. The data were then processed and quality controlled using MATLAB to remove the header, extraneous data from the periods prior to deployment and post recovery, and erroneous records, and were then saved as a CDP (CREP Data Product) text file.

Raw STR data were smoothed with a 180-day running mean reducing the associated daily variability for visualization purposes and highlighting the main temperature patterns. Daily OISST data were smoothed using a 7-day running mean for the same purpose.

Table 23. STRs deployed and recovered between 2012 and 2014 by NOAA-CREP in Timor-Leste. No data were collected from the mid-depth STR recovered at LAU-01 (record in grey).

SITE ID	LATITUDE	LONGITUDE	DEPTH (m)	DEPLOY DATE	RECOVER DATE
BOB-02	-8.85328816	125.0132672	14.9	10/17/2012	9/22/2014
DIL-02	-8.55484044	125.4992917	6.1	10/15/2012	10/9/2014
DIL-02	-8.55465126	125.4991272	14.0	10/15/2012	10/9/2014
DIL-02	-8.55459971	125.4989724	24.7	10/15/2012	–
VIL-03	-8.30331881	125.5584685	13.1	10/18/2012	9/16/2014
VIL-10	-8.22428752	125.6167984	6.1	10/25/2012	9/18/2014
VIL-10	-8.22440553	125.6168395	13.1	10/25/2012	9/18/2014
VIL-10	-8.22448508	125.6168435	25.0	10/25/2012	9/18/2014
MAF-01	-9.15203	125.8220562	14.6	10/21/2012	–
MAN-09	-8.47532158	125.9065769	4.9	10/24/2012	9/24/2014
MAN-09	-8.47513382	125.9067561	14.6	10/24/2012	9/24/2014
BAU-04	-8.41960078	126.4270697	12.8	10/19/2012	9/28/2014
LAU-07	-8.6842867	126.9897779	11.0	10/22/2012	–
LAU-01	-8.34661318	127.1611709	4.6	10/23/2012	10/6/2014
LAU-01	-8.3463836	127.160992	14.3	10/23/2012	10/6/2014
LAU-01	-8.34633071	127.1609347	25.3	10/23/2012	10/6/2014
LAU-05	-8.41080515	127.3122215	14.6	10/20/2012	10/3/2014

Seawater Chemistry

Field Method

At each Climate Monitoring site, 1 discrete near reef seawater sample (recovered at ~15-m depth) and 1 surface seawater sample (recovered at ~1-m depth) were collected using 5-L Niskin bottles. In 2013, a third seawater sample was collected ~1-km offshore from each site (recovered at ~1-m depth). See Table 24 for a complete list of water samples collected in 2013 and 2014. Each time a water sample was collected, it was divided into: (1) a 500-mL glass bottle and preserved with mercuric chloride (for dissolved inorganic carbon [DIC] and total alkalinity [TA] analysis) and (2) a 250-mL HDPE plastic bottle (for salinity analysis). During both 2013 and 2014 field efforts, 1 in 4 water sample collections were replicated to ensure analytical reproducibility.

Table 24. Water samples collected around Timor-Leste in 2013 and 2014. Three water samples (surface, benthic, and offshore) were collected at eight of the Climate Monitoring sites in 2013 and additional samples were collected at a subset of the reef fish survey sites. Two water samples (surface and benthic only) were collected at the same eight Climate Monitoring sites in 2014.

SITE ID	LATITUDE	LONGITUDE	DATE	SURFACE (m)	BENTHIC (m)	OFFSHORE (m)
2013 Climate Monitoring Sites						
BOB-02	-8.85324089	125.0132288	6/14/2013	0.9	14.0	
BOB-02	-8.8474899	125.0066692	6/14/2013			0.9
DIL-02	-8.55469116	125.4992045	6/27/2013	0.9	14.0	
DIL-02	-8.54703639	125.4959428	6/27/2013			0.9
VIL-03	-8.3033375	125.5585172	6/6/2013	0.9	15.4	
VIL-03	-8.3089315	125.5526682	6/6/2013			0.9
VIL-10	-8.22437125	125.6168803	6/6/2013	0.9	13.7	
VIL-10	-8.22253654	125.623466	6/6/2013			0.9
MAN-09	-8.47521907	125.9067249	6/19/2013	0.9	11.6	
MAN-09	-8.46729632	125.9064028	6/19/2013			0.9
BAU-04	-8.41959751	126.4270859	6/20/2013	0.9	14.3	
BAU-04	-8.41341812	126.4302182	6/20/2013			0.9
LAU-01	-8.34639223	127.1610254	6/21/2013	0.9	14.3	
LAU-01	-8.33927021	127.1554364	6/21/2013			0.9
LAU-05	-8.4108282	127.3121913	6/25/2013	0.9	16.8	
LAU-05	-8.40311006	127.311871	6/25/2013			0.9
2013 Other (non-climate) Sites						
OEC-43	-9.19571104	124.372808	6/16/2013	0.9	13.1	
OEC-43	-9.188659	124.3683361	6/16/2013			0.9
ATA-62	-8.15301334	125.6024217	6/18/2013		13.7	
DIL-12	-8.51264996	125.74406	6/27/2013		12.5	
LAU-29	-8.36221207	127.075241	6/26/2013		11.3	
LAU-03	-8.36288187	127.1034242	6/26/2013		11.3	
LAU-09	-8.38678312	127.2780601	6/25/2013		12.8	
2014 Climate Monitoring Sites						
BOB-02	-8.85320778	125.0131945	9/22/2014	0.9	14.6	
DIL-02	-8.55465	125.49912	10/9/2014	0.9	13.7	
VIL-03	-8.303372115	125.5584964	9/16/2014	0.9	14.9	
VIL-10	-8.224377288	125.6168642	9/18/2014	0.9	13.1	
MAN-09	-8.475181097	125.9066781	9/24/2014	0.9	14.6	
BAU-04	-8.41943	126.4268	9/28/2014	0.9	14.3	
LAU-01	-8.34643	127.16095	10/6/2014	0.9	14.6	
LAU-05	-8.41082	127.31222	10/3/2014	0.9	15.5	

In 2013, electronic measurements of temperature and pressure were taken at the location where each water sample was collected using a Seabird SBE-39 subsurface temperature recorder. In 2014, immediately upon returning to the dive boat, a conductivity-temperature-depth instrument was used to sample through the water column above the 15-m survey site using a SBE-19plus.

