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TARAWA LAGOON MANAGEMENT PLAN

Volume I

Project Summary

February 1995

BioSystems

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Management Plan for Tarawa Lagoon, Republic of Kiribati

Volume I: Project Summary

Pacific Islands Marine Resources
Project No. 879-0020

Submitted to:

Ministry of Environment and Natural Resources Development,
Government of Kiribati

and

Atoll Research Programme,
University of the South Pacific, Suva, Fiji

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"The views expressed and opinions contained in this report are the author's and are not intended as statements of policy of either USAID or the author's parent institution."

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Preface

This report is one of three volumes on the development of management strategies for Tarawa Lagoon, Republic of Kiribati. This project was conducted by BioSystems Analysis, Inc., the Atoll Research Programme of the University of the South Pacific, and the government of Kiribati, with primary funding from the U.S. Agency for International Development.

Tarawa is of particular concern because of the high human population density of this capitol atoll. The resulting high rates of resource exploitation, alteration of the coastline, and disposal of human waste have led to several significant environmental problems. Most important among these are a severe depression of several food sources, particularly bonefish, and severe contamination of nearshore waters and shellfish beds with fecal bacteria.

The principal objectives of this project were:

- To assess the status of the lagoon and determine the extent and severity of problems.
- To identify opportunities to improve harvests from or conditions in the lagoon
- To develop a management strategy to address the environmental problems and take advantage of opportunities

The three volumes of this report are:

I. Summary of the Tarawa Lagoon Management Plan. This volume summarizes the major points of the management plan. It is designed as an extended, graphics intensive executive summary of the plan and the principal results of the underlying scientific studies.

II. An Environmental and Resource Assessment of Tarawa Lagoon. This volume reports on the scientific research conducted on the lagoon, including investigations of human activities, circulation, water quality, food chain, reefs, and harvestable resources including fish and shellfish. It includes a summary of the principal findings of the scientific research as they relate to management.

III. Management Plan for Tarawa Lagoon. This volume contains the Plan itself, including a description of the issues and opportunities, a summary of the recommended actions, and a proposed action plan for implementation.

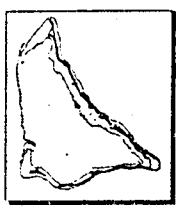
This volume summarizes the major points of the Tarawa Lagoon Management Plan presented in Volumes II and III. Volume I is designed as an extended, graphics-intensive executive summary of the main elements of the Management Plan and the underlying scientific studies. The interested reader is encouraged to read Volumes II and III in their entirety to understand the basis for the management recommendations that follow. This document is laid out in much the same format as the multi-media slide presentation given to the Government of Kiribati in Tarawa in July 1994.

Introduction

This volume of the Tarawa Lagoon Management Plan, "the Plan," is a graphics-intensive summary of the two other volumes. It follows the general pattern of information presented in Volume III, the management plan, and a multimedia presentation given to the government and public in July 1994.

The Plan is based on an intensive effort of a large team of international and local scientists to conduct an assessment of the natural and human resources of the lagoon and then develop a management plan through an interactive pubic participation program. Research and natural resource assessment activities peaked in mid-1993. Public participation program activities to inform the public about the research findings and involve them in creating a management plan peaked in mid-1994.

A Strategic Plan for the Restoration of Tarawa Lagoon, Kiribati



BioSystems Analysis, Inc.

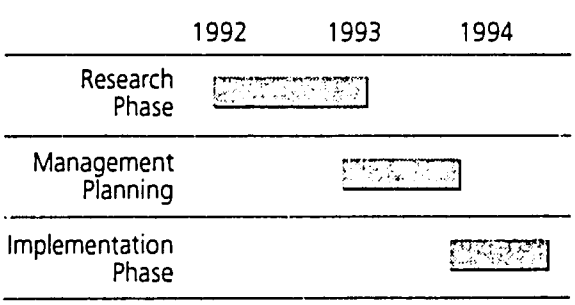
FUNDING

- United States Agency for International Development
- Goverment of Kiribati
- University of the South Pacific

IMPLEMENTATION

- BioSystems Analysis, Inc.
- Ministry of Environment and Natural Resource Development
- University of the South Pacific, Marine Studies Program

MAIN STAGES



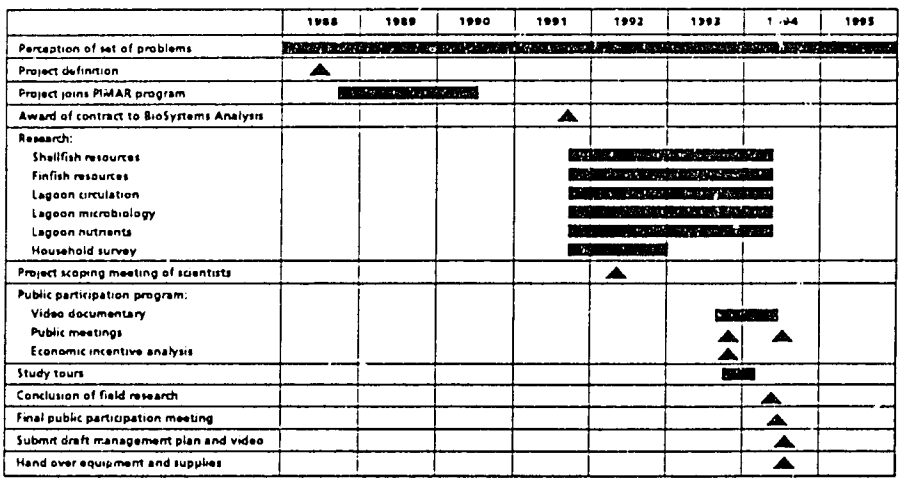
Main Features of the Research Program

The resource assessment aspects of the plan included a shellfish, coral reef and benthic ecology assessment; a finfish assessment, with special emphasis on bonefish; a study of primary and secondary production, along with an analysis of the food web in the lagoon water column; and a computer simulation of lagoon circulation with special emphasis on the impact of causeways. A household survey of 4% of the households in South Tarawa and 2% of the households of North Tarawa was used as a tool to understand public attitudes and lagoon use patterns.

PROGRAM FEATURES

- Training and technology transfer
- Research and resource assessment
- Public participation
- Management plan

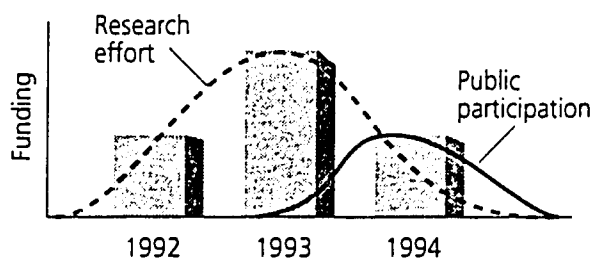
MANAGEMENT PLANNING PROCESS OVERVIEW



Training

Seventeen I-Kiribati citizens were employed on the project at different times, all of them received some training in computers, laboratory work, or in field research and data management activities. Four individuals were able to travel overseas for short-term training or to attend international conferences.

ALLOCATION OF EFFORT FOR RESEARCH AND IMPLEMENTATION OF THE PROJECT



Public Participation Program

The effort to disseminate information to the public and the government evolved into a major public participation program. This phase of the project included two video documentaries, two sets of public meetings, four issues of a bilingual newsletter, a set of ten bilingual posters, and a contest for a restoration image of the lagoon. Additional work was done to assess economic incentives in order to bring a broader section of the public into the process of restoring the lagoon. One video, "The Bonefish

TRAINING

• Local training on the job	17 employees
• International training	4 study tours

PUBLIC PARTICIPATION

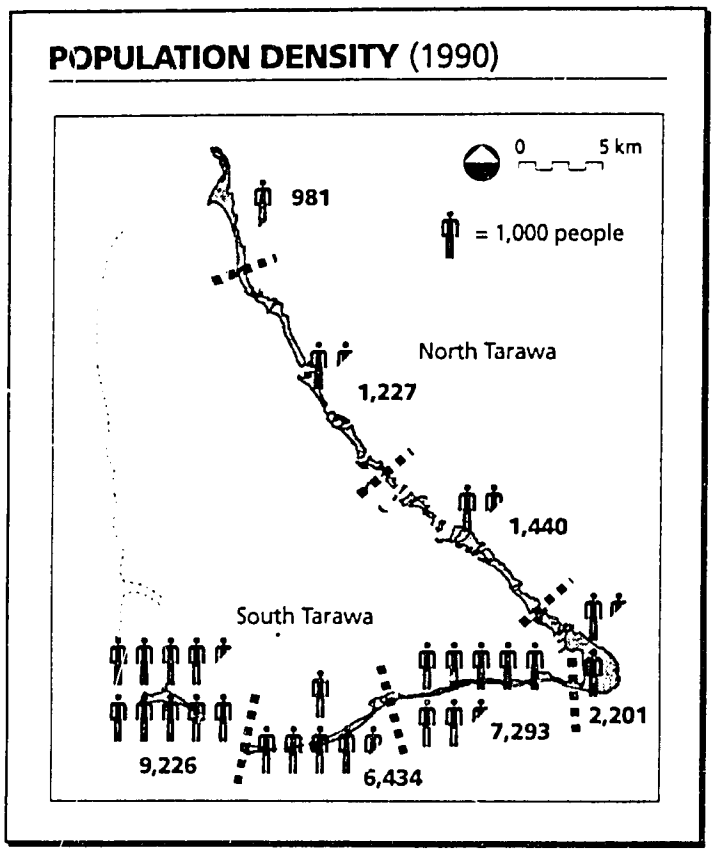
- Documentaries
- Meetings
- Newsletter
- Poster
- Contest
- Economic incentives

video, "The Bonefish Commentaries", was drawn from 13 hours of interviews of I-Kiribati citizens discussing the history of bonefish fishing in Tarawa and the decline of the resource due to splash fishing. The second video featured the scientific findings and proposed ways to restore the lagoon's productivity and health.

A Management Plan is Urgently Needed

A broad-based management plan is urgently needed. It is clear that restoring the natural resource potential of the lagoon and improving the livelihood and health of the people that use the lagoon will require a massive effort. Many people are dependent on the lagoon to meet their minimal nutritional requirements, and yet a stream of documents has cataloged the deterioration of the lagoon's natural resources since the 1970's. The public health situation has continued to deteriorate, in spite of a cholera epidemic in 1977 and the extremely-high incidence of gastrointestinal illness suffered by the majority of the people in South Tarawa.

Furthermore, a plan is needed to integrate funding from donors and to coordinate the work of different ministries. The plan must also conform to the government's five-year planning effort. Without a plan, there is no organized way for the people of Tarawa to respond to the very real possibility of further deterioration of the lagoon and their quality of life. The people and government agencies of Tarawa need a management plan in order to unite their actions with those of many community, governmental, and non-governmental organizations. Only in this way can a systematic and organized effort be made to improve the productivity of the lagoon and the health of the people.



Population Growth Impacts the Lagoon

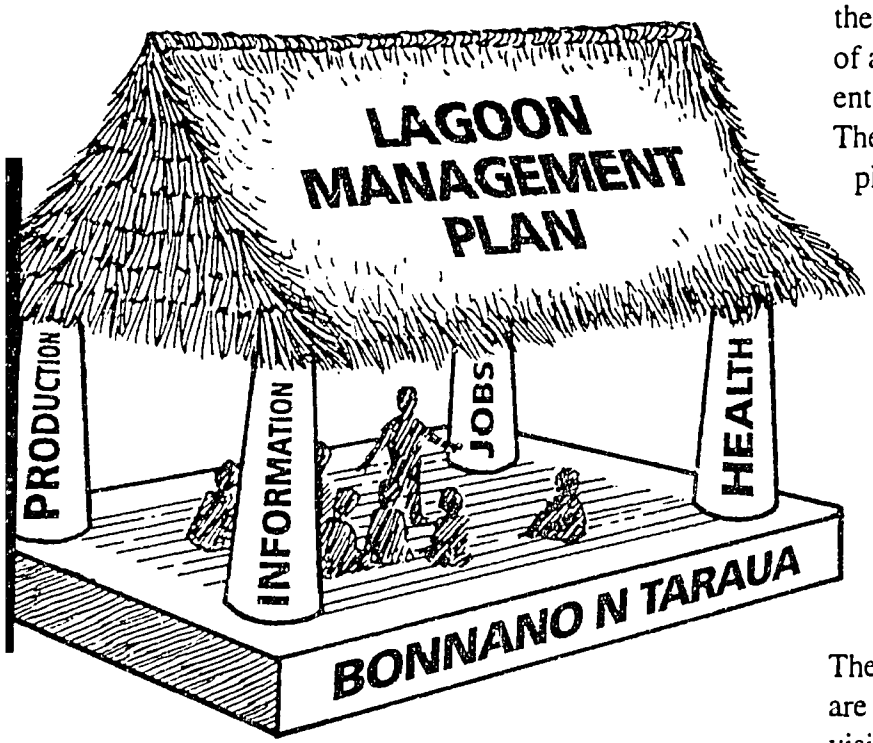
Population growth is one of the main issues confronting the people of South Tarawa. The current rate of growth for South Tarawa is 3.1 percent per year. Thus, by the end of 1994, the population of Tarawa will be approximately 32,544. The population will quickly exceed 40,000 in the next few years in spite of plans to distribute up to 10% of the population on some of the outer islands and an active birth control campaign.

Introduction of New, Efficient Fishing Technology

Outboard motor powered canoes and large skiffs now dominate lagoon fishing activity. The most destructive form of fishing is *te ororo*. *Te ororo* or splash fishing is too efficient. It involves gillnets up to one mile long. After the net is set, a heavy iron crow bar is splashed in the water to scare fish into the net. Local business men fish their gear twenty-four hours a day using up to three crews of men on one set of gear. Without immediate action to protect its few remaining resources, the lagoon will become a great, empty wasteland from which people obtain very meager resources on an occasional basis.

High Fecal Coliform Counts in the Lagoon along South Tarawa

Coliform bacteria counts exceed recommended standards for bathing or shellfish collecting. The coliform bacteria come from the excretory activities of the thousands of people and domestic animals living on South Tarawa. Gastrointestinal ailments are so common they are not even seen as unusual or a problem by most people.



The Plan is like a *Maneaba*

The Tarawa Lagoon Management Plan can be conceived of as a *maneaba*. The *maneaba* concept implies the security associated with the shared productivity and responsibilities of a family unit. The image here is for the entire island community that uses the lagoon. The four pillars of the proposed management plan are: to increase natural resource production from the lagoon, to provide more information to the community about lagoon-related issues, to increase the number of jobs available, and to improve public health. The foundation for these different activities is a proposed broad based organization for the cooperative management of the lagoon.

Goals, Objectives and Action Plan

The pillars of the management plan maneaba are the conceptual goals. The goals being the vision of the future condition of the lagoon in the broadest sense of community and government aims. The objectives are specific targets along the way to the goal. The actions are specific tasks that lead to achieving the target objectives. The Plan contains a long list of recommendations that can and should be translated into action items for implementation.

MANAGEMENT AND COORDINATION MECHANISM

Program Image ➡	The Bountiful Lagoon
Goals ➡	Increased Production More Jobs Better Health Increased Public Understanding
Initial Funding ➡	South Pacific Regional Management Program
Program Implementation ➡	Government of Kiribati *Bonnano N Taraua* Lagoon User Public
Technical Assistance ➡	Donor Agencies
Beneficiaries ➡	Fisheries Children Business

Bonnano N Taraua to Interact with Many Groups

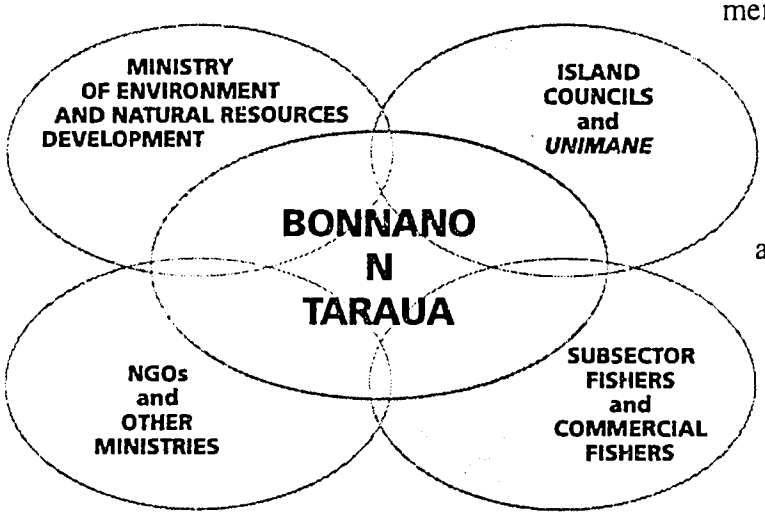
One of the main results of the series of public participation meetings was the creation of the *Bonnano n taraua. Bonnano n taraua* having the general meaning of cooperative management or working together. The relationship of the *Bonnano n taraua* with other groups can be viewed as an interactive task force that will interacts with constituencies

WHO ARE THE MEMBERS OF *BONNANO N TARAUA?*

- Fishermen
- Gleaners
- Ministries
- Island councils
- Businessmen
- Other groups as needed

WHAT ARE THE FUNCTIONS OF THE LAGOON MANAGEMENT COUNCIL?