Analysis

Water samples were shipped to the NOAA Pacific Marine Environmental Laboratory (PMEL) in Seattle, WA for laboratory analysis of dissolved inorganic carbon, total alkalinity, and salinity.

See PMEL's methodology to collect seawater samples for carbonate chemistry analysis (http://www.pmel.noaa.gov/co2/files/dic_sample_technique_revised_5-17-10.pdf).

Calcification Accretion Units (CAUs)

Field Method

The following description was adapted from the methods section of Vargas-Angel et al. (2015). Each CAU assembly comprised two 10-cm × 10-cm PVC plates separated by a 1-cm plastic spacer and mounted on a stainless steel all-thread rod. These assemblies were attached to a stainless steel stake installed into hard substrate around the perimeter of each climate survey site, and left to accrete for approximately 2 years (Figure 114). During recovery, each CAU was placed in a Ziploc bag to minimize the loss of attached calcified material during transport. Recovered CAUs were frozen at –5°C for preservation during transportation to the laboratory in Honolulu, Hawaii. See Table 25 for a complete list of CAUs deployed and recovered.

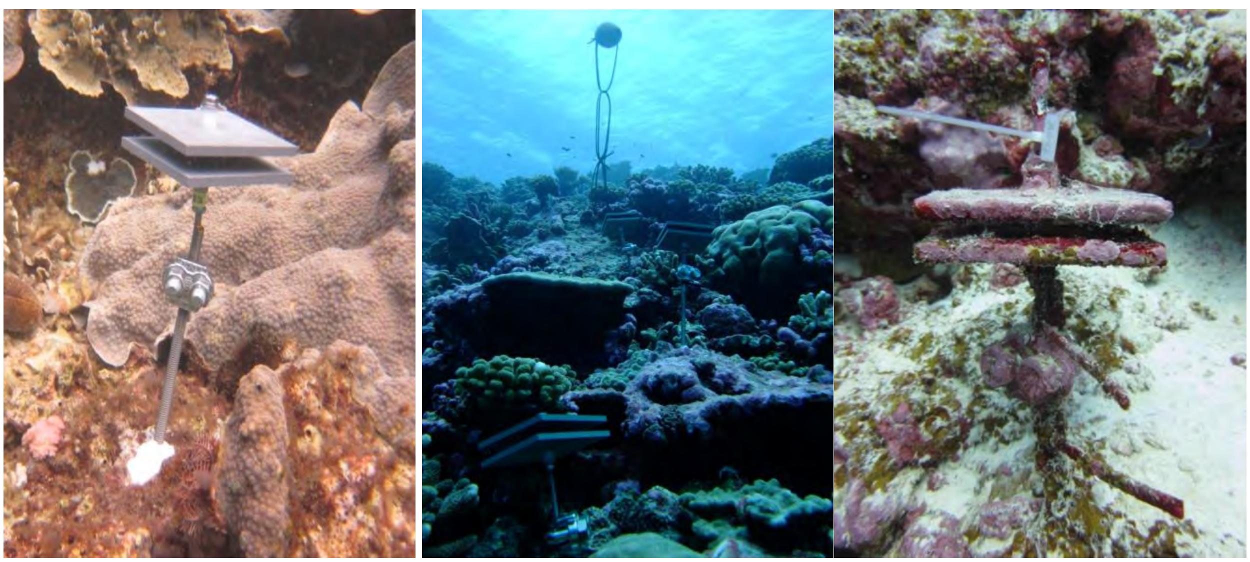


Figure 114. Newly deployed Calcification Accretion Unit (CAU) on the seafloor at one of the Climate Monitoring sites in Timor-Leste (*left*). CAUs installed within a Climate Monitoring site with an STR deployed nearby (*middle).* CAU about to be recovered approximately two years later (*right*).

Table 25. CAUs deployed and recovered between 2012 and 2014 in Timor-Leste.

SITE ID	LATITUDE	LONGITUDE	DEPTH (m)	DEPLOY DATE	NUMBER DEPLOYED	RECOVER DATE	NUMBER RECOVERED	SOAK TIME (days)
BOB-02	-8.85329	125.01327	14.0	10/17/2012	5	9/22/2014	4	705
DIL-02	-8.55465	125.49913	13.1	10/15/2012	5	10/9/2014	5	724
VIL-03	-8.30332	125.55847	14.3	10/18/2012	5	9/16/2014	5	698
VIL-10	-8.22441	125.61684	13.1	10/25/2012	5	9/18/2014	4	693
MAF-01	-9.15203	125.82206	14.6	10/21/2012	5	–	–	–
MAN-09	-8.47513	125.90675	14.6	10/24/2012	5	9/24/2014	1	700
BAU-04	-8.4196	126.42707	13.7	10/19/2012	5	9/28/2014	5	709
LAU-07	-8.68429	126.98978	11.0	10/22/2012	5	–	–	–
LAU-01	-8.34638	127.161	14.6	10/23/2012	5	10/6/2014	5	713
LAU-05	-8.4108	127.31222	14.6	10/20/2012	5	10/3/2014	5	713

Analysis

In the laboratory, after disassembly of each CAU, plates were dried at 60°C for 2–5 days, and were classified as dry when the difference in weight between sequential weighings was less than 0.1 g. After drying, each individual plate was submerged in a 5% hydrochloric acid bath (HCl) for 24-hours or until all calcium carbonate ($CaCO_3$) had dissolved. As the HCl solution was neutralized by the $CaCO_3$ dissolution (indicated by the absence of gas bubbles), additional HCl was added to complete the dissolution process. Often, the addition of acid was repeated several times in a 24–72-hour period until all $CaCO_3$ was removed. The remaining fleshy tissue was scraped onto pre-weighed 11-µm cellulose filter paper, vacuum filtered along with all 5% HCl supernatant from the dissolution process, and dried at 60°C until constant weight using the same dryness criteria above; 48 hours minimum. The clean, scraped, and dried CAU plates were re-weighed, and the mass of $CaCO_3$ was determined by subtracting the combined weight of the fleshy tissue and PVC plates from the initial dry weight of the CAU prior to dissolution. To determine the rate of $CaCO_3$ accretion, the mass of $CaCO_3$ was normalized for surface area of each CAU (400 cm^2—accounting for all upper and lower plate surfaces) and the amount of time in days that each CAU was deployed, rendering a measure of net $CaCO_3$ accretion in units of g $CaCO_3$ cm^{-2} yr^{-1}. This reef calcification rate was averaged between the CAU units recovered at each site.

Autonomous Reef Monitoring Structure (ARMS)

Field Method

ARMS, composed of nine PVC plates (23 cm x 23 cm) stacked in alternating series of open and semi-enclosed layers, were affixed to the seafloor between 12–15 m in replicate sets of three (Figure 115A). They remained on the benthos for two years during which time they were naturally colonized with marine organisms (Figure 115B). After the 2-year deployment period, the ARMS units were encapsulated within a 106-µm nitex-lined crate, brought to the surface, placed within a large seawater holding bin and transported to shore. On shore, they were disassembled plate by plate, with both sides photo-documented (see the ARMS plate collages in Appendix E). The plates were then scraped clear of all the accumulated sessile biomass and immediately homogenized in a blender, filtered with a 40-µm net, subsampled, and preserved for metabarcoding (Figure 115C).

The seawater used during processing was sieved using 2-mm, 500-µm and 106-µm geologic sieves to create three size fractions (Figure 115D). The >2 mm fraction was sorted to morphospecies, photographed, and brachyuran crabs were preserved for DNA barcoding (Figure 115E). The two smaller motile fractions were preserved for additional lab and molecular processing. See Table 26 for a complete list of ARMS deployed and recovered.

Figure 115. Clockwise starting from upper left: A) SCUBA diver attaching an ARMS to the seafloor; B) An ARMS about to be recovered after deployment for ~2 years; C) Scraping an ARMS plate; D) A sieved 2-mm fraction; E) Sorting through the organisms recovered from the 2-mm fraction.

Table 26. ARMS deployed and recovered in Timor-Leste from 2012 to 2014.

SITE ID	LATITUDE	LONGITUDE	DEPTH (m)	DEPLOY DATE	NUMBER DEPLOYED	RECOVER DATE	NUMBER RECOVERED
BOB-02	-8.85329	125.01327	14.0	10/17/2012	3	9/22/2014	3
DIL-02	-8.55465	125.49913	13.1	10/15/2012	4	10/9/2014	3
VIL-03	-8.30332	125.55847	14.3	10/18/2012	3	9/16/2014	3
VIL-10	-8.22441	125.61684	13.1	10/25/2012	3	9/17/2014	3
MAF-01	-9.15203	125.82206	14.6	10/21/2012	3	–	–
MAN-09	-8.47513	125.90675	14.6	10/24/2012	3	9/24/2014	3
BAU-04	-8.4196	126.42707	13.7	10/19/2012	3	9/28/2014	3
LAU-07	-8.68429	126.98978	11.0	10/22/2012	3	–	–
LAU-01	-8.34638	127.161	14.6	10/23/2012	3	10/6/2014	3
LAU-05	-8.4108	127.31222	14.6	10/20/2012	4	10/3/2014	4

Lab Methods

Decantation—Due to sediment within the 500-µm and 106-µm fractions that can inhibit metabarcoding laboratory processing, a decantation procedure was conducted on these fractions from each ARMS unit to separate the sediment from the organic matter (Leray and Knowlton 2015). Upon the completion of the decantation process, half of the sample was crushed with a mortar and pestle for DNA extraction and metabarcoding while the other half was preserved as a backup.

DNA barcoding—Legs from brachyuran crabs were subsampled, and genomic DNA was extracted using standard proteinase-k digestion followed by phenol-chloroform extraction on the AutoGenprep 965 (Autogen). Primers designed by Geller et al. (2013) were used to target approximately 658 base pairs of the COI gene and automated sequencing techniques were used to sequence in both directions.

DNA metabarcoding—DNA was extracted from 10 grams of the homogenized sessile scrapings and from the decanted 500-µm and 100-µm motile fractions using the MO-Bio PowerMax Soil extraction kits. Using the reverse primer, jgHCO2198 (Geller et al. 2013), and the forward primer, mlCOIintF (Leray et al. 2013), a 313 base pair fragment of COI was amplified using a PCR (polymerase chain reaction) touchdown protocol with 16 initial cycles: denaturation for 10 seconds at 95°C, annealing for 30 seconds at 62°C (–1°C per cycle), and extension for 60 seconds at 72°C, followed by 25 cycles at 46°C annealing temperature (Leray et al. 2013; Leray and Knowlton 2015). PCRs were performed in triplicates and inspected on agarose gels. Triplicate PCR products were pooled, cleaned using Agencourt AMPure beads, and quantified using Biotum AccuClear Ultra High Sensitivity Quantification Kit. PCR products were then inserted directly into the Kappa Systems Hyper-Prep sample kit using dual-end Illumina adapters for ligation. Sample libraries were validated by visualization on an Agilent 2100 BioAnalyzer, quantified using qPCR, pooled, and sequenced on an Illumina MiSeq platform. Each library yielded approximately 250,000 reads per sample, and a standard quality control filter was run to parse the Illumina reads into FASTQ files sorted by index.