- Discuss and approve projects
- Implement projects
- Communications
- Monitor success of community management
- Job creation
- Annual conference



LOCAL MANAGEMENT IS LOCAL CONTROL OF:

- Who fishes
- Where they fish
- When they fish
- How much they are allowed to take
- What equipment they fish with
- Enforcement

that include government ministries, the island and town councils, *unimane*, commercial fishermen, commercial seafood buyers, and representatives of the subsistence gatherers that depend on the sand flat and baitfish resources for their livelihood. It would have an executive committee and meet as whole at least once a year to help set government priorities.

Cooperative Management is the Key Policy Element of Plan

The core theme of the management plan is the institution of a cooperative management mentality in the government and in the public at large. Cooperative management can be seen as a blend of central government support with local management of the natural resources adjacent to the communities. Local management involves determining who can fish, where they fish, when they fish, how much they are allowed to take, and what equipment they can use. In other words, the local community determines what is done and how it is enforced. There are limits to what a central government with limited financial resources can do to impose and enforce regulations from a distance. If limits are to be set on the take of lagoon resources, these limits must be imposed by the local communities.

Annual Meetings of the *Bonnano N Taraua*

It is not the intent of this report to dictate how controls should be implemented. The important thing is that all members of the lagoon user community regularly get together under the policy umbrella of cooperative management and to talk to each other and decide how they would like to take care of their lagoon resources.

Attitude	Action	Result
Unlimited resource Available to all	Harvest as much as possible, as fast as possible	Fewer fish

Attitude	Action	Result
Limited resource Available to all	Limited sustainable harvest	More fish

CENTRAL GOVERNMENT SUPPORT

- Provision of information about the status of the resource
- Funding
- Monitor activities of local manager

MANAGEMENT ALTERNATIVES

- *Bonnano N Taraua* sets goals and communities work out ways to achieve goals
- If the communities do not do a good job, management reverts to MENRD

Tragedy of the Commons

It is important to begin the process of encouraging people to think about the use of the lagoon in a different way. In a sense, we have to turn people's thinking about the lagoon upside-down. The current view, which is based on English Common Law, is that the lagoon is open to all to do anything they want. The result is what is known as "the tragedy of the commons," in which people feel they have the right to go anywhere in the lagoon and harvest anything they want, without regard to other people or the long-term status of the resource. Most people have the attitude, "If I don't catch them myself then somebody else will catch them." The net result of this community perspective and government policy direction is to have fewer fish and shellfish in the lagoon.

Some Limits on Resource Extractions are Needed

This type of thinking must change. To restore the lagoon's resources, people must begin to view the lagoon as a whole for the benefit of everyone and to understand that constraints on human behavior are necessary to maximize the potential of the lagoon. In other words, for the lagoon to produce its maximum sustainable yield of food and other benefits to the community, people's behavior will have to change and the extraction of lagoon resources must be constrained. By shifting attitudes to make people aware that the lagoon's resources are very limited and that the objective is to have a higher sustained harvest, it is necessary for people to appreciate that there will have to be some constraints on their fishing activities.

Government Advise and Monitor—Communities Enforce

Under a cooperative management regime, the government's role is to monitor the lagoon through annual resource assessment programs, to assist in providing funding, and to actually monitor the activities of the different groups who are doing the local management. One important feature of the *Bonnano n taraua* is to help set goals for the lagoon as a whole and to delegate these goals to communities, villages, or island councils. It is important to recognize that if the communities that surround Tarawa do not satisfactorily manage their adjacent resources, then responsibility for the management will have to eventually revert back to the Ministry of Environment and Natural Resources and the Fisheries Division. This, however, would be the least desirable result.

RECOMMENDED EQUIPMENT RESTRICTION

- Ban or restrict gill nets
- Ban scuba and hooka equipment for collecting and harvesting

REDUCTION OF GILL NET ACTIVITY IN THE LAGOON FOR 5 YEARS

- Quickest way to restore the lagoon to full productive petential

SOME ALTERNATIVE GILL NET RESTRICTIONS

- Ban all turtle fishing nets
- Ban *te ororo* fishing
- Ban gill nets in areas with living coral reefs
- Ban sale and importation of all gill nets
- Ban connecting nets together to make long nets
- Ban sale of lagoon fish caught with gill nets
- Ban loans for buying gill net equipment
- Time of use restriction

Recommendations

One of the cornerstones of the Tarawa Lagoon Management Plan is an effort to increase the productivity of the lagoon to approach its maximum sustainable yield. To achieve this, it will be necessary to protect many of the resources in the lagoon for many years so that large reproductive populations can develop to allow for a managed, sustained harvest.

Gear Restrictions Needed

The proposed Management Plan has two main fishing gear restriction advisories. The first applies to the use of gill nets. It is strongly recommended that the use of gill nets in the lagoon be dramatically curtailed as soon as possible. Gill nets are one of the main causes for over fishing and the reduction in the size of the population and biomass of fish in the lagoon. Gill nets also destroy coral reefs.

Stop Most Kinds of Gillnetting in the Lagoon

The consensus of the scientific team was that the quickest way to restore the lagoon to its full potential is an almost complete moratorium on

all gill net activities for up to five years.

A total ban is unnecessary. However, certain types of gill netting should be stopped right away. We strongly recommend a complete ban on *te ororo* fishing. The use of very long nets and splashing with a heavy iron bar has accelerated the decline of the resources of the lagoon. We recommend a complete ban on the use of gill nets to catch turtles. We also strongly recommend banning gill nets around all coral reefs because gill nets inevitably get caught on the reef and break off new reef growth. This results in the loss of habitat for juvenile fish. Very small-mesh gill nets of 1-inch or less are widely used by households to collect a few baitfish for meals. A single shackle of nets with 1-inch mesh probably is not excessively destructive to the resources of the lagoon and probably should be permitted for subsistence fishermen. The same is probably true for cast nets.

No More Loans for Lagoon Fishing Gear

It seems clear that the Kiribati Development Bank and the Bank of Kiribati should restrict loans given to any group that is going to import or use gill nets in the lagoon. Gill net restrictions are not intended to apply, however, to ocean fisheries such as flying fish that rely on this gear. Increasing ocean fishing activity should be encouraged since it reduces the pressure on depleted lagoon resources.

Ban The Use Of SCUBA Gear for Commercial Divers in the Lagoon

We also recommend a ban on the use of SCUBA equipment, hooka equipment, and swim fins for collecting resources in the lagoon. Restricting use of these gear types for collection activities will assure there is a reservoir of spawning-size adults in the deeper waters of the lagoon that can seed the sand flat areas with a variety of species, including *te nuou*, *te bun*, *te koikoi*, bêche-de-mer and other important species. SCUBA

CREATION AND MANAGEMENT OF PROTECTED AREAS

- Preserve at Na'a
- Aquaculture park
- Fish sanctuary

diving equipment should be permissible only for scientific purposes, tourism, and public education projects.

Create Protected Areas

The creation and management of protected areas in the lagoon is essential for the restoration of bonefish populations and many other species of fish and shellfish. Protected areas can include sanctuaries, preserves, or parks. We recommend setting aside 20 percent of the lagoon as a fish sanctuary to help restore populations as quickly as possible. The final configuration of preserves or fish sanctuaries would be one of the main areas of discussion for the *Bonnano n taraua.*

DECREASE FISHING ACTIVITY IN THE LAGOON

INCREASE FISHING ACTIVITY IN THE OCEAN AND OUTER REEF

Shift from Lagoon-based to Ocean-based Fisheries

Another of the main recommendations is a substantial decrease in fishing activity in the lagoon and a substantial increase in fishing activity in the ocean outside the lagoon. As people are encouraged to decrease their fishing activity in the lagoon, they will need to find alternative fisheries resources to harvest. Studies by regional fisheries agencies have shown that the deep bottom-fishing resources around Tarawa and the adjacent islands are very large and can sustain a significant fishery. There are also substantial flying fish resources around Tarawa. The most significant resources are oceanic tuna. The transition from a lagoon-based fishery to an ocean-based fishery can not happen overnight, but it is essential that it does happen in an organized way so that there are no unnecessary dislocations in income and nutrition for the majority of the people of Tarawa. This Plan in no way intends to take food out of people's mouths or cause severe dislocations in life style without concomitant remedies.

NON-LAGOON RESOURCES

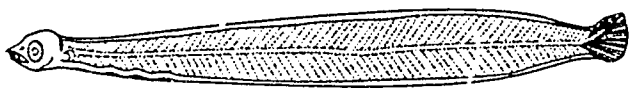
- Tuna
- Flying fish
- Deepwater bottom fish
- Squid and others

MANAGED CHANGE

- Extension program
- Loans
- Open passages
- FADS
- 200-mile exclusionary zone

A program of managed change could include an upgraded fisheries extension program, loans for people who want to convert from lagoon-based to ocean-based fisheries, more fish

OVER 30 SPECIES OF FISH AND SHELLFISH HAVE BEEN FOUND ENTERING THE LAGOON AT TANAEA

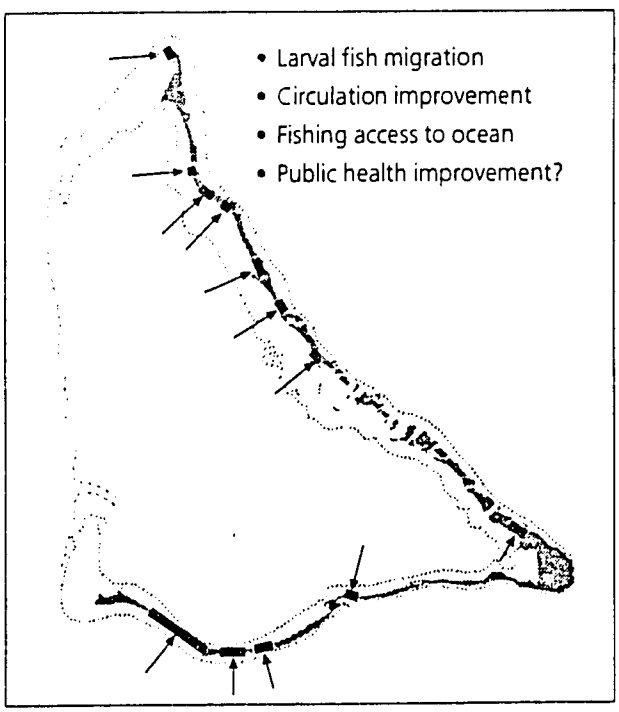


Bonefish leptocephalus larva

HOW DO WE OPEN OPEN UP THE CAUSEWAYS?

- Community work project
- Coordinate requests for funding for funding from donor agencies
- Cost benefit analysis

WHY OPEN THE CAUSEWAYS?

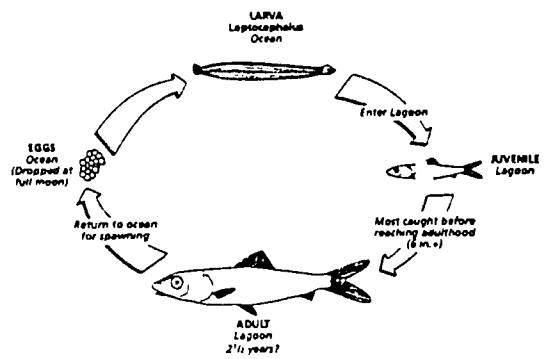


aggregation devices, and more passageways through the causeways to allow fishermen to moor their boats in the lagoon but move easily outside the lagoon to fish in the ocean. One of the most important changes should be a 200-mile exclusionary zone to make the tuna resources exclusively at the disposal of the people of Tarawa. The current policy allows high seas purse-seiners to come within 12 miles of the islands to catch tuna. This reduces the abundance of tuna, rainbow runner, mackerel, and other resources that would otherwise be available to ocean-going fishermen fishing out of Tarawa. Tuna, especially skipjack and yellow-fin bigeye tuna, easily travel 10 miles per hour. Thus, within one day, a school can come from over 200 miles away and be in Tarawa's waters. As long as the government's policy allows large tuna clippers to fish within that 200-mile zone, it will be impossible for a Tarawa-based tuna industry to develop and be profitable.

Open the Causeways

The intensive study of circulation in the lagoon showed that opening the causeways will enhance flushing of the lagoon only about 10 percent faster than it is now, and thus it will not be a solution to the public health problem. But opening significant passageways through all existing causeways will increase circulation somewhat, allow more fish larvae and juvenile fish to enter the lagoon, and allow passageways for commercial fishermen to go out and fish in the ocean. Most tropical reef fishes have a very complex life cycle, where adults aggregate and spawn, releasing their eggs into the ocean. The eggs hatch into juvenile fish which then later migrate into the lagoon and back onto the coral reefs. This is also true of bonefish, the most important species of finfish in the lagoon. After the adults move offshore to lay their eggs, leptocephalus larvae hatch and remain in the ocean for

BONEFISH LIFE CYCLE



BONEFISH MANAGEMENT RECOMMENDATIONS

- Ban *te ororo* fishing
- Ban bonefish fishing 3 days before to 3 days after full moon
- Ban gill nets with a mesh greater than 1" and less than 3.5"
- Research on basic biology and life cycle
- Public education program on bonefish
- Island councils to enforce regulations

BAITFISH RECOMMENDATIONS

- Stop Te Mautari harvest of baitfish in lagoon
- Set up fish sanctuary in the lagoon
- Retain all baitfish resources for local people

approximately two months. We demonstrated that bonefish larvae migrate back into the lagoon through the passageways at Tanaea . In our studies we demonstrated that over 30 species of fish and shellfish larvae enter the lagoon through this passageway. It is not hard to imagine what opening up all the other causeways would do to help restock the lagoon with young fish and shellfish.

Measures to Restore Finfish Resources

Scientific experts have been documenting the decline of the bonefish resources for nearly 20 years. As part of the Plan, we strongly recommend the following measures: a total ban on *te ororo* fishing, a ban on bonefish fishing three days before to three days after the full moon, and a ban on gill nets with a net mesh of less than 3.5 inches and greater than 1.0 inch in the lagoon. The basic biology and life cycle of the bonefish should be the subject of continuing research. A public education program is also essential to protect the bone-fish resources.

The goatfish resources also have been heavily over fished. Since goatfish form pre-spawning aggregations just before the new moon, we recommend a moratorium on harvesting goatfish during the new moon period so that these stocks can reestablish themselves.

The baitfish have been severely impacted by a variety of factors, including the practice of Te Mautari Limited (TML) fishing for bait with underwater lights in the lagoon. We recommend that TML cease fishing for baitfish in the lagoon or adjacent to the lagoon along the western reef. Within the lagoon, a fish sanctuary should be set up for all species of fish, but a large sanctuary would be particularly beneficial to baitfish resources.

The goldspot herring, *tarabuti*, has been particularly hard hit by fishing practices in the lagoon and is on the verge of extinction. Populations of this species are known to fluctuate greatly over time and its absence from the lagoon may or may not be directly

related to the TML. When they do begin to reestablish themselves in the lagoon, however, sanctuaries should be provided so they can continue to reproduce and provide a resource for the rest of the lagoon. In general, it is our recommendation that all baitfishes should be retained as food fishes for the people as a subsistence fisheries resource.

Restoring Shellfish Resources

The present *te bun* resources are in fairly good condition. An extensive harvest is needed to meet the daily nutritional needs of many people, as well as a growing commercial harvest from the deep water *te bun* beds. Much more work needs to be done on the life cycle of *te bun* to understand the best way to manage this resource. In particular, a study of spat collecting substrates is warranted. There are strong indications that the *te bun* resource is very irregular and must be monitored constantly to assure a sustainable harvest for subsistence collectors. To protect the resource, we recommend a ban on SCUBA and hooka gear and swim fins for the collection of *te bun*. This will assure a deep water reservoir of adult broodstock to reseed the lagoon.

TE BUN MANAGEMENT RECOMMENDATIONS

- Ban scuba and hooka equipment for collecting
- Ban use of swim fins for commercial harvest
- Conduct research on habitat requirements
- Conduct public education program on *te bun*

One of the factors causing irregular recruitment of *te bun* in the lagoon appears to be lagoon circulation. The average residence time of water in the lagoon is approximately ten days. The *te bun* release eggs into the water column where they hatch and circulate freely for possibly as long as several weeks. As a result, most of the larvae are flushed out of the lagoon before they are ready to settle on the bottom. It appears that *te bun* larvae remain in the lagoon long enough to settle out only under unusual circumstances such as a disruption in the normal circulation pattern caused by the abrupt onset of westerly winds or other unknown factors. A *te bun* assessment program is needed to annually estimate the size of the stocks in

Tarawa Lagoon. If stocks begin to fall, it may be necessary to stop the commercial harvest for a time.

The *te nuou* in the lagoon are in very good condition. Large numbers of *te nuou* occur in some of the deeper water areas of the lagoon where they are not harvested. Juvenile, pre-spawning-size *te nuou* are usually beneath the sand and are not harvested at all. Only the sexually mature adults are found above the sand where they are harvested by subsistence collectors. At this time there appears to be no reason to impose any management restrictions on the harvest of *te nuou*.

GIANT CLAM RECOMMENDATIONS

- Ban harvest of all giant clams for 5 years
- Ban use of scuba, hooka equipment and fins
- Start giant clam hatchery production program from local stock
- Set up clam preserves

The giant clam resources are in a very dire condition. We recommend a ban on the harvest of giant clams for at least five years. Since giant clams are relatively slow to reach sexual maturity; it is necessary to protect the few remaining clams so they can produce the next generation, which may then be able to reseed the atoll. Eventually it may be possible to have a limited giant clam harvest. A much more plausible scenario is to set up a giant clam culture operation that provides individual residents of Tarawa with giant clams that they can culture under their own supervision. Giant clams have the potential to produce abundant protein for local residents. The Fisheries Division's giant clam culture program should be expanded to provided the residents of Tarawa some clams for a test growout program. The present practice of the fisheries division of sequestering the few remaining clams in an area where they can have some protection should be coupled with an outright ban on harvesting clams.