Analysis

Morphospecies (2-mm size fraction)—Overall abundance of >2 mm organisms was averaged between ARMS units recovered at each site to give a site-level metric. Organisms were additionally averaged by ARMS unit at the island scale for comparison with other ARMS recovery locations across the Pacific. Dominant phyla and taxa groups within phyla were averaged between ARMS units and compared across sites.

Crab DNA barcoding—Resulting sequences of crabs were clustered into Operational Taxonomic Units (OTUs) and blasted (cross checked) against existing DNA-barcoding libraries (Barcode of Life Data Systems [BOLD] and Moorea Biocode). Matched sequences with >97% identity and >85% coverage were identified to an existing record of the species within the databases. Those crab sequences with <97% identity and >85% coverage underwent a phylogenetic Bayesian approach using the Statistical Assignment Package (SAP) to assign OTUs to higher taxonomic levels in the absence of a direct match. Species richness was averaged by ARMS unit at each site and examined on the island scale in relation to the richness of brachyuran crabs from other ARMS units collected by NOAA-CREP in the Pacific Ocean. Broad scale richness values were calculated per ARMS unit richness rather than by island due to the variability in the number of ARMS units deployed across islands.

Metabarcoding bioinformatics—Sequences were assembled, trimmed, cleaned, and dereplicated following standard bioinformatics techniques using available software programs. Dereplicated sequences were then aligned to COI barcodes from the BOLD database. Matched sequences ≥97% identity and ≥85% coverage are presented herein. Sequences that did not have a direct match have not been directly DNA barcoded and thus species resolution is not available. Once the phylogenetic approaches and bioinformatic software have been refined, the remaining unknown sequences can be determined. Currently available software is not capable of working through 10 million plus sequence reads that span across multiple phyla. However, through the efforts of a third-party bioinformation specialist working on these data sets for Timor-Leste, a solution will be found in the near future to provide phyla-based resolution of the remaining sequences that will indicate percent cover of the phyla communities that have recruited to the ARMS units.

Benthic Cover

Field Method

At each Climate Monitoring site, digital photos of the benthos were collected at 1-m intervals along two transects implementing a high-resolution digital camera mounted on a pole. This process generated ~30 photographs per site.

Analysis

Benthic photographs were analyzed using CPCe following the same method as described in the *Analysis: Benthic Cover Derived from Analysis of Benthic Images Collected during Fish Surveys* section of Appendix G.

Appendix J. DNA Barcoding and Metabarcoding Explained

DNA barcodes are short, species specific genetic sequences used to identify taxa, similar to how a fingerprint can identify individual humans or the way a supermarket scanner can distinguish products using the black stripes of the Universal Product Code. For metazoans (organisms from the animal kingdom), the leading genomic region for DNA barcoding is the cytochrome oxidase I (COI) gene of the mitochondrial genome. Prior to DNA barcoding, biological specimens were identified using morphological features such as color, size, and shape of body parts and required taxonomic training, the use of morphological "keys", and undamaged specimens. DNA barcoding solves these problems by requiring just a tiny amount of tissue and no taxonomic expertise.

Barcoded organisms tend to be individually photographed, preserved, and when possible, visually assigned to the lowest known taxon. Once sequenced, they are termed Operational Taxonomic Units (OTU) and are typically matched at a 97% sequence similarity to existing sequences with known species names that reside within publicly available DNA-barcode libraries such as the Barcode of Life Data Systems (BOLD; http://www.boldsystems.org/). OTUs are pragmatic proxies for "species" and those that match directly with known sequences within the DNA libraries are assigned a species name. In the absence of a direct match, OTUs can undergo a phylogenetic computational approach to assign them to higher taxonomic levels such as to a genus or family level. As more and more organisms are vouchered, identified, barcoded, and their sequences submitted to DNA-barcode libraries, previously unidentified sequences can regularly be blasted (cross-checked) against the barcode libraries to increase taxon resolution assuming the sequences are stored and properly archived.

DNA metabarcoding is a cutting-edge molecular technique that resembles DNA barcoding in that it targets a specified gene and obtains short genetic sequences for identification. However, this technique sequences hundreds to thousands of organisms at one time rather than focusing on a single unique individual. Thus, individual metabarcoding samples are viewed as sampled communities.

Metabarcoding samples tend to be bulked, homogenized, or filtered (water) and may or may not have obvious signs of biological material. As a result, barcode libraries are critical to metabarcoding techniques in the identification of organisms. Given the sheer diversity of coral reef cryptobiota, there are thousands of organisms that do not have an associated DNA barcode identified in a library and are, in fact, probably new to science. Thus, to date, species-level identification is not possible for all sequences obtained from metabarcoding. Sequences not identified can be clustered into OTUs based on DNA sequence similarity as discussed above. As DNA libraries grow, sequences can be re-examined to not only obtain species identifications but to investigate community composition metrics. Innovative bioinformatic (computational) processing mechanisms focused on the phylogenetic relationships of sequences are currently being developed and will provide and enhance a deeper resolution of the millions of sequencing data obtained from combined ARMS units to understand diversity and composition across spatial scales. As these methods develop and improve, the ARMS deployed around Timor-Leste will be integrated into a global analysis of cryptobiota diversity and composition, the first of its kind.

Appendix K. Species Data from the Metabarcoding Matches

Table 27. Species data from the metabarcoding matches. That is, the subset of sequences that matched existing Operational Taxonomic Unit (OTU) barcodes within the Moorea Biocode database. Singletons and database hits totaling less than 10 sequences are removed.