MARINE TURTLE MANAGEMENT RECOMMENDATIONS

- ALTERNATIVE 1
  Total ban on taking any marine turtles for 20 years
- ALTERNATIVE 2
  Follow SPRMTCP recommendations

Turtles Must be Protected

The marine turtle resources around Tarawa are very limited. Available information indicates only a few turtles still come to the Tarawa area to feed and possibly a few still nest around Naa. We recommend that the area around Naa be set up as a preserve so that the turtle who do come to the area can lay eggs undisturbed. We

also recommend controls on the harvest of marine turtles.

No Net Loss Of Mangroves

Mangroves provide essential habitat for juvenile fish and shellfish, which later become part of the food products that are eaten by the subsistence fishing community. We recommend a "no net loss policy." This means that if mangrove trees are cut down anywhere, they should be replanted or a new plot of mangroves should be started up in a new area. We have heard many complaints about substantial changes in the shoreline and at the same time it appears that mangroves are being cut. It must be remembered that mangrove roots hold sand and mud substrate in place and prevents erosion of beach front areas. People concerned about the loss of their beach fronts should consider planting mangroves to retain sand and sediment around their properties and to assure the future accumulation of beach front property.

MANGROVE RECOMMENDATIONS

- Set a "no net loss policy"
- Study ways to increase mangrove production
- Set up mangrove replanting program
- Start public education program

Bêche-de-mer Restrictions Needed

There is a small resource of bêche-de-mer that is being intensively harvested. We recommend a number of measures to protect this resource. One is to allow collection by hand only and another is to ban the use of weighted spears to collect deep water bêche-de-mer. Banning SCUBA and hooka equipment would assure there is always a deepwater reserve of adult bêche-de-mer to help restock the rest of the lagoon. A size limit should be set on bêche-de-mer to assure that they have a chance to reproduce before they are harvested. The *Bonnano n Taraua* should include beche-de-mer buyers and exporters and involve them directly in the management decisions controlling the sustainable harvest of bêche-de-mer .

BÊCHE-DE-MER RECOMMENDATIONS

- Allow collection by hand only
- Ban weighted spear point for deep harvesting
- Ban scuba, hooka equipment and fins
- Set minimum size limit
- Research and public education program
- Involve Tarawa businessmen in management

Aquaculture will Benefit People if Well Planned

An aquaculture development plan is needed to provide for the orderly growth of this industry as soon as possible. It appears to be very possible to culture giant clam, black pearl, seaweed, and possibly marine sponges in Tarawa Lagoon. If an aquaculture plan is instituted in the very near future, orderly growth of the industry can occur with minimal disruption to other uses of the lagoon. Rapid development of aquaculture in other parts of the world has created conflicts between aquaculture developers and farmers and traditional users of the water space and tide flats. For instance, setting aside good habitat for growing seaweeds, giant clams, or pearl oyster and the necessity of restricting fishing activity in areas where aquaculture activity is going on would affect subsistence collectors who have traditionally used these areas to meet their nutritional needs.

Serious Public Health Issues

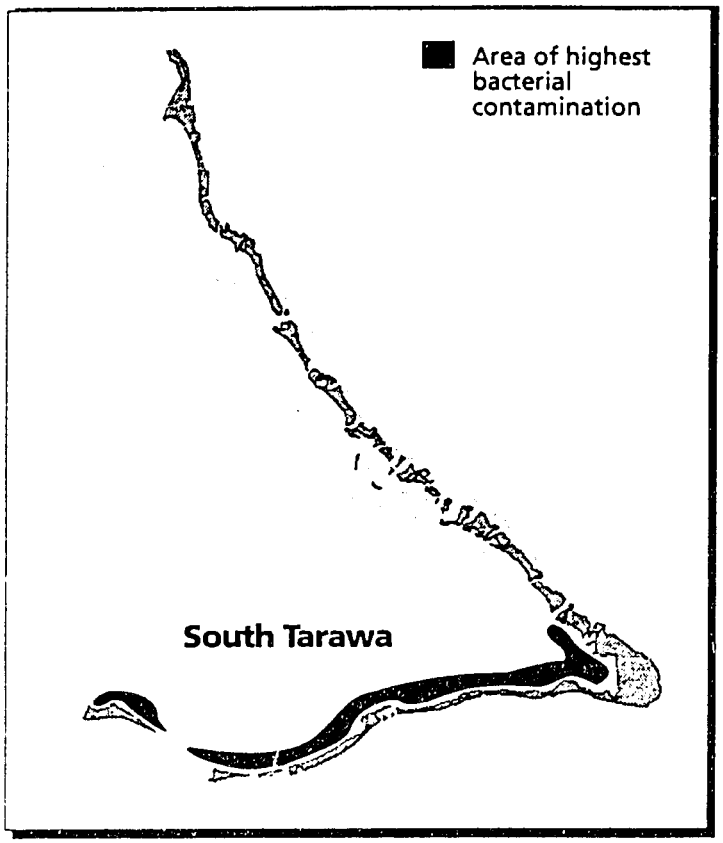
Public health issues urgently need to be addressed. South Tarawa has the highest incidence of childhood gastrointestinal illness in the Republic of Kiribati and one of the highest in the world. This is extremely disruptive to the economic productivity and well-being of the entire community. The problem should not be ignored and will only get worse unless appropriate actions are taken.

A strategy for dealing with the problem must be pushed to the forefront of all decision-making processes. The first problem is to actually define the level of contamination at many different points along the lagoon. Without an ongoing system to monitor contamination levels, it will be impossible to determine if progress is being made. The main goal should be to reduce toileting in the lagoon. This means that a sewage system must be put in place as soon as possible. Until then, it is imperative that short-term and long-term remediation measures be put into place. Eventually, Tarawa

PUBLIC HEALTH RECOMMENDATIONS I

SEWAGE

- Define the problem
- Reduce toileting in the lagoon
- Communicate and educate
- Remediation
- Define sewage outfall plume



will have a modern sewage treatment system similar to that on any number of island communities throughout the world. In the meantime, several alternatives should be explored, including reintroduction of the over-the-reef latrines, composting, seawater flush systems, and other types of systems that would help direct human waste away from the lagoon and out into the open ocean.

The study of the level of *E. coli* found in the lagoon suggests that much of the near shore waters are highly polluted. This is where people bathe and children play. The shellfish collected near shore on the sand flats along South Tarawa are contaminated and people should be shown how to cook or cleanse them before they are eaten. Not all the *E. coli* contamination, however, is from humans. The pig-raising facilities near Bikenibeu also contribute large quantities of fecal coliform bacteria to the lagoon that appear as contaminants in laboratory tests and contribute to gastrointestinal disease.

We also recommend that the Fisheries Division proceeds with plans to institute a ciguatera test program. It may be necessary to develop a test for the specific type of ciguatera found on Tarawa.

PUBLIC HEALTH RECOMMENDATIONS II

- Define rainfall effect
- Pathogen depuration of *te bun*
- Pathogen test
- Ciguatera

Plan to Create Jobs

Another pillar under the maneaba of the Lagoon Management Plan is the creation of jobs for the people in Tarawa. We are aware that it is government's policy to stop urban drift from the outer islands to South Tarawa and that the development policy, in general, is not directed toward creating more jobs in South Tarawa. Nevertheless, measures must be taken to accommodate the young people who are leaving high school and starting families so they can have jobs and not be dependent on other family members.

We recommend that the *Bonnano n taraua* approach all ongoing activities on the island as opportunities for the creation of private

JOB CREATION RECOMMENDATIONS

- Aquaculture
- Research
- Tourism
- Commercial ocean fishery
- Outer reef tropical fish collection
- Sustainable lagoon commercial harvest in coming years

PUBLIC UNDERSTANDING

- Bilingual newsletter and books
- Public meetings
- Radio spots
- Involvement of NGOs
- Reports to Lagoon Management Council

sector jobs. The Council should specifically address the creation of private sector jobs through aquaculture, scientific research and monitoring, tourism, accelerated growth of commercial ocean fishing, outer reef tropical fish collection, and eventually through commercial harvest within the lagoon of the species that are restored to their former productivity.

Community Must be Part of Plan Implementation

Community awareness of lagoon issues and government related activities is relatively low. Existing sources of information such as the broadcasting corporation and the newspaper, which has a limited circulation, are probably not adequate to keep the main issues in front of the public so that informed discussion and decision-making can take place at the village and community level. We recommend the MENRD continue with the newsletter *Voice Of My Lagoon* and institute a program of non-formal community education so that the public can be informed and thus make more enlightened decisions about local management issues and their own conduct.

The proposed implementation program is conceived of as a three-year program employing creative and innovative methods to initiate the process of community involvement in improving the lagoon. Funding for much of the program is anticipated to come through the South Pacific Regional Environmental Program (SPREP) and the bilateral aid agencies of New Zealand, Australia, Japan, China and the U.S.A.

PN-ABU-917

TARAWA LAGOON MANAGEMENT PLAN

Volume II

Technical Report

February 1995

BioSystems

BIOSYSTEMS ANALYSIS INC.

PN-ABU-917

Management Plan for Tarawa Lagoon, Republic of Kiribati

Volume II: Technical Report

Pacific Islands Marine Resources
Project No. 879-0020

Submitted to:

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Government of Kiribati

and

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"The views expressed and opinions contained in this report are the author's and are not intended as statements of policy of either USAID or the author's parent institution."

February 1995

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Preface

This report is one of three volumes on the development of management strategies for Tarawa Lagoon, Republic of Kiribati. This project was conducted by BioSystems Analysis, Inc., the Atoll Research Programme of the University of the South Pacific, and the government of Kiribati, with primary funding from the U.S. Agency for International Development.

Tarawa is of particular concern because of the high human population density of this capitol atoll. The resulting high rates of resource exploitation, alteration of the coastline, and disposal of human waste have led to several significant environmental problems. Most important among these are a severe depression of several food sources, particularly bonefish, and severe contamination of nearshore waters and shellfish beds with fecal bacteria.

The principal objectives of this project were:

- To assess the status of the lagoon and determine the extent and severity of problems.
- To identify opportunities to improve harvests from or conditions in the lagoon
- To develop a management strategy to address the environmental problems and take advantage of opportunities

The three volumes of this report are:

I. Summary of the Tarawa Lagoon Management Plan. This volume summarizes the major points of the management plan. It is designed as an extended, graphics intensive executive summary of the plan and the principal results of the underlying scientific studies.

II. An Environmental and Resource Assessment of Tarawa Lagoon. This volume reports on the scientific research conducted on the lagoon, including investigations of human activities, circulation, water quality, food chain, reefs, and harvestable resources including fish and shellfish. It includes a summary of the principal findings of the scientific research as they relate to management.

III. Management Plan for Tarawa Lagoon. This volume contains the Plan itself, including a description of the issues and opportunities, a summary of the recommended actions, and a proposed action plan for implementation.

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1.0 Introduction

Volume III, Management Plan, hereafter simply callled, "the Plan", discusses the goals, objectives, crisis management, , current actions, and future actions that are necessary to restore Tarawa Lagoon. This introduction explains the steps that lead to the Plan. Following this section, the scientific findings on which the Plan is based are summarized. Next follows a section on the institutional structure underlying the proposed Plan is discussed, and finally there is a proposal for actions focused around the *Bonnano N Tararua,* a village based, cooperative management oriented annual conference of lagoon users.

In part, the Plan is based on the results of three years of comprehensive scientific analysis of the conditions in Tarawa Lagoon and the effects of human uses of the lagoon. The results of this analysis are in Volume II of this report. A key institutional element of the Plan is the formation of the *Bonnano N Tararua* to refine the goals and objectives, implement the recommended actions, and revise the Plan as necessary in the future.

1.1 Planning Approach

Development of the Tarawa Lagoon Management Plan involved a research phase, a public participation phase, and a planning phase, all of which overlapped (Figure 1.1). During the research phase, the present status and the probable future trends of key natural resources in the lagoon were assessed, and information regarding Tarawa residents' opinions and practices was gathered. The public participation phase provided representatives of the community of lagoon users, including village residents, fishers, and the government, with an opportunity to become involved in the planning process.

1.1.1 Resource Assessment Program

A team of scientists with expertise in all of the relevant disciplines was assembled from Tarawa, the United States, and Australia. This technical assistance team met for a scoping conference on Tarawa in April 1992, during which the details of the scientific approach were decided. A summary of the key findings, presented below in Section 2, is based on the findings in Volume II, the Technical Report. The main topics of the resource assessment program were the following:

- Shellfish and benthic ecology.
- Finfish, with an emphasis on bonefish and traditional knowledge of the fishery.

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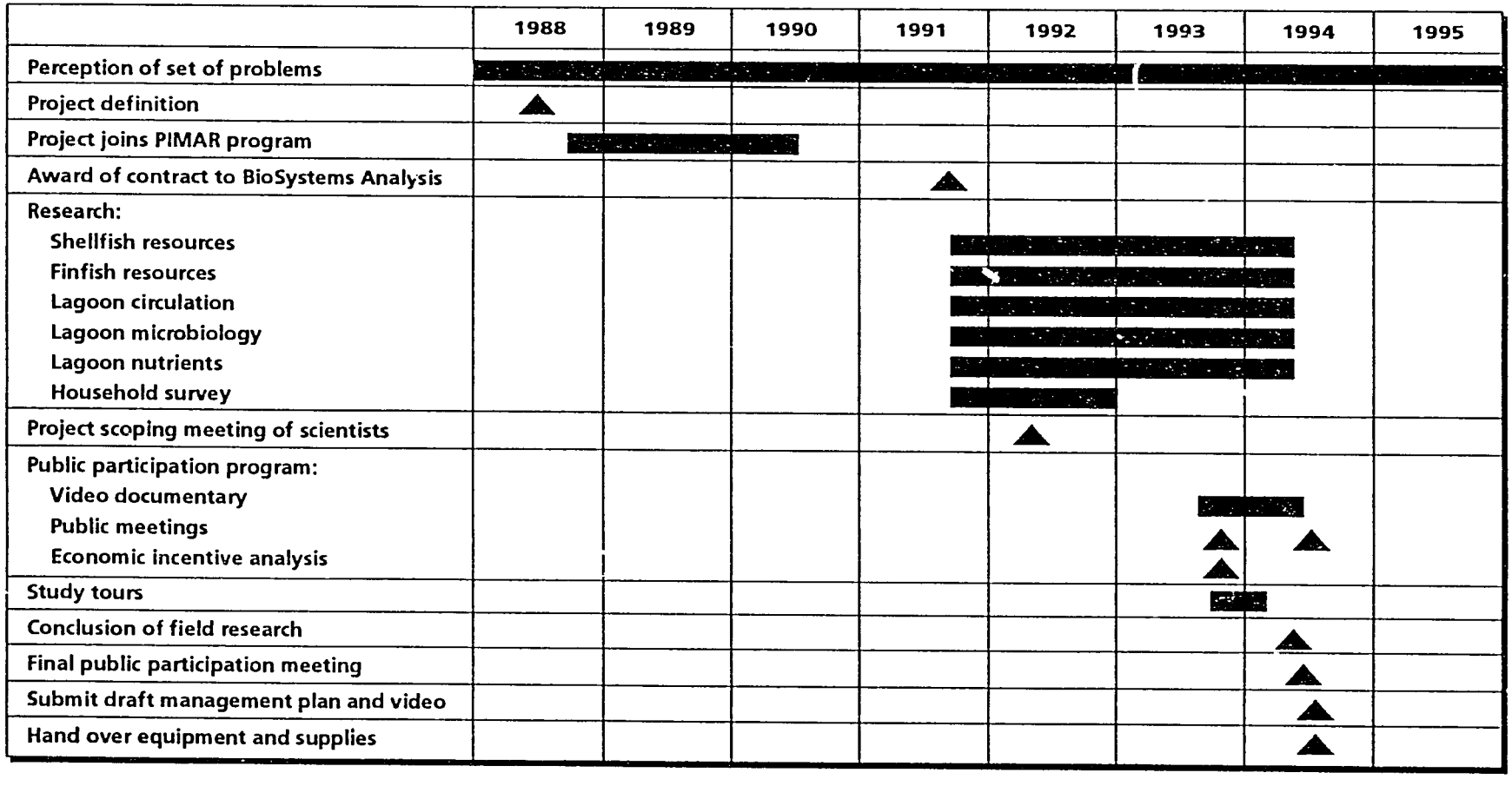

Prepared by BioSystems Analysis, Inc./1994

Figure 1.1 Major tasks conducted during project.

- Primary and secondary production, including an analysis of the food web in the lagoon water column.

- Computer simulation of lagoon circulation, with an emphasis on the impact of causeways.

- A survey of the residents of North and South Tarawa.

1.1.2 Public Participation Program

At the initial scoping meeting and throughout the resource assessment phase, Tarawa community leaders strongly recommended that the technical assistance team communicate the results of its research to the public quickly, effectively, and in a way that would be useful to the community. To address the leaders' concerns, the public participation program was added to the project in late 1993. This program was a multifaceted effort to communicate to the government and the public the essential aspects of the research findings that are relevant to managing the lagoon and to solicit ideas and opinions regarding how the lagoon could be managed.