Database Match	Taxa Level Identified	Taxa Group	Common Name	Total # of Matched Sequences
Gammarus mucronatus	Species	Amphipod	Amphipod	24
Gammarus stalagmiticus	Species	Amphipod	Amphipod	52
Chthamalus dalli	Species	Barnacle	Barnacle	48
Haemorhous mexicanus	Species	Bird	House Finch	11
Gallus gallus	Species	Bird	Junglefowl	93
Pinna muricata	Species	Bivalve	Prickly Pen Shell	15
Pinctada maculata	Species	Bivalve	Gulf Pearl Oyster	30
Pinctada albina	Species	Bivalve	Sharks Bay Shell Pearl Oyster	19,093
Ophiothrix trilineata	Species	Brittle Star	Brittle Star	15
Macrophiothrix rhabdota	Species	Brittle Star	Brittle Star	110
Macrophiothrix megapoma	Species	Brittle Star	Brittle Star	196
Macrophiothrix demessa	Species	Brittle Star	Brittle Star	1,431
Macrophiothrix propinqua	Species	Brittle Star	Brittle Star	8,840
Canthocalanus pauper	Species	Copepod	Copepod	14
Acartia sp. mw-2008	Genus	Copepod	Copepod	27
Euchaeta marina	Species	Copepod	Copepod	29
Undinula vulgaris	Species	Copepod	Copepod	33
Paracalanus parvus	Species	Copepod	Copepod	39
Temora discaudata	Species	Copepod	Copepod	66
Cosmocalanus darwinii	Species	Copepod	Copepod	81
Pontellina plumata	Species	Copepod	Copepod	91
Scolecithrix danae	Species	Copepod	Copepod	99
Copilia mirabilis	Species	Copepod	Copepod	168
Acartia negligens	Species	Copepod	Copepod	384
Clausocalanus furcatus	Species	Copepod	Copepod	1,219
Xanthias latifrons	Species	Crab	Crab	14
Chlorodiella laevissima	Species	Crab	Crab	24
Deckenia imitatrix	Species	Crab	Freshwater Crab	30
Liomera sp. lp-2009	Genus	Crab	Crab	48
Atergatis floridus	Species	Crab	Crab	90
Pseudoliomera variolosa	Species	Crab	Crab	90
Tweedieia laysani	Species	Crab	Crab	119
Euxanthus sp. lp-2009	Genus	Crab	Crab	137

Trapezia rufopunctata	Species	Crab	Coral Crab	241
Pilumnus sp. lp-2009	Genus	Crab	Crab	1,827
Azadinium spinosum	Species	Dinoflagellate	Dinoflagellate	360
Arothron nigropunctatus	Species	Fish	Pufferfish	10
Parupeneus multifasciatus	Species	Fish	Goatfish	10
Diagramma picta	Species	Fish	Grunt (Fish)	11
Ctenochaetus striatus	Species	Fish	Striated Surgeonfish	12
Ctenochaetus strigosus	Species	Fish	Kole Tang	15
Lutjanus ophuysenii	Species	Fish	Brown-Stripe Red Snapper	22
Katsuwonus pelamis	Species	Fish	Skipjack Tuna	24
Centropyge argi	Species	Fish	Pygmy Angelfish	29
Genicanthus lamarck	Species	Fish	Lamarck'S Angelfish	29
Auxis thazard	Species	Fish	Frigate Tuna	35
Cheilinus oxycephalus	Species	Fish	Snooty Wrasse	35
Dascyllus trimaculatus	Species	Fish	Domino Damselfish	55
Chromis degruyi	Species	Fish	Damselfish	83
Thunnus albacares	Species	Fish	Yellowfin Tuna	96
Hyporhamphus quoyi	Species	Fish	Longtail Garfish	106
Chaetodon kleinii	Species	Fish	Sunburst Butterflyfish	236
Selar crumenophthalmus	Species	Fish	Bigeye Scad	260
Pseudanthias huchtii	Species	Fish	Red Cheek Fairy Basslet	344
Myripristis murdjan	Species	Fish	Soldierfish	635
Cheilinus chlorourus	Species	Fish	Floral Wrasse	1,494
Acanthocybium solandri	Species	Fish	Wahoo	2,069
Euthynnus affinis	Species	Fish	Mackerel Tuna	4,008
Pseudanthias squamipinnis	Species	Fish	Lyretail Coralfish	4,363
Pictichromis paccagnellae	Species	Fish	Royal Dottyback (Fish)	24,444
Paragoniastrea australensis	Species	Hard Coral	Hard Coral	10
Cyphastrea serailia	Species	Hard Coral	Hard Coral	24
Tubastraea coccinea	Species	Hard Coral	Orange Cup Coral	409
Agaricia agaricites	Species	Hard Coral	Lettuce Coral	888
Leptastrea purpurea	Species	Hard Coral	Hard Coral	3,218
Porites astreoides	Species	Hard Coral	Mustard Hill Coral	15,636
Drosophila signata	Species	Insect	Fly	13
Paratrechina longicornis	Species	Insect	Longhorn Crazy Ant	15
Cotesia rubecula	Species	Insect	Wasp	17
Cotesia congregata	Species	Insect	Wasp	18
Sycophila taprobanica	Species	Insect	Wasp	22
Pseudevadne tergestina	Species	Insect	Water Flea	29
Cryptotermes brevis	Species	Insect	West Indian Drywood Termite	1,220
Trichomyrmex destructor	Species	Insect	Destructive Trailing Ant/Singapore Ant	1,316