The core of the public participation program were two meetings held in October 1993 and July 1994. The participants in these meetings were invited from various communities, including government, major nongovernmental organizations, and villages in North and South Tarawa. Most of the members of the technical assistance team participated in the first meeting. The focus of this first meeting was the presentation of the key scientific findings. The second meeting promoted I-Kiribati participation and solicited ideas and feedback on the management process.

The other elements of the public participation program were the following:

- Two video documentaries:
  - "The Bonefish Commentaries" (in Kiribati and English)
  - "My Lagoon, My Life: The Making of a Lagoon Management Plan" (in English)

- Ten bilingual 2 - × 4 - foot color posters

- Four issues of a bilingual four-page newsletter, "Voice of the Lagoon"

- A contest in which the public was invited to submit drawings that could be used to symbolize the lagoon improvement program.

"The Bonefish Commentaries," released in May 1994 in Kiribati and English, presents I-Kiribati citizens from North and South Tarawa discussing their views on the bonefish situation. Citizen comments on bonefish were selected from 13 hours of taped discussions on many lagoon-related

topics. After defining the problem, local residents and fishers discussed management alternatives that could be used to improve the bonefish situation.

The second video documentary, "My Lagoon, My Life," reviews the making of the management plan and presents the research team's findings, with emphasis on the methods and results. Whereas only I-Kiribati citizens appear in "The Bonefish Commentaries," international scientists and I-Kiribati scientists appear in this video.

The four issues of the bilingual newsletter, "Voice of the Lagoon," focus on the two public participation meetings. The first issue was published after the first meeting; the second issue summarizes some of the research findings; the third issue reviews the topics to be discussed in the second public participation meeting, with emphasis on bonefish issues; and the fourth issue discusses the outcome of the second public participation meeting.

The main outcome from the second conference was the creation of the Bonnano N Tararua. This roughly means cooperative management or working together. The suggested membership consisted of 38 individuals as follows:

Urban Councils (3)
One representative from South Tarawa Urban Council (TUC), One from Betio Urban Council (BTC) and one from the North Tarawa Urban Council (ETC)
Unimane (3)
TUC, BTC, ETC
One fishermen per village (20)
Irekenrao (Womens groups) (3)
Roronrikirake, one per council area (3)
Government Representatives (5)

MENRD	Environment
MHARD	Home Affairs
NHSW	Health
NF	Finance
Development Bank of Kiribati	

A technical expert (1)

The main work of the *Bonnano N Tararua* would be to set goals and priorities for lagoon restoration activities and to serve as a forum to talk through difficult issues related to resource management such as community based enforcement.

1.2 Why a Management Plan is Needed

Sixteen years have passed since the Chief Fisheries Officer of the time, A.P.J. Holness, stated in a letter (dated January 17, 1978) to the Office of the Chief Minister that Tarawa Lagoon's resources had been noticeably declining over the previous five years. Nothing was done to arrest the decline in fisheries resources. Analyses by Yeeting and Wright (1989) showed that the lagoon resources were being seriously overexploited and that a substantial reduction in catch per unit effort had occurred in recent years. Analyses presented in Volume II show that these conditions continue today.

The public health problems of Tarawa associated with the unhealthy nearshore lagoon waters also persist. Each year, thousands of people are admitted to health clinics and the hospital for problems that are directly linked to unsanitary conditions. Unless direct action is taken, this problem will become increasingly serious as Tarawa's population continues to grow.

This Plan provides the government and the community with a framework for systematically resolving the key issues of managing natural resources and, thereby, improving the conditions in Tarawa Lagoon. The following sections discusses the critical issues regarding use of the lagoon.

1.2.1 Excessive Pressures on Tarawa Lagoon

Some of the lagoon's resources are severely overexploited. Evidence of overexploitation is summarized in Section 2.0. below and presented in further detail in Volume II. This exploitation has resulted in reduced catches, smaller fish, and the near disappearance of some stocks. This evidence suggests that the combination of a large human population and increasingly efficient fishing methods is more than the fisheries can support. Because of human pressure, fisheries such as bonefish and giant clam are unable to replenish themselves; most fish are taken before they have a chance to reproduce.

1.2.2 Continuing Population Growth

One reason for the overexploitation of lagoon resources is the large number of people using the lagoon.

Addressing the challenges facing Tarawa Lagoon is impossible without looking at the impact of the tremendous population growth on Tarawa Atoll. A report sponsored by the South Pacific Regional Environmental Program (Chung 1993) determined that the population of South Tarawa is growing at a rate of 3.1 percent per year. Thus, South Tarawa's 1990 population of 25,154 will expand to 28,421 by the end of 1994. Even if the government's policy of decentralizing the population by moving people to other islands is successful, the population of South Tarawa is

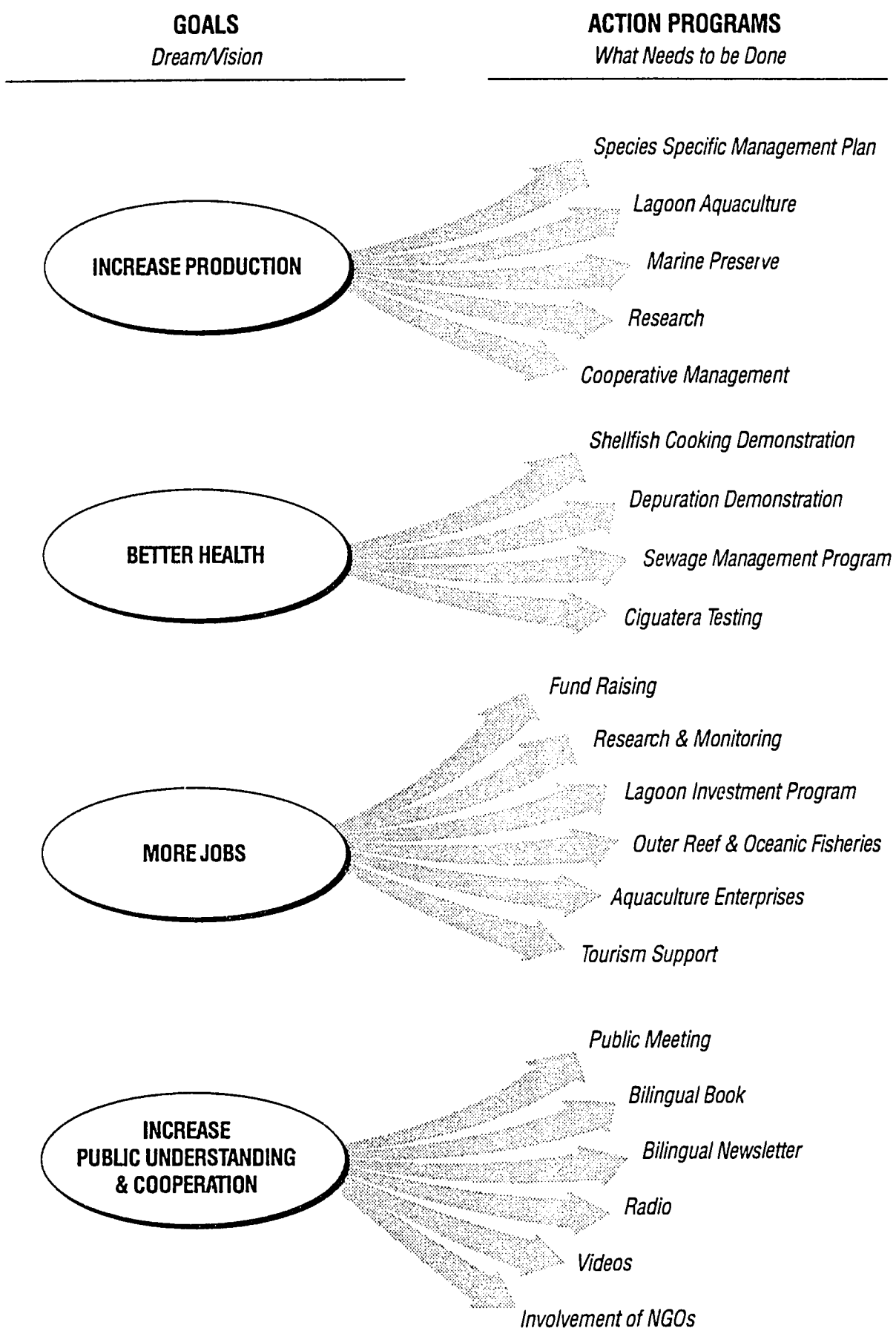

Figure 1.2 Management goals to be achieved through action programs.

expected to reach approximately 40,000 by 2005. If this increase were to occur, it would mean that 20 times as many people will rely on Tarawa Lagoon for their food in 2005 as did only forty years ago.

A dense human population would not, however, put stress on the lagoon if appropriate accommodations were made to allow lagoon stocks to maintain themselves. The challenge for the people and the government of Tarawa is to immediately take the appropriate social, institutional, and infrastructural actions to ensure that the lagoon can meet food supply and health requirements.

1.2.3 Overly Efficient Methods of Fish Collection

The increased efficiency of methods used to collect fish and shellfish over the past decades has further accelerated the rate at which lagoon resources are being exploited.

As Tarawa's growing population has caused an increasing demand for food from Tarawa Lagoon, the people have utilized more efficient techniques to take more fish from the lagoon with less effort. Outboard motors have replaced paddles and sails on many canoes, long fine-mesh nylon gill nets have replaced traditional fish traps, and *te ororo* (the splash fishing method, see Johannes and Yeeting, Volume II) has become the main commercial fishing method in the lagoon.

These new technologies initially increased catches. The impact on the fishery, however, has been so dramatic that fishers now uniformly report that they must take more time and expend more effort to catch the same number of fish they caught only a few years ago (See Phillips volume II).

1.2.4 Future Possibilities

Without planning, conditions in Tarawa Lagoon will continue to deteriorate.

Just as the demand for food has resulted in more efficient fishing technologies, an ever-increasing number of people will increase the demand for lagoon resources. Without a resource management plan, the social and economic pressure being put on Tarawa Lagoon will lead to increasingly powerful fishing methods for capturing an ever decreasing resource. More powerful boats, longer and finer gill nets, scuba gear, dredges, and other techniques could begin to be used in the lagoon's fisheries.

If the current pattern continues, more dissention between the fishers using the lagoon may occur. There will soon be more commercial operators, using innovative techniques to catch fish for sale.

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Fewer subsistence fishers will be able to rely on traditional canoes or shoreline fishing because catching fish will be too difficult. Few people will be able to afford the cost of gear or the operating costs of powerful boats.

1.2.5 How Management Planning Can Help

Management planning offers a way to reverse the decline in Tarawa Lagoon's resources.

The deterioration of the lagoon can be reversed if effective actions, based on a rational examination of the needs of the lagoon and the people, are implemented. Developing a process to reduce the impact of the growing population on Tarawa Lagoon will aid the people of Tarawa.

Management planning provides a way to reduce pressures on lagoon resources. A properly designed and implemented management plan will allow lagoon resources to recover by reducing the actions that cause the most harm and by providing alternative resources and methods for acquiring resources so that food supplies are not seriously disrupted.

1.3 What the Plan Accomplishes

This section illustrates the Plan's usefulness and flexibility in dealing with issues regarding Tarawa Lagoon. Figure 1.2 depicts the relationship between goals and action programs.

1.3.1 Sets Goals, Objectives, and Actions for Tarawa Lagoon

The goals of the Plan state how the community wants the lagoon to look in the future. They provide a vision rather than a specific target.

The objectives of the Plan are specific targets that are set to achieve the goals. In contrast to goals, which are general aims of the community, objectives are used to determine appropriate actions.

The actions of the Plan are implemented by the government, nongovernmental organizations, and individuals to achieve the goals and objectives, whether stated or not. For example, an individual's goal may be to provide adequate housing for himself and his family. His objective may be to have a new, larger house. This objective would be met by the action of building a house or extending the existing house so that it is large enough.

One of the goals for Tarawa Lagoon is to improve fishery production. A related objective is to reduce and then reverse the decline in bonefish. An action recommended to achieve this objective

might be to reduce or eliminate the use of the splash fishing method. The stock would then be monitored to ensure its recovery; the results of the monitoring would be used to determine further action.

This process is key to preparing and executing a plan. Only a clearly stated set of goals can focus the Plan's intent. Clear objectives are necessary to determine whether the actions taken are effective. Clearly stated goals and objectives also indicate which actions are most important and urgent.

1.3.2 Establishes a Framework for Managing Tarawa Lagoon

The most important part of the Plan's framework for managing Tarawa lagoon is the creation of *Bonnano N Tararua* to establish policies, priorities, and projects. This nongovernmental agency would have broad authority and latitude, ensuring that management of the lagoon takes into account local and political concerns, but is not excessively constrained by them. Figure 1.3 depicts the *Bonnano N Tararua* as the foundation for the Lagoon Management Plan.

The Plan suggests specific projects that should be undertaken and provides methods by which the government and the community can work together in a system called cooperative management, whereby the workforce, technical support, and financial resources can be brought together to implement the projects.

1.3.3 Assigns Roles and Responsibilities

The Plan clearly delineates the roles of all parties, thereby providing direction and assigning responsibility for actions taken. The Plan intends that the government give the *Bonnano N Tararua* the authority and responsibility to establish the policies, priorities, and projects to be undertaken each year. With the authority, the *Bonnano N Tararua* will give the necessary "people power" to make the process of restoring Tarawa Lagoon meaningful for the participating public.

The various agencies of government would have the responsibility of organizing and providing technical support for all conferences and meetings. The Plan, however, is intentionally designed to limit government's role in the process to technical and, where appropriate, financial support. The actual conduct, decisions, and projects undertaken would be made by the public participants.

1.3.4 Establishes an Ongoing Revision Process

This Plan recommends specific actions to be taken immediately and in the near future to address the urgent needs of Tarawa Lagoon. It also provides specific recommendations for the ongoing process of cooperative management to refine and update the Plan, adopt an annual strategy for actions affecting the lagoon, and establish specific annual projects to manage the lagoon's resources.

The Plan recommends an annual Tarawa Lagoon management conference, where each year's management strategy and projects would be identified. The public would be encouraged to participate in the conference and in the projects identified. The work program resulting from each conference would identify the roles and responsibilities of each of the individuals, organizations, or government agencies involved in each project.

The annual Tarawa Lagoon management conference would provide a time and place for everyone to convene to engage in a public process to review the status of the lagoon and adopt strategies and projects for the next year. The process is intended to be completely open to the public, and the public will be encouraged to participate actively. In support of the Annual Conference, the Plan also provides for periodic meetings in all of the communities of Tarawa, both to develop local implementation strategies and to monitor the progress of established projects.

1.3.5 Maintains Consistency with Government Economic Development Plan

The Plan is intended to conform to the goals set forth in the Seventh Five-Year Development Plan: 1992-1995. The Plan will contribute to the nation's Five-Year Economic Development Plan in the following ways:

- **Achieve an accelerated rate of economic growth:** Tarawa Lagoon's contribution to the national economy is not measured as an independent item in national economic planning; however, a healthier, more productive lagoon would contribute to an accelerated rate of economic growth. For example, by improving Tarawa's lagoon-based food supply, less imported food would be needed. Because locally produced food from the lagoon costs less than imported food and goods, the cost of food and the cost of living could be kept down. Also, gastrointestinal illness would decrease, which would contribute to increasing the productivity of people at all levels of the economy.

- **Increase diversification of the economy and provide greater self-reliance:** The Plan provides for the creation of new private enterprises and jobs, all of which would improve Tarawa's economic self-reliance. For example, increasing fisheries and aquaculture production in the lagoon would reduce Tarawa's reliance on imported

foods. The program to divert fishing effort to the ocean resources would contribute to export earnings.

- **Improve living conditions and the welfare of the people:** The Plan intends to improve the health of Tarawa residents by reducing the number of incidences of illness associated with improperly prepared shellfish from the lagoon, and by implementing testing for ciguatera toxins (fish poisoning).

- **Maintain greater economic and financial stability:** The Plan's effect on local food production, enterprises and jobs, and public health would bring more money into the local economy, and would allow the labor force to be more productive because it would experience fewer incidences of illness. Increased cash in the economy and reduced health care costs would generate additional economic activity because residents would possess additional disposable income.

1.4 Content of the Plan

The Plan offers a consolidated, comprehensive presentation of goals, objectives, and actions for the present and future management of Tarawa Lagoon. The public discussion that will be stimulated by the Plan offers the communities their first real opportunity to forge a common vision for the future of the Lagoon. The public would have an opportunity to design programs and projects and to agree to certain responsibilities to implement the projects as individuals or as groups of residents.

1.4.1 Results of Scientific Research

Section 2 below discusses results of the research phase that pertain to managing Tarawa Lagoon. The results of research conducted under each scientific discipline are presented first, then several key scientific issues are generally discussed.

1.4.2 Structure of the Plan

Section 3 discusses the background for the plan, including the goals and objectives. Goals and objectives for Tarawa Lagoon were determined by examining the scientific findings and the expressed preferences of participants in the public participation workshops. The goals are as follows:

- Improve the productivity of the lagoon to meet present and future needs on Tarawa

- Ensure that Tarawa residents have easy access to safe and reliable sources of food.

- Promote job development for residents.

- Promote continued health improvements for all Tarawa residents.