Culex quinquefasciatus	Species	Insect	Mosquito	1,379
Rattus norvegicus	Species	Mammal	Brown Rat	15
Sus scrofa	Species	Mammal	Wild Boar	56
Homo sapiens	Species	Mammal	Human	7,830
Lyncina lynx	Species	Marine Snail	Cowry	10
Purpuradusta minoridens	Species	Marine Snail	Cowry	13
Mitromorpha metula	Species	Marine Snail	Cone Snail	15
Erosaria beckii	Species	Marine Snail	Cowry	16
Turbo petholatus	Species	Marine Snail	Tuban Shell	20
Haminoea sp. 3 maem-2006	Genus	Marine Snail	Bubble Shell	23
Notadusta punctata	Species	Marine Snail	Cowry	30
Erosaria labrolineata	Species	Marine Snail	Cowry	33
Tympanotonus fuscatus	Species	Marine Snail	Mud Creeper	37
Astralium rhodostomum	Species	Marine Snail	Turban Shell	42
Micromelo undata	Species	Marine Snail	Bubble Snail	53
Staphylaea staphylaea	Species	Marine Snail	Cowry	55
Asteronotus cespitosus	Species	Marine Snail	Nudibranch	272
Bistolida ursellus	Species	Marine Snail	Cowry	523
Erato sp. 1-cm-2003	Genus	Marine Snail	Bean Cowry	524
Parougia albomaculata	Species	Marine Worm	Polychaeta	75
Palola sp. as-2005	Genus	Marine Worm	Polychaeta	707
Octopus cyanea	Species	Octopus	Octopus	28
Petrolisthes sp. lp-2009	Genus	Porcelain Crab	Porcelain Crab	21
Asparagopsis taxiformis	Species	Red Algae	Red Algae	14
Stylocheilus longicauda	Species	Sea Hare	Sea Hare	425
Metalpheus sp. lp-2009	Genus	Shrimp	Snapping Shrimp	11
Gnathophyllum americanum	Species	Shrimp	Shrimp	91
Periclimenes sp. lp-2009	Genus	Shrimp	Shrimp	876
Hippolytidae sp. lp-2009	Family	Shrimp	Broken-Back Shrimp	4,222
Alpheus bengalensis	Species	Shrimp	Snapping Shrimp	7,322
Cuapetes tenuipes	Species	Shrimp	Shrimp	37,839
Sarcophyton glaucum	Species	Soft Coral	Rough Leather Coral	130
Thymoites unimaculatus	Species	Spider	Small Orange Spider	10
Placospongia sp. ucmpwc866	Genus	Sponge	Sponge	10
Tethyid sp. ucmpwc1062	Family	Sponge	Sponge	14
Geodia californica	Species	Sponge	Sponge	16
Rhizaxinella sp. g319653	Genus	Sponge	Sponge	17
Geodia phlegraei	Species	Sponge	Sponge	20
Oceanapia sp. ucmpwc1016	Genus	Sponge	Sponge	23
Halichondria sp. halsp-1	Genus	Sponge	Sponge	25
Pione velans	Species	Sponge	Sponge	25

Hemiasterella sp. ucmpwc1021	Genus	Sponge	Sponge	28
Suberites sp. ucmpwc859	Genus	Sponge	Sponge	32
Timea sp. g303973	Genus	Sponge	Sponge	59
Iotrochota birotulata	Species	Sponge	Sponge	93
Halichondria sp. halsp-5	Genus	Sponge	Sponge	373
Halichondria okadai	Species	Sponge	Sponge	443
Tedania klausi	Species	Sponge	Sponge	571
Clathria prolifera	Species	Sponge	Sponge	764
Stellettinopsis megastylifera	Species	Sponge	Sponge	1,395
Hymeniacidon flavia	Species	Sponge	Sponge	1,564
protosuberites' sp. por14649	Genus	Sponge	Sponge	45,302
Sadayoshia sp. lp-2009	Genus	Squat Lobster	Squat Lobster	28
Symplegma rubra	Species	Tunicate	Tunicate	11
Botryllus tyreus	Species	Tunicate	Tunicate	261
Mespilia globulus	Species	Urchin	Blue Tuxedo Urchin	36

GLOSSARY OF TERMS

TERM	DEFINITION	SOURCE
Agarose	Agarose is the preferred matrix for work with proteins and nucleic acids because of its neutral charge and lower degree of chemical complexity.	www.coris.noaa.gov
Algae	Unicellular, multicellular, solitary, or colonial organisms that contain chlorophyll. They lack roots, stems, leaves, flowers, and seeds. Algae are in the Kingdom Protista.	www.coris.noaa.gov
Anthropogenic	Made by people or resulting from human activities.	www.coris.noaa.gov
Aragonite	A mineral species of calcium carbonate ($CaCO_3$) with a crystal structure different from the other two forms of $CaCO_3$ (vaterite and calcite); it is precipitated from ocean surface waters mainly by organisms (e.g., coral) that use this aragonite form of calcium carbonate to make their shells and skeletons.	www.coris.noaa.gov
Backreef	The shoreward side of a reef, including the area and sediments between the reef crest/algal ridge and the land. It corresponds to the reef flat and lagoon of a barrier reef and platform margin reef systems.	www.coris.noaa.gov
Baseline	A quantitative level or value from which other data and observations of a comparable nature are referenced.	www.coris.noaa.gov
Bathymetry	The science of measuring ocean depths to determine the topography of the sea floor.	www.coris.noaa.gov
Benthic	Bottom dwelling; living on or under the sediments or other substrate (benthic region = bottom layer lining a body of water).	www.coris.noaa.gov
Benthos	An organism whose habitat is on or near the bottom of a stream, lake, or ocean.	www.coris.noaa.gov
Biodiversity	The total diversity and variability of living things and of the systems of which they are a part. This includes the total range of variation in and variability among systems and organisms at the bioregional, ecosystem and habitat levels, at the various organismal levels down to species, populations and individuals and at the level of the population and genes.	www.coris.noaa.gov
Bioinformatics	The analysis of biological information using computers and statistical techniques; the science of developing and utilizing computer databases and algorithms to accelerate and enhance biological research. Bioinformatics is particularly important as an adjunct to genomics research, because of the large volume of complex data generated.	www.coris.noaa.gov
Biomass	An estimate of the amount of living matter per some unit volume or area.	www.coris.noaa.gov