Objectives are listed below, grouped in by topic:

- Create a framework for the management of Tarawa Lagoon

  - Establish a planning process whereby decisions can be made rationally and fairly, using the best available information

  - Establish a governing body to oversee lagoon management

  - Improve the public's awareness of the lagoon's condition and the effects they have on it

  - Maximize public participation in planning and management

  - Incorporate Customary Marine Tenure practices to the extent that they are compatible with Tarawa's political and legal structure

  - Establish cooperative management as the approach that underlies management of the lagoon

  - Continue scientific research and monitoring so that conditions under the Plan are periodically reevaluated

- Improve fishery production in Tarawa Lagoon

  - Stop the decline of bonefish and allow stocks to increase

  - Allow baitfish stocks to recover

  - Reduce declines of other lagoon fish

  - Allow stocks of giant clams to recover

- Provide alternative sources of food and income

  - Shift emphasis from utilizing the lagoon as a source of food to using the ocean

  - Improve fishers' access to ocean resources

  - Identify alternative stocks

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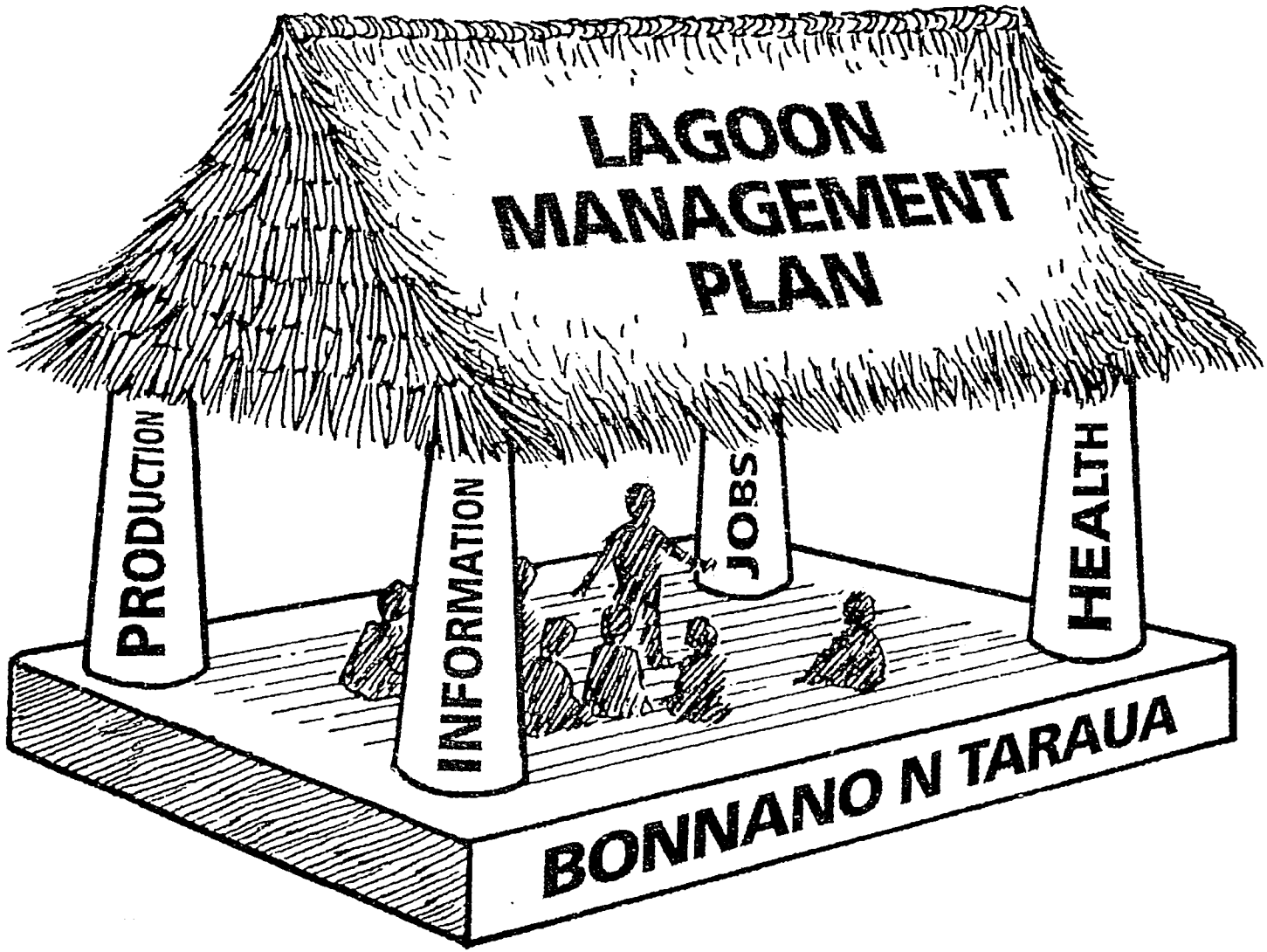

Figure 1.3 The management plan as seen from the perspective of traditional *maneaba*.

- Improve public health
  - Reduce the use of the lagoon as a toilet
  - Improve access to other toilet facilities
  - Improve the safety of food collection and preparation techniques

1.4.3 Planning Agenda

Section 4.0 describes the actions that the *Bonnano N Tararua* is recommended to take. These actions are flexible: they may establish frameworks for other actions, implement regulations, or provide alternative methods for obtaining food. Each action is a response to one of more of the Plan's objectives.

Section 4.0 is organized as follows:

- Immediate actions
- Management actions for the first conference of the *Bonnano N Tararua*
- Research and monitoring
- Implementation of actions

2.0 Results of Scientific Research

2.1 Introduction

This section summarizes the results of a study of the environmental and ecological conditions of Tarawa Lagoon, with particular emphasis on the relationship between the human population and the lagoon. Three characteristics of Tarawa Lagoon are central to its ecological function and productivity. First, Tarawa Atoll is in the equatorial upwelling region, an area in which biological productivity is higher than in the rest of the tropical Pacific. Second, Tarawa Lagoon is open to the ocean along its western boundary, resulting in a rapid exchange of water with the ocean. Third, as the capital of the Republic of Kiribati, Tarawa's human population is large, with an exceptionally high population density in South Tarawa.

This study examined circulation, water chemistry, trophic ecology, reefs, finfish production, and shellfish production. In addition, human interaction with the lagoon was examined in two ways: with a formal household survey and with informal, unstructured interviews with knowledgeable fishers. This combination of methods provided complementary information about the lagoon and about people's use and perceptions of it. Much of this information is based on field studies conducted between April 1992 and July 1994.

Below is a brief summary of the condition of Tarawa Lagoon, as revealed by this and previous studies. Following the summary is a discussion of several key management issues that are addressed by one or more components of the study.

2.2 Condition of Tarawa Lagoon

The status of Tarawa Lagoon was examined from three perspectives during the study: ecological condition, human health, and fishery production.

2.2.1 Circulation

A computer model was used to simulate the movement of water and substances in the lagoon. The model was calibrated against tidal stage, flows through passages between islets, and salinity. The calibrated model gave a mean residence time for lagoon water of 9.5 days, which is in agreement with other estimates.

We used the model to estimate the distribution of phosphate and intestinal bacteria in the lagoon, assuming that the human population was the only source of these bacteria. Simulated phosphate concentrations in the lagoon were well below observed concentrations, supporting previous estimates that human inputs are a minor contribution to the overall nutrient budget of the lagoon. Based on data collected in the lagoon in 1993, phosphorus uptake rates in the lagoon were sometimes positive and sometimes negative (indicating release), possibly because of variation in the equatorial upwelling source. Simulated concentrations of intestinal bacteria agreed reasonably well with measured concentrations. Concentrations were highest on reef flats adjoining heavily populated islets and were below limits of detection more than 1 kilometer away from the reef flat in the lagoon.

We investigated the importance of passages to circulation in the lagoon by using simulated tracers. Closing all the passages in North Tarawa had only a minor effect on bacterial contamination on nearby reef flats, because strong tidal flushing and die-off of bacteria are the principal modes by which concentrations are reduced. Closing these passages or, alternatively, removing causeways to open old passages in the southeastern corner of the atoll or along South Tarawa improved the water quality of the relatively isolated southeastern region by no more than 11 percent. The effect of these passages on water quality and on the movement of sediments is therefore minor compared to the influence of the large opening along the western margin of the lagoon.

2.2.2 Ecosystem Health

Regarding water quality and the base of the food chain, the ecosystem of Tarawa Lagoon appears to be in excellent condition. Because of the large open western reef, water exchange between the lagoon and the ocean is rapid. Thus, the residence time, or the average time water spends in the lagoon, is only about one week, which means that contaminants from land probably do not accumulate in the lagoon.

Analyses of water quality showed that conditions in the lagoon are far from eutrophic; plankton abundances, although higher than in the surrounding ocean, are not excessive. Furthermore, oxygen and nutrient concentrations indicate that water quality is good. Chlorophyll (an indicator of phytoplankton biomass), zooplankton biomass, and particulate matter were elevated in the lagoon, with highest concentrations in the eastern part of the lagoon.

The rate of primary production was about 22 gC m^{-2} y^{-1}, and the zooplankton production rate was about 0.9 gC m^{-2} y^{-1}. With reasonable assumptions about the relationship of fishery yield to zooplankton production, this rate of production can support only a small part of the diet of Tarawa's human population. The rest of the fishery production in the lagoon must be supported by production of benthic animals (e.g., bivalves) that feed on phytoplankton.

Ctenophores (comb jellies) were abundant in the lagoon, particularly in the southern part. In spite of their high biomass, they do not appear to be important consumers of zooplankton.

2.2.3 Reefs

Tarawa Lagoon provides an unusual setting for coral reefs because it lies in the equatorial upwelling, a region of relatively high productivity. Coral cover and diversity decreases from west to east and from north to south because of the one-sided opening of the atoll. Algae are abundant and the reefs are dominated by fragmenting coral species in much of the central lagoon, probably as a result of relatively high productivity. Most reef areas appear to be healthy, except for some mortality along the barrier reef and substantial coral mortality in the southeastern lagoon. Radiocarbon dating indicates that this mortality occurred within the last few hundred years, and may have occurred during this century. If this dieback is recent, then the urbanization of Tarawa may have been responsible for the reef kill. As a consequence of this mortality, much of the reef habitat and associated communities on the shoals of the southern lagoon have been lost.

2.2.4 Bacterial Contamination

Bacterial contamination along the lagoon reef flats was high, especially near large villages. Median fecal coliform (FC) values in water samples taken from eight of nine (88%) transects exceeded current U.S. standards for water used to grow shellfish (43 FC/100 ml). Samples from four of the nine transects (44%) exceeded human bathing water standards (200 FC/100 ml). All shellfish collected within 25 meters of shore exceeded the accepted standard for shelifish meat (240 FC/100 g meat), whereas shellfish collected farther out on the reef (>1,000 m) contained no measurable FC.

Model studies revealed that low levels of contamination in offshore waters are caused by the rapid mixing of water off of the reef flats and the die-off of bacteria. In addition, model studies showed that causeways can increase the bacterial concentrations in adjacent waters, but only slightly.

Two methods of reducing FC in shellfish were tested: depuration in saltwater and cooking. FC was depurated from *te bun* within three days by holding them in clean seawater. FC concentrations were reduced by almost 1,000-fold following ten minutes of cooking. Thorough cooking is currently the only method recommended for preparing shellfish so that they are safe to consume.

2.2.5 Fish

We studied the status of the finfish resources in the lagoon by conducting landing surveys with fishers, by systematically sampling in the lagoon (independent of existing fisheries), and by interviewing knowledgeable fishers. Finfish resources in Tarawa Lagoon have declined since 1977.

From 1977 to 1992-1993, the catch per unit effort (a measure of abundance) and proportion of catch of several important fishery species, including bonefish, declined significantly.

Particular attention was paid to bonefish. Several lines of evidence point to a serious decline in the bonefish stock. First, catch per unit effort is lower than in 1977. Second, fish caught today tend to be smaller, with averages of 0.8 kilograms in the fisheries-independent study and 0.7 kilograms in the landing survey, compared with 1.3 kilograms in 1977. Third, most of the fish caught were juveniles that had not spawned; of the adults, most were males and very few were large females. The ratio of males to females increased from 1.4:1 in 1977 to 6.8:1 in 1992-1993. This finding suggests that fishing has removed most of the older, larger female fish, and most of the remaining fish will be caught before they have a chance to spawn.

The evidence cited above for a decline in bonefish was supported by independently conducted interviews with fishers. Many expert fishers said that bonefish stocks had been destroyed or greatly depleted. According to these reports, bonefish undergo a mass migration from the lagoon to the ocean to spawn, but many passages have been closed by causeway construction, which has blocked this migration. Instead of seeking alternative routes, the bonefish have apparently stopped migrating in all areas except Buariki. Even in Buariki, the major aggregation, which used to occur before the migration, has failed to materialize for two years. The end of distinct spawning migrations may mean that the population will disappear in a few years.

The decline in bonefish can be traced to two causes: blockage of migration routes and over fishing. Excessive fishing has occurred through the use of the splash or *te ororo* method of gill netting. Pre-spawning aggregations and migratory bonefish are particularly vulnerable to this method.

Several other fish stocks also appear to have declined. For example, other migratory fish, such as goatfish and mullet, have virtually disappeared, probably for reasons similar to those responsible for the decline in bonefish.

Reef fish such as snappers (e.g., *te morikoi)* are more abundant in the western part of the lagoon than in the southeastern part, probably because of better habitat conditions. Many of these species are less abundant than in the past. Several species of small baitfish (e.g., *te tarabuti*) have become rare. These declines in abundance are probably caused by over fishing.

2.2.6 Shellfish

Shellfish and other bottom-dwelling organisms have pronounced gradients in abundance related to the depth patterns of the lagoon and the degree of isolation from the ocean.

Most of the attention in this study was on shellfish collected on the lagoon reef flats. The most commonly collected, in terms of numbers, is the small conch *te nouo*. Because of rapid reproduction

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and growth, this species appears to be capable of withstanding intense collection without collapsing. Thus, this fishery appears to be in excellent condition.

The fishery for *te bun*, probably the most popular shellfish collected on the reef flats, is in a slightly less favorable condition. These clams occur on the reef flat, usually in association with seagrass beds, and on the nearby lagoon slopes. These deeper populations probably supply young for the shallower *te bun* beds, which are harvested more intensely. Although the deeper populations are now abundant, this has not always been the case; these deep populations could be wiped out if appropriate measures are not taken. The total *te bun* harvest is estimated at 2,000 mt; 1,000 mt on the reef flats by subsistence collectors and 1,000 mt by commercial divers. Whether the population can sustain this level of exploitation for long is unknown.

Most of the deep lagoon floor holds few shellfish, but the southeastern corner supports dense urchin communities, averaging approximately 40-70 per square meter for the three larger species of urchins. Marked west-east and north-south zonation in all aspects of the benthos is related to differences in habitat and the degree of isolation from nutrient-rich oceanic waters. Giant clams were not targeted for study, but surveys revealed that they are very sparse.

2.2.7 Household Survey

A sample of the residents of Tarawa were interviewed in their homes in the Kiribati language to determine their opinions and expectations regarding conditions in Tarawa Lagoon. A total of 132 households (4%) from South Tarawa and 37 households from North Tarawa (6%) was surveyed. The stratified survey sample was designed to ensure representation by household categories including traditional leaders within all villages of Tarawa, and people living on and away from the shore of the lagoon.

Overall the people of Tarawa appear to be knowledgeable about the kinds of food sources the lagoon can provide and the ways of collecting them. Older and more experienced fishers also had a thorough knowledge of the habits of fish. People in Tarawa, however, seemed to be relatively unaware or unconcerned about the current state of the lagoon. Although many stated that fish or shellfish were harder to obtain than three years ago, few understood why this situation might be so or what could be done about it. Most residents had little understanding of how the government might interact with people to improve conditions in the lagoon.

The survey revealed widespread adoption of technologies designed to catch more fish and smaller fish, with less time and less effort than historical methods. Respondents indicated that people should reduce their take from the lagoon, but were generally unwilling to do so themselves or to support new governmental regulations or fees to manage the lagoon. On the other hand, a majority of respondents were willing to assist individually or on a community basis with projects intended to improve conditions in the lagoon. Respondents indicated a high level of support for public education,

awareness, and training projects. Although people generally believed that causeways were partly responsible for deterioration in the lagoon, they still supported construction of more causeways to improve travel between islands.

2.3 Management Issues

2.3.1 Causeways

The effects of causeways on the lagoon have been known for some time. The principal impact of causeways is that they block fish migrations, especially those of bonefish, goatfish, and mullet. These fish must migrate to the ocean to spawn and their larvae must migrate back into the lagoon from the ocean, so blocking migration routes directly affects stocks of these fish. Not all passages are suitable for migration, however. For example, bonefish do not migrate through many of the open passages of North Tarawa.

Blocking passages has affected not only fish, but also the ability of people to catch them. Fish traps designed especially for bonefish or goatfish once caught vast numbers of these fish; with these migrations blocked, the fish are no longer there to be caught.

Although causeways provide convenient access between islands, they block access from the lagoon to the ocean. The lack of easy access to the ocean may have forced more fishers to stop their ocean fishing activities since causeway force them to travel long distances for ocean access and thus they find it easier to concentrate their effort on the lagoon.

The effect of causeways on circulation, sediments, and contaminants has been discussed in the past, but modeling and other studies suggest that causeways have only a minor effect on circulation. For example, opening passages now blocked in the southeastern elbow of the atoll would improve water quality there by only about 10 percent. Calculations also show that causeways were probably not the cause of increasing concentrations of fine sediment in the southeastern part of the lagoon, and therefore not the reason for the death of corals in that area.

2.3.2 Fishing Practices

Changing fishing practices over the past several decades have had a profound influence on the availability of fish. This influence is particularly evident for bonefish, most of which used to be collected in rock traps. Bonefish now are collected with handlines and, to a greater extent, gill nets (particularly using the splash method). The difference in effect on the fish is twofold. First, fish caught in rock traps had already spawned, thereby ensuring the continuing availability of young fish. With the use of gill nets and handlines, they are caught at all times. Second, current methods are

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much more efficient, so the same number of fishers can catch a greater portion of the fish population. Both of these effects have contributed to the decline in bonefish.

The use of gill nets and outboard motor boats has enabled fishers to much more effectively catch their preferred fish. Furthermore, the long gill nets used in the splash method are extremely effective for collecting bonefish and other fish. Finally, small-mesh gill nets catch these fish before they are large enough to spawn, so future stocks are no longer ensured.

The result of the shift in technology is that fishers take a greater proportion of the fish from the lagoon than they did when using the old technology. In addition, as the population on Tarawa grows, the number of fishers increases. These two factors combined have resulted in over harvesting of the fish in the lagoon, particularly bonefish and a few other species.

2.3.3 Commercial Fishing

Several types of small commercial fishing activities are active in the lagoon. These activities include catching various kinds of fish for sale, collecting *te bun* from deep locations for sale along the road, collecting baitfish for commercial fishing activities, and collecting bêche-de-mer for export.

All these activities have the potential to harm lagoon resources. The bonefish stock is so low that commercial fishing is a significant hinderance to recovery. The collection of *te bun* in huge numbers from the reef slopes could eventually eliminate the breeding stock, resulting in a population collapse. Commercial baitfish collection has apparently wiped out several species of baitfish such as *te tarabuti*. The bêche-de-mer fishery does not compete with subsistence activities, but could wipe out that commercially valuable resource. If not managed effectively, commercial activities tend to have a disproportionately larger impact on resources than does purely subsistence collecting.

2.3.4 Public Health

People collect food and bathe in Tarawa Lagoon, and use it as a toilet. The high incidence of diarrhea and other intestinal diseases may be due in part to these uses. Levels of bacterial contamination are particularly high near heavily populated areas and near areas where pigs are kept in pens along the shore. The contamination from people and pigs goes directly into the water where it can infect swimmers and shellfish. Eating contaminated shellfish can cause diarrhea and transmit other more serious diseases, such as cholera.

3.0 Structure of the Plan

This section discusses the goals and objectives outlined in Section 1.3 and provides details on the framework for the Plan. This framework includes a description of the *Bonnano N Tararua* and a discussion of the principles of cooperative management, by which responsibility for lagoon management can be allocated to governmental and local entities.

3.1 Goals

The following goals are provided to guide the future planning and management decisions of individuals, the community, and the government. The goals are intended to present a community, or *maneaba*, vision for Tarawa Lagoon. Figure 1.3 depicts the lagoon management plan as an element in a traditional maneaba. The plan is the roof; the protection. The goal are the pillars holding up the plan. The goals provide the overall framework through which individual objectives are met and projects are carried out. The foundation is the community of people that want a better lagoon. These people are the members of the Bonnano N Tararua.

The concept of interconnecting the social concepts of the traditional maneaba (community involvement in collective security and sharing) and a modern natural resource management plan is a effort to leap the cultural and information barriers between western science and planning and traditional Kiribati culture. It is presented as a program image; a design concept for posters and tee shirts. The traditional maneaba is the unit of collective action. The people of the maneaba take care of each other and the area adjacent to maneaba. The figure strives to make the lagoon an area of collective responsibility. Everybody covered by the plan will benefit. By concept, all residents of Tarawa can be members or at least represented by a member of the *Bonnano N Tararua* and all should benefit by implementing the plan.

Goal 1: Improve the productivity of the lagoon to meet present and future needs.

By 2010, the population of Tarawa is predicted to be approximately 20 times larger than it was just after World War II. The lagoon fisheries, however, are already severely depleted, compared to just a few years ago, and some fishery resources are close to extinction. These species will become extinct unless a conscientious program is set in place to allow these stocks to recover. The Plan provides a means for these endangered stocks to recover while improving habitat conditions for all fishery resources.

Seafood is an important part of the diet of the people of Tarawa. For hundreds of years the primary source of seafood has been the lagoon. Opportunities exist in the ocean near the atoll, but have not been developed as fully as they could be. This Plan provides ways for the residents to take advantage

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of those ocean resources through changes in fishing methods, gear, and season. At the same time, the Plan provides for technical and, where appropriate, financial assistance to fishers to make the changes with minimum adjustment.

Goal 2: Ensure that people have easy access to safe and reliable sources of food.

Thousands of people depend on Tarawa Lagoon for their daily food. Each person should be able to continue to obtain fresh seafood from the lagoon and the ocean so that they are not forced to purchase imported sources of protein, such as canned fish. The Plan would reduce over harvesting of the lagoon's fishery resources by shifting the times, places, and methods of fishing in the lagoon, and would allow the fish populations to recover. A significant amount of the fishing would be simultaneously shifted to the near shore ocean fishery. In each case, the Plan is designed so that technical and financial assistance would be available to fishers; they can then make the needed changes with a minimum of adjustment.

Conservation measures are needed to protect the vestigial remains of once abundant resources. Temporary hardships may affect people who do not have the financial, educational, or motivational resources to make changes in their way of life or in their careers. These people need to be assisted in making the necessary adaptations to survive in an urbanized Tarawa. If a community-led, balanced management regime that emphasizes the creation of alternatives and new opportunities is not established, the subsistence fishers will undergo worse hardships in the near future.

Goal 3: Promote job development throughout Tarawa.

Any change in fishing practices, whether to increase or decrease fishing pressure in Tarawa Lagoon, creates opportunities for new businesses and jobs to make the needed equipment, employ the new techniques, and maintain the equipment. The Plan intends that all such opportunities be identified in the ongoing planning and implementation projects so that focused technical and financial assistance can be provided to help those businesses get started and employ people.

Goal 4: Promote continued improvements in health for all the people of Tarawa.

The reports prepared in support of the Plan document facts that are well established in many other reports. The health of the people of Tarawa is seriously affected by unsanitary practices associated with the lagoon. The health situation will get worse as the population increases, unless efforts that are already underway to reduce the use of the lagoon as a toilet are more successful. This Plan provides suggestions for further progress.

3.2 Objectives

This section discusses the Plan's specific objectives by category. These objectives are derived from the above goals and, in turn, lead to the specific actions recommended in the Plan.

3.2.1 Create Framework for the Management of Tarawa Lagoon

The following objectives relate to all the goals. The management framework needs to be in place for the planning process to succeed.

Establish a planning process whereby decisions can be made rationally and fairly, using the best available information. This process would remove the bulk of decision making from the national political and local arenas. Establishing such a process would ensure that decisions are as fair as possible for all citizens.

Establish a governing body to oversee lagoon management. A nongovernmental body would have the independence and breadth needed to impose regulations for the benefit of the lagoon and its users.

Improve the public's awareness of the lagoon's condition and the effects they have on it. As described in section 2.2.7 many residents are unaware of the deteriorating condition of the lagoon and the possible causes for this situation. The public must be informed so they can become full partners in planning for and managing the lagoon.

Maximize public participation in planning and management. The government and Island Councils cannot manage the lagoon alone. Regulations imposed by the central government cannot be enforced in the absence of broad public support and participation in management programs. Cooperation and participation by the general public is essential for the success of lagoon management.

Establish cooperative management as the approach that underlies management of the lagoon. Cooperative management is discussed below in Section 3.4. This approach provides all lagoon users with a say in the lagoon's governance.

Incorporate Customary Marine Tenure practices to the extent that they are compatible with Tarawa's political and legal structure. The integration of Customary Marine Tenure (CMT) in the planning and management of Tarawa Lagoon is discussed below in Section 3.4. The philosophy and general approach of CMT should be considered in developing actions, although not all aspects of CMT could be implemented.

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Continue scientific research and monitoring so that conditions under the Plan are periodically reevaluated. Establishing continuous or periodic monitoring is essential to evaluate the effectiveness of the Plan. Research programs are needed to examine specific issues, such as the status of the bêche-de-mer fishery and the effectiveness of methods for reducing contamination in shellfish. Universities with programs in tropical sciences should be encouraged to conduct research to increase knowledge about the lagoon.

3.2.2 Improve Fishery Production in Tarawa Lagoon

Many of the action items are designed to improve production of one or more of the lagoon's fisheries. The current status and trends of these stocks are discussed in Section 2.0 and by Beets and Johannes and Yeeting in volume II.

Stop the decline of bonefish and allow stocks to increase. The bonefish stock of Tarawa Lagoon is in a precarious state and must be immediately protected from further decline. In fact, a larger bonefish stock is needed so that people can increase their harvest of this favorite fish.

Allow baitfish stocks to recover. Some baitfish stocks have been decimated by over harvesting. They need to be allowed to recover to a level that will allow some harvesting.

Reverse declines of other lagoon fish. Populations of several other species of lagoon fish are declining, although none as precipitously as bonefish. The pressure on these stocks may, intensify if harvest restrictions result in a temporary decrease in the harvest of bonefish. Thus, all fish stocks in the lagoon need to be protected simultaneously.

Allow stocks of giant clams to recover. If giant clams are to be preserved, they must be protected from harvest immediately, and steps must be taken to allow the population to increase.

3.2.3 Provide Alternative Sources of Food and Income

The objectives in Section 3.3.2, if achieved, would cause a short-term reduction in the harvest of lagoon fish. This decrease could be seen as a problem for the fishers of Tarawa, because a valuable food supply would be reduced. This situation can, however, also be seen as an opportunity; if alternative food sources can be found, then when lagoon stocks recover there will be enough for everybody.

Shift emphasis from utilizing the lagoon as a source of food to using the ocean. Fishers need to be encouraged to obtain as much of their food as possible from the ocean. This resource is unlimited from the point of view of Tarawa families.

Improve fishers' access to ocean resources. Fishers, especially those in the eastern part of South Tarawa, have to travel a long way to fish in the ocean. If access to the ocean can be improved for these fishers, the proportion of fishers who harvest in the ocean rather than in the lagoon would increase .

Identify alternative stocks. Some stocks that are not currently harvested could become available for harvest, providing an alternative to the currently harvested lagoon species.

3.2.4 Improve Public Health

Several objectives relate to improving public health. In a broad sense, a variety of opportunities for improving public health exist, but only a few of these opportunities relate to use of the lagoon.

Reduce the use of the lagoon as a toilet. Using one body of water as both a toilet and a food source causes health problems. Any actions that reduce waste input to the lagoon, whether or not they directly involve the lagoon, would improve this situation.

Improve access to other toilet facilities. Providing alternatives is usually more effective than instituting bans or restrictions. Both approaches should be pursued further to reduce the incidence of disease.

Improve the safety of food collection and preparation techniques. Even if waste input to the lagoon were reduced, the concentration of fecal bacteria in the water would be unsafe for raising shellfish at many locations. Additional measures need to be implemented to reduce the danger of harvesting and eating shellfish from these contaminated areas.

3.3 *Bonnano N Tararua*

The core management concept of the Plan is the creation of an organization called the *Bonnano N Tararua*. This organization is a logical outgrowth of an ongoing process taking place in the Ministry of Environment and Natural Resources Development (MENRD).

3.3.1 Background

In mid-October 1993, BioSystems' scientists presented the preliminary results of their research findings to the government and the public in two public participation meetings. The scientists, government representatives, and public expressed many concerns at these meetings. These concerns

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were communicated to the government in a special report to the minister, the Honorable Tiwau Awira, on 1 November 1993.

In January 1994, the MENRD organized a lagoon management committee to address some of the most urgent concerns. This committee consisted of members of the MENRD and one representative from BioSystems. At a subsequent meeting held in March 1994, the committee was expanded to include other ministries. The committee's first set of actions was to propose legislation to protect the bonefish and giant clam resources of the lagoon.

Using a relatively autonomous organization to guide the development and management activities of a body of water has been proven to be successful, based on a history of managing aquatic resources in Asia, Europe, and North America (Imperial et al. 1992). Bodies of water, whether rivers, lakes, lagoons, or ocean shoreline, generally cross many political jurisdictions. The activities that affect the bodies of water are usually under the control of many government entities. For example, pollution problems can be the responsibility of several ministries or divisions of government. Thus, forming a council of representatives from several government ministries and many lagoon user groups is a logical method for successfully addressing lagoon problems; such a council will be responsive to the needs of the public and to the mandated responsibilities of the affected ministries of the government of Kiribati.

The *Bonnano N Tararua* is intended to provide a process through which all Tarawa residents can participate in decision making through representation. This process invites input from many government agencies and encourages public participation from a broad spectrum of the public. The *Bonnano N Tararua* would be responsible for implementing the Plan, including achieving stated goals and refining actions as new information is obtained.

3.3.2 Organization

The *Bonnano N Tararua* should be regarded as an institution that brings together all groups with an interest in the lagoon. Figure 3.2 shows how all these groups can interact. The *Bonnano N Tararua* would not answer to any government ministry. The intent is that the ministries would hear the recommendations and take action. Close ties would be maintained with ministries that have a stake in the lagoon. Authority over certain activities, normally vested in one or more ministries, would be shared with the *Bonnano N Tararua*. These activities would be identified through negotiations between representatives of the *Bonnano N Tararua* and the ministries following each annual conference.

3.3.3 Initial Responsibilities

The responsibilities of the *Bonnano N Tararua* would initially include the following:

- Set specific objectives for the rehabilitation of the lagoon.
- Hold periodic meetings to discuss problems and possible solutions.
- Hold an annual conference to receive and produce reports on the status of the lagoon.
- Make recommendations to ministries, the Cabinet, Island Councils, and village councils.
- Approve and establish priorities for certain projects for implementation.
- Advise government agencies to comply with the policies and priorities of the *Bonnano N Tararua*.
- Issue statements to the newspaper and radio on lagoon management issues.
- Publish materials concerning lagoon management and a newsletter on lagoon management activities.
- Implement the public participation processes.
- Conduct informal public education in all villages.

3.3.4 Annual Conference

Each year, the *Bonnano N Tararua* would hold a two- or three-day conference to develop strategies and plan the implementation of projects. The public could attend the conference and, at designated times, present their views. Preferably, the conference would extend into the weekend so that more people could conveniently attend. The purpose of the annual strategy conference would be to determine the status of the lagoon's resources and water quality and to recommend practical strategies for achieving realistic objectives.

The *Bonnano N Tararua* executive committee would meet periodically throughout the year (quarterly, for example) to receive technical input on the condition of the lagoon, review the progress of the Plan and annual strategy implementation, and receive comments from the public. In addition, the *Bonnano N Tararua* could create task forces to address specific issues, such as managing the giant clam or creating near shore ocean fishery opportunities for subsistence fishers. These periodic meetings and the work of the task forces would also provide the foundation for the annual strategy conference.

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3.3.5 Authorities and Rules of the *Bonnano N Tararua*

To ensure the legitimacy of the *Bonnano N Tararua*, the government should formally establish the council and give it the necessary authorities. The Plan provides that the *Bonnano N Tararua* would have specific authority to recommend policies to the President, establish priorities for selected government projects pertaining to the lagoon, and advise agencies to comply within certain areas specifically authorized by the government.

To be effective, the *Bonnano N Tararua* would also need to establish rules for orderly communication so that no one person could dominate the agenda or decision-making process. The council should create a temporary subcommittee to develop procedures and rules. The subcommittee could decide on the procedures for appointing a chairperson, creating other subcommittees and determining their authority, conducting public meetings, and making decisions. For example, on the last day of the annual conference each year, there could be a vote to select a leader and four new members of an executive committee.

3.4 Cooperative Management

This section discusses the concept of cooperative management and explains its application in managing Tarawa Lagoon. In cooperative management, the responsibility and authority for managing the lagoon would be held jointly by all parties with a stake in the condition of the lagoon. Integrating CMT practices into management is also recommended, to the extent feasible.

3.4.1 Background

In general, central government management of near shore fisheries of Pacific islands has been unsuccessful, despite good intentions and concerted efforts. In fact, as participants in the South Pacific Commission's 1988 Workshop on Pacific Inshore Fisheries Resources acknowledged, there are "few, if any, Pacific Island inshore fisheries which are currently managed" (i.e., by government departments).

The costs and complexities of effectively monitoring and managing small, multispecies, multimethod fisheries by conventional methods have generally been prohibitive. Indeed, data requirements for the management of multispecies fisheries can be so great that adequate data for scientific management may never become available (Walters 1986).

Moreover, computer models and statistical analyses have routinely failed to provide the reliable predictions needed to guide management, even for simple temperate-zone fisheries. Furthermore,

managers increasingly recognize that many important uncertainties are political or social and beyond the scope of current modeling and statistical efforts (Hilborn 1987).

In a report on survey activities of the Kiribati Fisheries Division, a well-respected fisheries biologist in the Pacific Island region stated the following about conventional large-scale marine resource assessments: "Given the resources (human and financial) available to island countries, it is unrealistic and probably even unnecessary to expect large-scale scientific resource assessments to be made. Such assessments all too often yield relatively little, especially in the short term, despite the cost and effort involved. A more pragmatic view, and one used on recent surveys in Fiji, holds that the most important thing in the early stages of the development process is to build up a 'feel' for, or basic understanding of, the resources of an area. This is most easily done in comparison with experience in other areas" (Lewis 1984).