Calcification	The process by which corals and calcareous algae extract calcium from seawater and produce it as calcium carbonate (accretion = growth by virtue of an increase in intercellular material).	www.coris.noaa.gov
Calcium Carbonate	A molecule consisting of calcium, carbon, and oxygen secreted by corals to their skeleton. It is also secreted by mollusks to form their protective shells.	www.coris.noaa.gov
Carbonate Chemistry	When CO_2 from the atmosphere comes into contact with seawater, it dissolves into the water where it undergoes chemical reactions to form inorganic carbon (in the form of carbonic acid, hydrogen ion + bicarbonate and/or hydrogen ion + carbonate).	https://www.e-education.psu.edu/earth103/node/677
Climate Change	The long-term fluctuations in temperature, precipitation, wind, and all other aspects of the Earth's climate. It is also defined by the United Nations Convention on Climate Change as "change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"; an observed change in the prevailing or average weather conditions.	www.coris.noaa.gov
Climatology	The scientific study of climates, including causes and long-term effects of variation.	https://www.google.com/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=climatology+definition&*
Coastal	The areas of land and sea bordering the shoreline and extending seaward through the breaker zone. Coastal areas throughout the world are under enormous environmental stress caused by a wide range of factors, including pollution and the destruction and deterioration of marine habitats.	www.coris.noaa.gov
Conductivity	The ability or power to conduct or transmit heat, electricity, or sound. Because the electrical current is transported by the ions in solution, the conductivity increases as the concentration of ions increases.	http://www.lenntech.com/applications/ultrapure/conductivity/water-conductivity.htm
Coral Bleaching	The process in which a coral polyp, under environmental stress, expels its symbiotic zooxanthellae from its body. The affected coral colony appears whitened; for example, if the sea surface temperature (SST) exceeds the climatological maximum for a region by 1 degree Celsius or more, this stress can result in bleaching, which is often followed by mortality.	www.coris.noaa.gov
Crustose Coralline Algae	Crustose coralline algae are red algae of the division Rhodophyta. They are very important members of a reef community as they cement and bind the reef together.	www.coris.noaa.gov

(*continued*)	They are particularly common in high wave energy areas but can be found throughout all reef zones. Crustose corallines resemble pink or purple pavement. Morphology can range from smooth and flat, to rough and knobby, or even leafy.	
Cryptofauna	Small organisms that often live in protected or concealed microhabitats.	https://en.wikipedia.org/wiki/Fauna#Cryptofauna
Cytochrome Oxidase I (COI)	A gene from mitochondrial DNA used as a DNA barcode to identify species	https://en.wikipedia.org/wiki/Cytochrome_c_oxidase_subunit_I
Deep Sea	The water beneath the permanent thermocline that usually has a low and uniform temperature.	www.coris.noaa.gov
Depth Invariant Index Layer	Pixel values converted to an index of bottom type independent of depth to account for natural variation in bottom reflectance, turbid water, and sensor noise. These depth-invariant indices of bottom type lie along a continuum, but pixels from similar habitats will have similar indices.	http://www.unesco.org/csi/pub/source/rs10.htm
Depth Soundings	Depth sounding refers to the act of measuring depth. It is often referred to simply as sounding. Data taken from soundings are used in bathymetry to make maps of the floor of a body of water, and were traditionally shown on nautical charts in fathoms and feet.	https://www.google.com/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=depth+soundings&*
Dereplicated Sequences	The process of finding duplicated (replicate) sequences.	http://drive5.com/usearch/manual/dereplication.html
Detritivores	Animals that feed on dead organic material, especially plant detritus.	https://www.google.com/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=detritivore+definition&*&dobs=detritivore
Dissolved Inorganic Carbon	Inorganic compounds that are dissolved in the water.	www.coris.noaa.gov
DNA Barcoding	A taxonomic method that uses a short genetic marker in an organism's DNA to identify it to a particular species.	https://en.wikipedia.org/wiki/DNA_barcoding
Ecosystem	An ecological community and the interactions therein of living (including humans) and non-living factors considered together as a unit of the environment.	www.coris.noaa.gov
Fore Reef	The portion of a reef seaward of reef crest. A synonym of reef slope.	www.coris.noaa.gov
Georeferencing	Relating the internal coordinate system of a map or aerial photo image to a ground system of geographic coordinates.	https://en.wikipedia.org/wiki/Georeferencing

Gleaning	A fishing/collecting method used to gather marine organisms in shallow coastal, estuarine, and freshwater habitats exposed during low tide.	https://genderaquafish.org/portfolio/gleaning/
Habitat	The place or environment where a particular organism, population, or species lives.	www.coris.noaa.gov
High-Throughput Sequencing	A rapid method of determining the sequence of bases in a DNA molecule; also referred to as "next generation sequencing", technologies that parallelize the nucleotide sequencing process, producing thousands or millions of sequences at once. Using these technologies may lower the cost of DNA sequencing beyond what is possible with standard methods.	www.coris.noaa.gov
Homogenized	In cell biology or molecular biology research, homogenization is a process whereby a biological sample is brought to a state such that all fractions of the sample are equal in composition. A homogenized sample is equal in composition throughout, so that removing a fraction does not alter the overall molecular make-up of the sample remaining and is identical to the fraction removed.	https://en.wikipedia.org/wiki/Homogenization_(biology)
Hydrocast	A process in which water is collected at various depths, providing data on differing water characteristics.	https://www.google.com/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=hydrocast+definition&*
Intertidal	The region between the highest water line and the mean low tide level.	www.coris.noaa.gov
Invertivores	Animals that eat invertebrates.	https://en.wikipedia.org/wiki/List_of_feeding_behaviours
Lagoon	A shallow, quiet waterway separated from the open sea by a reef crest.	www.coris.noaa.gov
Linear Regression Analysis	Regression in which the relationship is linear.	www.coris.noaa.gov
Macroalgae	Large algae that project more than ~two centimeters above the substratum.	www.cdoris.noaa.gov
Mahalanobis Distance	Mahalanobis distance measures the distance of a point x from a data distribution. The data distribution is characterized by a mean and the covariance matrix, thus is hypothesized as a multivariate gaussian. It is used in pattern recognition as similarity measure between the pattern (data distribution of training example of a class) and the test example. The covariance matrix gives the shape of data distribution in the feature space.	https://en.wikipedia.org/wiki/Mahalanobis_distance
Metabarcoding	DNA metabarcoding identifies multiple species at the same time by sequencing a targeted region of pooled DNA and	https://en.wikipedia.org/wiki/Environmental_DNA