3.4.2 Customary Marine Tenure

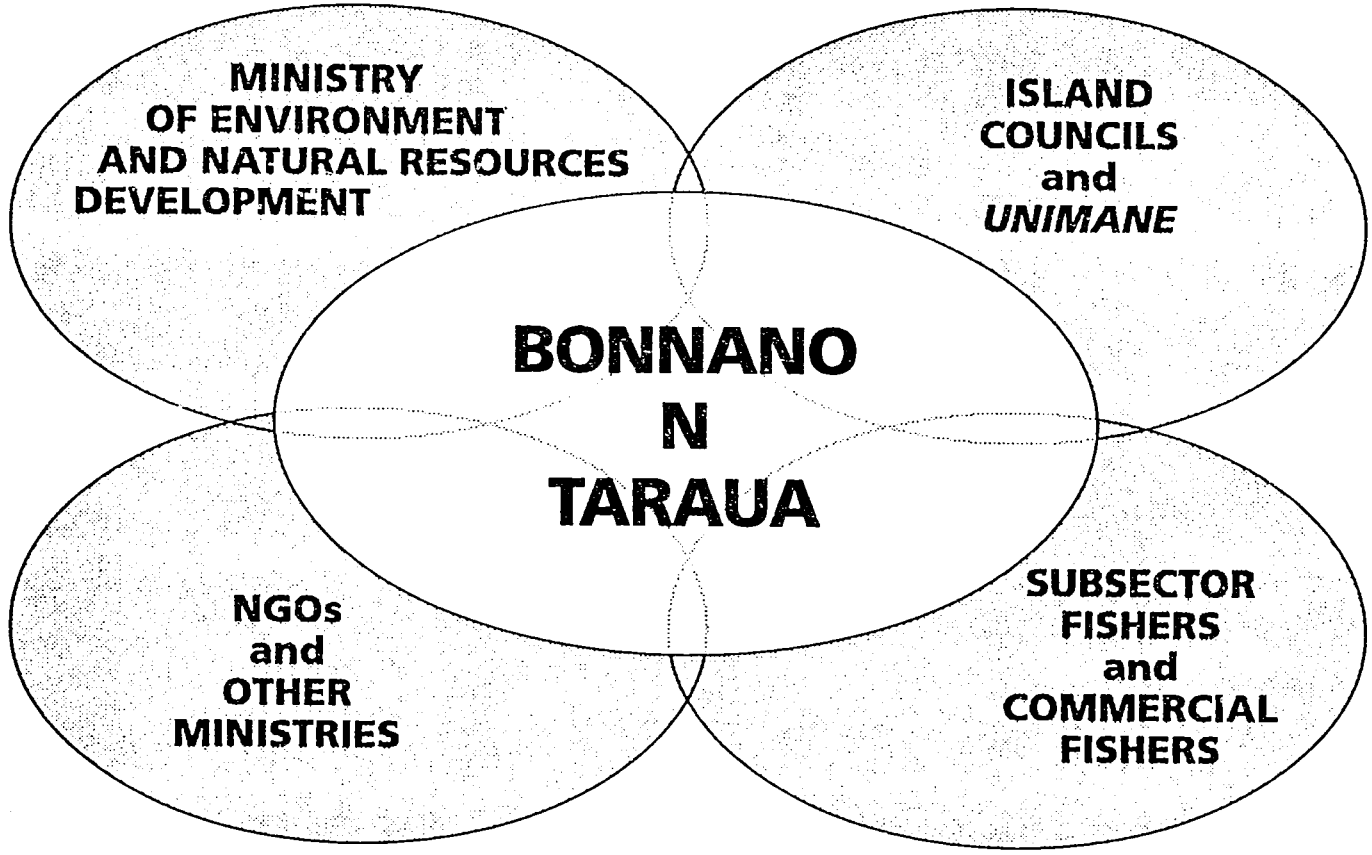
One approach that has been gaining support among small-scale tropical fisheries advisors around the world is to give fishers greater roles in and greater responsibility for managing their own fisheries. Panayatou (1982) said, for example, "The revival and rejuvenation of traditional customary systems . . . with limited but crucial government involvement is one of the most promising policy options for upgrading and managing artisanal fisheries." CMT on Tarawa is on the verge of extinction, and resurrecting it as a management tool may not be possible. Given the increase in population, including many outer-island people with no traditional ties to the local lagoon resources, the imposition of a rigid CMT policy would lead to considerable conflict and hardship.

CMT systems, which are based on local customs and values, possess many of the essential features of Tarawa's history of *mronron*. Both systems are operated by groups of individuals organized around common interests and common resources. Both can coordinate their members' actions, allocate and protect their resources, regulate the distribution of their catch and profits, share risks, exclude outside fishers, and represent the fishing community in dealings with outsiders, including government officials.

3.4.3 Incorporating CMT into Cooperative Management

Another common government approach to the problems of small-scale fishers in tropical countries is to attempt to introduce cooperative approaches to management. The failure rate of these approaches in the Pacific Islands, as in many other regions, however, has been high.

An important contributing factor to the high failure rate appears to be that the initiatives came from outside the fishing communities, rather than from the fishers themselves, and were not based on local



Prepared by BioSystems Analysis, Inc./1994

Figure 3.1 Schematic representation of relationship between the *Bonnano N Taraua*, the government and community groups.

customs and values. Another factor is that they bring together only commercial fishers and neglect subsistence fishers. Tarawa has more subsistence fishers than commercial fishers.

The Plan's intended approach to cooperative management is to rely on individual and community initiative and participation. The government's role would be to provide technical and, where appropriate, financial support. This approach is the reason for providing the *Bonnano N Tararua* with as much authority as the government can comfortably provide.

A cooperative management approach that integrates western, science-based resource management with *mronron* and CMT systems has the advantages that it can:

- Provide culturally sanctioned rules for allocating marine resources equitably, apprehending and punishing transgressors, and adjudicating disputes (usually without recourse for government, thereby greatly reducing administrative costs)
- Function as a form of conservation measure by limiting entry to a fishery and providing the owners (i.e., all fishers) with an incentive to regulate their own harvest
- Facilitate more flexible adjustments to changing biological or socioeconomic conditions affecting the fishery than can government regulations.

At the same time, technical and scientific input into local decisions, from government ministries or elsewhere, can provide a solid basis for decisions.

3.4.4 Other Advantages of Incorporating CMT

CMT can play other important roles in marine resource management by controlling local development, if their rights are secure. Coastal development such as land clearing, dredging, and filling can destroy nearshore habitats. In countries where CMT is strong, however, owners can apply political or legal pressure to stop development or to restructure it so that its environmental sustainability and social acceptability are ensured.

The ability of *mronron* or CMT systems to police their tenured waters may also prove useful in marine resource enhancement programs. Aquaculture is a case in point. Officials in charge of planting giant clams in at least one Pacific Island country where CMT no longer operates have had to keep the clams close to shore in an inappropriate environment to protect them from poachers. In Vanuatu, where CMT remains strong, and in Yap, the governments have been able to distribute juvenile clams throughout the country in appropriate habitats with the assurance that local CMT owners would make a serious effort to protect them.

The cooperative management approach recommended in this Plan also removes some of the burden from the understaffed and under funded marine resource management agencies. These agencies can then focus their efforts on regional and national issues, concerning themselves with local management issues only if the *Bonnano N Tararua*'s procedures fail.

If such failure occurs and local disputes are taken to higher authorities, such as a court of law, the value of the prior scientific investigations to support the *Bonnano N Tararua*'s procedures are critical for legal success. Delaying research until a legal situation arises greatly delays the provision of essential information.

Moreover, research carried out before the resources in question become the subject of formal legal dispute is more likely to elicit reliable information from informants. Once resources are at issue in the courts, participants may be tempted to describe traditional boundaries and traditional rights within them in a manner more in keeping with the interests of their village or clan than with tradition.

3.4.5 Implementing Cooperative Management

In this section, cooperative management is more fully described, and its applicability to Tarawa is discussed. The final section provides step-by-step suggestions for implementing a cooperative management process and outlines detailed task responsibilities for each participant.

International development projects charged with producing natural resource management plans in developing countries often generate detailed packages of recommended regulations and practices. Experience has shown that this approach is usually ineffective. "One of the main reasons is that it leaves local people largely out of the planning process. This undervalues relevant local knowledge and ways of doing things. It ignores the importance of finding management solutions that are acceptable to the people they affect and the likelihood that this will not be accomplished without full-scale local participation in the planning process" (Jull 1993), or cooperative management. Cooperative management in fisheries has been defined as the "comprehensive participation of fishermen in fisheries decision-making at the level of formulation, acceptance and implementation" (Kearney 1989).

As Jull (1993) states, "The answer to specific resource management questions is not to be found in *practices* which may be borrowed or replicated from abroad, but in *processes* which generate new relationships between indigenous peoples and the structures of the general community . . . and which yield specific solutions acceptable to the various parties involved." He also says that all researchers who have studied cooperative management "stress the values of process and the quality of relationships as the key to successful outcomes."

The cooperative management approach we recommend relies on self-help and self-regulation. Governmental regulation would be minimized, and participating individuals and communities would have substantial responsibilities for carrying out the challenging tasks ahead.

Management requires cooperation, whether the management is achieved through voluntary action or through a highly regulated system relying on police power. Cooperative management is a management system or process through which an appropriate combination of formal and informal participation is used to decide what actions are needed and to see that these actions are carried out. The Plan envisions a participation process that includes representatives of all affected groups; all interested parties would have an opportunity to express their views in the process.

It is important to see cooperative management as a process of decentralizing government. The responsibility lies not only with government but also with the local communities. It is a self-help or self responsibility relationship. The goal is not to turn the *Bonnano N Tararua* into a government committee so that communities can put the onus of managing Tarawa Lagoon on the government. The intent is to minimize formal, direct involvement by government.

The government should serve as an observer and present information to the *Bonnano N Tararua*. The *Bonnano N Tararua* could be envisioned as similar to other nongovernmental organizations, such as the Red Cross, except that it would be created by the government to give users of the lagoon authority to manage their resource.

Cooperative management should be positioned between CMT and management by the central government. CMT is based on the principle that customary law has solid legal backing and can be employed to address local issues, particularly local marine resource management issues. The Laws of Kiribati Act of 1989 covers the body of customary law; in general, customary law prevails unless it is inconsistent with national government laws (Perla 1993).

As on other Pacific Islands, the Kiribati Fisheries Division realizes that it is extremely difficult to manage most of its fisheries because the costs of research, monitoring, and enforcement would substantially outweigh the benefits.

The Fisheries Division, however, can play a vital role in lagoon management by working in the villages to meld local knowledge with modern, research-based knowledge to improve local management. This type of management—where a government fisheries department provides scientific information and advice and certain basic conservation laws, but fishers assume most of the responsibility for local management—is a form of cooperative management (Pinkerton 1989).

This government support can be divided into two categories: fisheries research and the provision of relevant extension services. In Kiribati, as elsewhere throughout the developing world, fisheries extension work has focused largely on fisheries development. Where cooperative management is operating in artisanal fisheries, however, supportive extension programs need to incorporate a new

set of skills and knowledge. Extension workers must obtain information on village marine management strategies and the practical local knowledge concerning marine resources. They also must provide the complementary scientific knowledge and education that villagers need to manage their resources better.

Residents generally do not want to be told how to manage their fisheries. Instead, they want education concerning practical management alternatives—answers to questions such as "What management measures are there for us to choose from?" and "Where, when, and for how long should they be applied?"

Management rules or principles should be implemented and the affected parties, whether commercial or subsistence fishers, should be given every opportunity to carry out management activities. This authority should be given with a minimum of formal laws or regulations, relying instead on the individual and joint efforts of private citizens as a first priority. Then efforts should be supported by a framework of regulations authorizing their activities and threatening more serious action if their voluntary efforts do not succeed.

The management principle to be repeated and discussed throughout the project implementation phase is the role of cooperative management in setting policies and priorities, and in accepting individual and community responsibility for the success of the projects undertaken to implement the policies. This principle requires active participation from all parties throughout the process so that everyone involved takes responsibility for the results.

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4.0 Action Programs

This section describes several actions programs designed to achieve the Objectives of the Plan. These programs are:

- Urgent actions for immediate implementation
- Management structures
- Public awareness and education
- Research and monitoring

Within each program, actions are grouped into related categories. One or more specific recommmendations are given for each action, the reasoning behind each recommendation is discussed and, in some cases, procedures or considerations for implementing the recommendations are presented.

The first set of actions are of such importance that they must be undertaken immediately to prevent irreparable or long-term damage to lagoon resources. The timetable for implementation of the remaining action programs should be decided by the *Bonnano N Tararua*.

4.1 Urgent Actions for Immediate Implementation

The planning and management structures needed to implement the Plan are not yet in place. Although existing agencies and procedures may be extended to implement some aspects of the Plan, those assignments have not yet been made. Some actions, however, are too urgent to wait until implementation structures are in place. The scientific studies undertaken to develop this Plan identified several lagoon management issues that are so important and of such urgency that they cannot be postponed. If these activities are not addressed immediately, irreparable or long-term damage to important lagoon resources may result.

Following is a list of five high priority management issues that need to be addressed immediately. All five issues fall within the authority of the government to address. If for any reason a long term solution cannot be addressed now, interim actions should be taken until the issue can be taken up by the *Bonnano N Tararua* at its first annual conference.

The public may oppose implementation of these urgent actions if they feel their livelihoods are threatened. Therefore implementation should proceed carefully. MENRD should implement these actions as regulations with the concurrence of Island Councils. Before these

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rules are published, however, a wide-spread education program must be undertaken (see Section 4.2). This program should be designed to convince people of the following:

- Certain resources, such as bonefish, are in trouble
- Actions must be taken now
- These actions will be effective if everyone helps
- The end result will be more for everyone once stocks recover

4.1.1 Immediate Actions to Protect Bonefish

Recommendation 1:	Stop all fishing of bonefish pre-spawning aggregations
Recommendation 2:	Cease *te ororo* fishing
Recommendation 3:	Exchange gill nets of 1- to 3½-inch mesh size for nets with a mesh size of at least 3½ inches.
Recommendation 4:	Limit gill nets used in fishing bonefish to at least 3½ inches mesh size and 10 meters length

The background behind the recommendations for bonefish is further discussed in Section 4.4.1. This section briefly discusses the recommendations for protecting bonefish in the near future.

4.1.2 Immediate Actions to Protect Giant Clams

Recommendation: Prohibit the taking of giant clams

Recent actions taken by the Fisheries Division to protect the few giant clams remaining in the lagoon are commendable. Additional actions should be considered to create a deep-water recovery area for the remaining population of giant clams. Under present regulations, it is still legal to take all the remaining clams.

4.2 Establish Management Structures

This action program will establish the framework for managing the lagoon, including establishing the *Bonnano N Tararua* and its Executive Committee, and preparing the government Ministries to work with the *Bonnano N Tararua*, and holding the first annual Lagoon Management Conference.

4.2.1 Create and Authorize the *Bonnano N Tararua* and its Executive Committee

The *Bonnano N Tararua* should be formally established by the government so that it has the authority and public influence needed to effectively implement the Lagoon Management Plan. The *Bonnano N Tararua*'s authority should be carefully defined. The extent and nature of the *Bonnano N Tararua*'s authority should be strong enough to ensure that government agencies participate and comply, but tempered sufficiently to ensure that the *Bonnano N Tararua* does not become another government agency.

It is up to the government to specify the authorities of the *Bonnano N Tararua*; some suggestions are presented below.

4.2.2 Provide Direction to Government Agencies to Assist the *Bonnano N Tararua*

Government leaders should formally direct all relevant government agencies to provide the technical support and assistance required for the *Bonnano N Tararua* to perform its responsibilities. This step should be a part of establishing the *Bonnano N Tararua* or implemented immediately thereafter. The *Bonnano N Tararua* should not find itself in a position whereby it cannot perform its job because it cannot get information or other cooperation from any government agency.

In addition, government agencies, the Kiribati Development Bank, and the Office of Foreign Affairs should be directed to assist the *Bonnano N Tararua* in creating new businesses and jobs through implementation of the Plan, including contracting for government services to the private sector

All government agencies should be responsible for identifying ways in which the people and the community as a whole can create new enterprises (including *mronron*) and jobs in the process of carrying out the actions included in the Plan. The tendency for government to undertake all such tasks under its existing programs and budgets should be minimized. The government should instead assist prospective entrepreneurs and employees to find ways to carry out the actions without becoming government projects.

4.2.3 Conduct the First Annual Lagoon Management Conference

Preparation for the first Conference should be done carefully and a full, detailed agenda prepared. This agenda should include at least the following items:

- Review the basis and content of this Plan
- Refine the Plan as needed
- Review the present status and trends in the lagoon, including each species considered important in the local economy
- Solicit input from the audience
- Establish annual goals and objectives for lagoon management
- Develop a Lagoon Management Strategy for the year
- Adopt implementation action projects for the year
- Finalize assignments of roles and responsibilities

The following items should also be discussed during development of the annual Management Strategy:

- Discuss fishing gear use in the lagoon (gillnets, scuba, etc.)
- Discuss fishing methods in the lagoon (*te ororo*)
- Discuss timing of fishing activities (spawning, seasons, etc.)
- Identify methods to increase fishing opportunities on the nearshore ocean side
- Identify practicable methods to reduce waste disposal in the lagoon
- Identify methods to create economic opportunities, such as:
  - Manufacture products for the lagoon or ocean fishery
  - Provide services in support of fishers (such as refrigeration)
  - Provide services to the government (such as data collection, maintenance of equipment, etc.)