(*continued*)	comparing the results against referenced databases.	
Metadata	Information about data or other information. Metadata or "data about data" describe the content, quality, condition, and other characteristics of data.	www.coris.noaa.gov
Morphospecies	Identification using clusters of variations or phenotypes within specimens to differentiate species.	https://en.wikipedia.org/wiki/Species#Typological_or_morphospecies
Motile	Organisms capable of self-locomotion.	www.coris.noaa.gov
Nearshore	Relating to or denoting the region of the sea or seabed relatively close to a shore.	https://www.google.com/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=nearshore&*&dobs=nearshore
Nutrient Cycling	All the processes by which nutrients are transferred from one organism to another. For instance, the carbon cycle includes uptake of carbon dioxide by plants, ingestion by animals, and respiration and decay of the animal.	www.coris.noaa.gov
Ocean Acidification	Ocean acidification occurs when CO_2 from the atmosphere is absorbed into the ocean and reacts with water to create carbonic acid. This process decreases both ocean pH and the concentration of the carbonate ion, which is essential for calcification by calcifying marine organisms such as corals.	www.coris.noaa.gov
Patch Reef	A coral boulder or clump of corals formed on a shelf, usually of less than 70 m depth, often in the lagoon of a barrier reef or atoll. It is unattached to a major reef structure.	www.coris.noaa.gov
pH	Provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral and <7 is acidic and >7 is basic).	www.coris.noaa.gov
Phenol Chloroform Extraction	A liquid-liquid extraction technique in biochemistry and molecular biology for purifying nucleic acids and eliminating proteins and lipids. This procedure is often performed multiple times to increase the purity of the DNA.	https://en.wikipedia.org/wiki/Phenol%E2%80%93chloroform_extraction
Photo Transect	A photo-transect survey aims to quantify the projected areal cover of species using digital photography and subsequent image analysis for monitoring or measurement.	http://sango.churashima.okinawa/monitoring_en/cpc.html
Photo Quadrat	A quadrat that is photographed for purposes of later analysis and permanent record for species monitoring or measurement.	www.coris.noaa.gov
Phyla	Plural for Phylum. A major division of a biological kingdom, consisting of closely related classes; represents a fundamental pattern of organization and, presumably, a common descent.	www.coris.noaa.gov

Phylogenetic	Biology that deals with relationships among organisms.	www.coris.noaa.gov
Phylogenetics	The study of the evolutionary history and relationships among individuals or groups of organisms (e.g., species or populations).	https://en.wikipedia.org/wiki/Phylogenetics
Piscivores	Animals that feed on fishes.	www.coris.noaa.gov
Pixel	Abbreviation of a picture element.	www.coris.noaa.gov
Planktivores	Organisms that feed on plankton; also called "planktonivore".	www.coris.noaa.gov
Radiance	The radiant flux emitted, reflected, transmitted, or received by a surface, per unit solid angle per unit projected area.	https://en.wikipedia.org/wiki/Radiance
Reference Values	The reference value is used for comparison during measurement system analysis, such as with a baseline.	http://support.minitab.com/en-us/minitab/17/topic-library/quality-tools/measurement-system-analysis/other-gage-studies-and-measures/what-is-a-reference-value/
Salinity	A measure of the salt concentration of water.	www.coris.noaa.gov
Sessile	Describes an organism that is immobile because of its attachment to a substrate. The term has also been applied to organisms, such as anemones, that move very slowly.	www.coris.noaa.gov
Sieve	A sieve, or sifter, is a device for separating wanted elements from unwanted material or for characterizing the particle size distribution of a sample, typically using a woven screen such as a mesh or net or metal.	https://en.wikipedia.org/wiki/Sieve
Size-Frequency Distributions	Displays the frequency of various outcomes in a sample.	https://en.wikipedia.org/wiki/Frequency_distribution
Spectral Signature	The radiance of a surface per unit frequency or wavelength, depending on whether the spectrum is taken as a function of frequency or of wavelength.	https://en.wikipedia.org/wiki/Radiance
Standard Error Of The Mean	The standard deviation of the sampling distribution of a statistic, most commonly of the mean divided by the square root of the number of samples.	https://en.wikipedia.org/wiki/Standard_error
Standard Proteinase-K Digestion	A way of extracting DNA from tissues or cell culture.	https://en.wikipedia.org/wiki/Surveyor_nuclease_assay
Stratified Random Survey	In statistics, a survey using a sample drawn from a population divided into tiers or strata specifically relating to the study being undertaken; a sample derived by dividing the data population into a number of nonoverlapping classes or categories from which cases are selected at random, the number of cases selected from each category being proportional to the variation therein.	www.coris.noaa.gov
Subsurface	Below the surface layer.	https://en.wiktionary.o

(*continued*)		rg/wiki/subsurface
Supernatant	The soluble liquid fraction of a sample after centrifugation or precipitation of insoluble solids.	www.coris.noaa.gov
Taxa	Taxonomic groups or entities.	www.coris.noaa.gov
Total Alkalinity	Alkalinity is the name given to the quantitative capacity of an aqueous solution to neutralize an acid. Total alkalinity is the equivalent sum of the bases that can lose proton(s) as a reaction to strong acid.	https://en.wikipedia.org/wiki/Alkalinity
Trophic	Related to or functioning in (levels of/types of) nutrition.	www.coris.noaa.gov
Turbidity	Clarity of water, usually influenced by the suspension of fine particles in the water column. The particles may be inorganic, such as silt, or organic, such as high densities of single-celled organisms.	www.coris.noaa.gov
Turf algae	Sparse to thick mats of highly diverse, diminutive and juvenile algae less than 2 cm high, composed of juvenile macroalgae and faster-growing filamentous species accompanied by the ubiquitous blue-greens, diatoms, and detrital sediments.	https://link.springer.com/referenceworkentry/10.1007%2F978-90-481-2639-2_174

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