The *Bonnano N Tararua* would convene the meeting. Knowledgeable people would be invited to speak briefly on some of the important topics and non-members would be given an opportunity to speak at specified times.

A thorough set of minutes of the conference should be taken. These should be transcribed, and a summary written of the key points and areas of agreement and disagreement.

4.3 Promote Public Awareness and Education

It is essential that the public be informed about the proposed actions of the *Bonnano N Tararua* and the reasons behind them. In addition, the public needs to be educated about how they affect the lagoon and how they might be harming it. Education programs should focus on schools and youth groups. This process must be done carefully so that the public is not

misinformed about the nature of the problem and the solutions.

The public education program should be in place before the first Annual Strategic Planning Conference so that the public is knowledgeable about the present situation, what they can do about it, what the options are, and how the options could be implemented. The public should have an opportunity to discuss these issues among themselves. Radio spots, public meetings and a monthly newsletter should be part of the program to disseminate information.

4.3.1 Conduct Village-based Workshops

Workshops should be held in each village to discuss conditions in the lagoon and the possible actions that could be undertaken to restore its productivity. These workshops could be convened by local or regional representatives on the *Bonnano N Tararua*, or by a small delegation. Each workshop would have several purposes:

- Inform people about the conditions in the lagoon
- Explain the concept of Cooperative Management
- Suggest several management alternatives
- Solicit candid opinions on the likelihood of success
- Solicit a commitment to cooperate with the work of the *Bonnano N Tararua*
- Seek offers of assistance in carrying out actions

These workshops must be more than a show. The people convening them, and the *Bonnano N Tararua* itself, must demonstrate through word and deed that they are committed to seeking and using public input. The public needs to be convinced that the *Bonnano N Tararua* will use the information in a constructive way. Therefore, conveners who are particularly skilled in conducting workshops will be needed. These people must be prepared to present the situation clearly and honestly and to assess the suitability of suggestions received in good faith.

The information gathered in these workshops should be summarized at the Annual Conference.

4.3.2 Build Awareness Using Radio and Newspapers

It is difficult for most people to absorb all of the information provided in workshops and conferences. To ensure that the public gets the information it needs, the issues should be discussed in writing (such as in the newspapers) and on the radio. The public should have many opportunities to receive, absorb, and discuss the information.

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Once lagoon actions are adopted, the media can be useful in getting the word out to people about the reasons for the actions and their success. The public needs to know that something useful has come out of the Conference and have an opportunity to join in implementing the actions.

4.3.3 Conduct Educational Programs

Today's children are the future managers and users of the Lagoon. The sooner they can be a part of the solution to the lagoon's problems, the sooner they can become responsible users of the lagoon. Furthermore, as the youth of Tarawa come to understand how to use the lagoon wisely, they will help to restore the lagoon's productivity as a source of food for everyone.

Today's children also offer an avenue of communication within the family. As the children receive information through their schools, churches, and organizations, they can discuss issues within the family. This can provide another forum within which solutions to the lagoon's needs can be discussed.

The youth educational program should be prepared by a committee of experienced teachers working under the guidance of the *Bonnano N Tararua*. This could be presented as a regular part of the school curriculum throughout Tarawa.

4.3.4 Involve the Community in all aspects of Lagoon Planning, Management, and Projects

Recommendation: The *Bonnano N Tararua* should continually develop more ways for individuals, non-governmental organizations, church groups, etc., to participate in the workshops, Annual Conferences, public service projects, and enterprise opportunities.

Public participation is essential for this Plan to succeed. The public must be involved from the beginning in setting priorities, choosing projects, and carrying them out. The Plan contains many ways in which the public may become involved in lagoon planning and management activities. Nevertheless, every opportunity should be explored and every reasonable avenue for participation should be developed. The *Bonnano N Tararua* should utilize the community workshops and the Annual Conferences to engage the public in developing even more ways for people to participate.

4.4 Species-specific Management Actions for Finfish

Acquiring the data necessary to provide a rigorous quantitative foundation for marine resource management is beyond reach in small-scale, multi-species tropical fisheries. As a consequence, fisheries biologists often are reluctant to recommend specific regulations. This is one of the reasons for the dearth of effective government management initiatives in Oceania, despite decades of fisheries research. Marine resources, meanwhile, have been seriously depleted in many areas.

Under these circumstances, fisheries managers should not aim for management ideals such as optimum or maximum sustained yield. The goal should be to manage in such a way that the fisheries are "in a less bad state" (ACNRR Working Party on the Management of Living Resources in Near-Shore Tropical Waters 1980). Less sophisticated, but more realistic and still invaluable objectives are to simply prevent serious overfishing, ensure reasonably satisfactory allocation of resources, and minimize conflict. To achieve even two out of three of these objectives is a major accomplishment in any fishery.

The following discussion of recommendations for the management of species and groups is indicative of what will eventually be required for the informed management of the whole lagoon. Eventually, virtually every species used for human consumption in the lagoon will need to be brought under some sort of management regime in order to approach the maximum sustainable potential for the lagoon. It is beyond the scope of this report, however, to present specific management plans with harvest targets, quotas, and projections of maximum sustainable yield for well-managed species.

4.4.1 Management of all Finfish

Recommendation 1: Manage all species of fish in the lagoon regardless of whether or not they are perceived to be in immediate threat.

Recommendation 2: Protect known spawning aggregations of all fish to ensure future spawning success.

The sampling program indicated that the abundance of most of the major species sampled has decreased significantly. It is strongly recommended that the pressure on all lagoon stocks be reduced. Some of the protective measures recommended for bonefish also may aid in the protecting other fish. Continued monitoring, reporting, and discussions between the *Bonnano N Tararua* and fishermen is critical to the success of the program.

Stocks of some fish species widely used in the community are greatly reduced but, as yet, are not threatened with local extinction. As more desirable species, such as bonefish, are further depleted, however, the fishing pressure on these other food species will increase. An

active management program for all species can identify and remedy problems early. A management program need not entail any regulation or reduction in present harvest for species that are not threatened.

4.4.2 Bonefish

Recommendations for bonefish are presented in Section 4.3.1. This section discusses the reasons for those recommendations and for the urgency suggested for implementing them.

Background

The bonefish resources of Tarawa are in serious trouble. The studies undertaken show that the population is stressed, bonefish are being caught before they have a chance to reproduce, the size of fish caught is declining, and the number of bonefish in the catch is declining.

Of particular concern is the practice of taking bonefish as they collect in prespawning aggregations before leaving the lagoon. These fish are being caught just before they can reproduce.

Taking fish before they can reproduce is equivalent to harvesting plants before they have produced the seed needed for the next generation. The situation is worse for fish, however, because their young are scattered in the ocean and only a few survive and return to the lagoon. To provide enough recruits for future generations, many more bonefish must be allowed to reproduce.

The most important action that can be taken to salvage the bonefish stock is to stop all fishing for bonefish where and when they form prespawning aggregations and subsequent spawning runs. This means closing specific areas to all net fishing or any other form of fishing for bonefish for 6 days around the full moon, which is when migration occurs. Specific ways to protect fish spawning aggregations are discussed in more detail by Johannes (1980). Similar bans have been used traditionally or are being used today in several Pacific Island countries (e.g., Johannes 1978, 1980, 1991).

Initially, bonefish prespawning aggregations may not appear during the full moon period. It is hoped, however, that spawning runs will occur again within a few years. Although there is no guarantee that bonefish spawning aggregations will ever reappear, experience with other fisheries suggest that reasonable protection of spawning adults will lead to an expansion of stock size so that once again thousands of individuals will aggregate in the days preceeding each full moon.

Interested parties, especially the fishermen of Buariki and representatives of the Fisheries Division, should agree upon conservation measures and put them into effect as a matter of

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great urgency. Radio publicity should be used to disseminate information about the bonefish problem so that the rest of the fishermen of Tarawa will understand that it affects all of them. This would encourage greater cooperation from fishermen who fish in the vicinity of Buariki, but who live in other parts of Tarawa.

The urgency of the situation in Tarawa is reinforced by the example of Abemama, an atoll south of Kiribati, once referred to as "the land of the bonefish." According to Tebano (1991), gill nets were used to catch virtually entire spawning runs, and construction of three causeways blocked some runs. Over the years, the spawning runs ceased, except for around the ends of the islands. Eventually these runs also ceased.

Even though Abemama is outside our area of focus, this situation deserves our attention. If known spawning runs have been destroyed, this reinforces the urgency of protecting Tarawa's last known spawning run of bonefish. Since bonefish larvae drift for a period before metamorphosis, it is likely that some larvae move between atolls. If there are no bonefish larvae in Abemama to provide a potential source of recruitment for Tarawa Lagoon, this increases the urgency to protect Tarawa's spawning adult bonefish.

An overview of the status and vulnerability of spawning runs in other atolls is clearly in order since gill nets, causeways, and plans for more causeways are widespread throughout the Gilbert Islands.

The "splash" method or *te ororo* is much more efficient than other methods since it allows fishers to catch many more fish than they could using ordinary gill nets, or by line fishing. This is good for individual fishers in the short term, but as most fishers ackowledge, it is too effective in the long term.

Te ororo is not new to Tarawa; however, the frequency of use, method, and length and mesh size of the gill nets has significantly changed. Ultimately, taking into account the pressures on the fishery and the destructive effects of *te ororo*, this fishing technique should be banned entirely. The damaging effect of *te ororo* has been recognized in other areas, and this method is now prohibited on Abaiang Island (Pulea and Farrier 1992).

Implementation

Te ororo fishing should be banned as soon as possible. All elements of *te ororo* should be stopped, including a ban on splashing with a metal rod to drive fish into nets and tying nets together to make a very long net. The sale or commercial trade in fish caught by this method also should be banned.

Banning *te ororo* fishing and the use of intermediate-size gill nets will create a financial hardship for some of the commercial fishers in Tarawa. Many of them may already

understand that the pattern of diminishing catch in the face of increasing net lengths and fishing time means that the bonefish stocks are nearly depleted and they will be forced out of business due to declining catch soon anyway.

These commercial fishermen must be encouraged to apply their expertise to open-ocean fishing. This means they could be provided with financial assistance such as loans and through a buy-back of their Lagoon gear. They also should receive technical assistance and training, if needed, in ocean fishing methods. The intent is to avoid severe financial hardship or defaults on loans from commercial banks or the Kiribati Development Bank.

Bonefish do not reproduce until they are quite large, about 35cm. Small-mesh gill nets capture smaller bonefish, including many that have not had a chance to reproduce. Increasing the mesh size of gillnets will allow most of these smaller bonefish to grow large enough to reproduce. According to fishers interviewed during the research program, this was a necessary step, although it would be painful for a while.

Gill nets are not species selective. In general, any fish with a head small enough to pass through the mesh but a body too large to pass through will be caught. If gill nets are used, it is almost impossible to manage for the maximum production of any single fish species.

The second problem with gill nets is that they are often discarded or lost in the lagoon and become tangled in coral heads and other objects. These discarded gillnets can continue to fish for a long time until they disintegrate. This kills fish for no reason, further depleting a valuable resource.

Kiribati recently signed the drift net regulation that banned gill nets on the high seas, a regulation designed to reduce indiscriminate overfishing. Gill nets are clearly a problem in Tarawa Lagoon, and overfishing would be reduced by restricting mesh size. An exchange program would allow fishermen with a 2½-inch or 3-inch mesh to get a new 3½-inch net. The exchange program should be set up so that no fishing operation or family ends up with a mile of 3½-inch mesh net. The intent of the program is to reduce net lengths and increase net mesh size.

This provision is not aimed at the subsistence fisher who has a single 20-meter net for catching bait fish along the shore for home consumption. To make the provision effective yet fair, it might read, "No net with mesh larger than 1 inch or smaller than 3½ inches can be used in the lagoon." The exact wording of the provision should be decided upon by the *Bonnano N Tararua*. Care should be exercised in drafting and enforcing the regulation to ensure that subsistence fishers are not deprived of food and that commercial fishermen do not start using very long 1-inch-mesh nets that would overfish populations of prespawning young fish.

One of the first measures the government can take is to stop the import of gill nets, except for the 1-inch gill net used along the shoreline by subsistence fishers. This would have the effect of slowly phasing out undesirable gillnets. Nylon gillnets have a relatively short life in the tropics since ultraviolet radiation eventually breaks down the nylon strands unless they are very carefully maintained.

Clearly any set of gill net regulations must be enforced by trained enforcement officers who make regular spot inspections of nets being used in the lagoon. These enforcement officers need to have the full authority and protection of the Kiribati law enforcement agencies to enforce the regulations. But more importantly, locally imposed complience by the leaders in each, church, maneaba and village will be needed to make any type of regulations work.

4.4.3 Baitfish

Recommendation: Retain all baitfish as food for subsistence fishermen and local forage fish by banning baitfishing by large commercial fishing vessels in Tarawa Lagoon.

Background

The fate of the goldspot herring (*tarabuti*) was a subject that came up repeatedly in conversations with I-Kiribati citizens. Many remembered that large numbers of this baitfish were once found in the lagoon and people would catch them with cast nets or gill nets. Now goldspot herring are virtually extinct.

The baitfish in Tarawa Lagoon and other atoll lagoons near Tarawa have been studied extensively (McCarthy 1984, 1985; Ianelli 1988; Walczak 1982; and others). All of these studies were from the perspective of the requirements of Te Mautari, Inc., the government-owned pole and line fishing company. The Australian Center for Agricultural Research (ACIAR) summarized the previous research and submitted a final report in 1992 (Rawlinson et al. 1992). The three primary species of baitfish are:

English Name	Scientific Name	I-Kiribati Name
Blue sprat	*Spratelloides delicatulus*	*te auan*
Goldspot herring	*Herklotsichthys quadrimaculatus*	*te tarabuti*
Spotted sardine	*Amblygaster sirm*	*te tiatiin*

Studies have shown that spotted sardines come into the lagoon to spawn. Since they are

photopositive, they are attracted to the night light used by commercial tuna fishing live bait boats, (*Bouki-ami*) which makes them exceptionally vulnerable to predators such as jacks. One study showed predators consumed twice as much food around the *bouki-ami* boats as under natural conditions. A quantitative analysis of the goldspot herring and blue sprat indicated these species are heavily exploited, particularly just at the time they become sexually mature. A study of the effect of the baitfishery on the artisanal fishery examined only the impact of predatory species such as jacks (*Caranx* sp.), queenfish (*Strongylura incisa*), and king mackerel (*Scomeroides lysan*). The study did not investigate the capture of baitfish by the artisanal fishery. One of the most common fishing activities seen along South Tarawa Lagoon beaches is of families driving sprat and herring into small-mesh gill nets. In spite of the importance of baitfish to subsistence fishers, studies show a progressive decline in the catch for these species since 1982 (Rawlinson et al. 1992).

Tarawa Lagoon, which is important for baitfishing operations because of its proximity to the tuna unloading facilities at Betio, has shown signs of overfishing. Decreased catch rates in Tarawa have necessitated the use of other sources of bait (Rawlinson et al. 1992).

Te Mautari has had deep financial difficulties almost from its inception. The baitfish vessels have always had difficulty obtaining bait because the abundance of these species fluctuates erratically. Analysis by ACIAR indicates that, even under the best conditions, there is not enough live bait in Tarawa and adjacent lagoons to support a profitable live bait industry. These studies indicate bait-boat operations should shift to long-lining in the near future. The AICAR report also suggests that an artisanal baitboat fishery could by tried using small vessels. This option should remain open to encourage lagoon oriented fishermen to become ocean fishermen.

4.4.4 Goatfish (*Te maebo*)

Recommendation: Set a moratorium on fishing for goatfish for six days around the new moon.

Background

Two species of goatfish are commonly caught in the lagoon yet *Te maebo* do not figure prominently in Fisheries Division catch statistics. This may be because they are caught almost entirely during their spawning migrations (unlike bonefish which have been caught every day), and these spawning migrations are restricted to the new moon and to only two locations on the atoll. This species is mentioned so frequently by fishermen, however, that it may be or was once more important in the lagoon fishery than the statistics suggest. Interviews revealed *te maebo* is the single most important species in the catch in Buariki, the

largest village in North Tarawa. Also, at least until recently, there were 30 rock traps designed specifically for catching *te maebo* off Betio.

4.5 Species-specific Management for Shellfish

Managing shellfish on a species-specific basis is somewhat more feasible than for finfish. Collection methods and life history of the species differ sufficiently to allow specific management activities to have a reasonable chance of success.

4.5.1 *Te bun*

Recommendation 1: Restrict the use of diving equipment to collect *te bun* commercially.

Recommendation 2: Develop a program to assess the status of the stocks on an annual basis to determine the size and condition of the stock. If the resource is being over-harvested, it may be necessary to limit the take by commercial divers.

Background

Te bun is one of the most important species of shellfish collected in the lagoon. *Te bun* is collected by women, children and men of all ages in the subsistence fishery for benthic mollusc that occurs through out the exposed sandflats and seagrass beds. The density of *te bun* on the sandflats near seagrass beds is approximately 4 individuals per square meter.

The most abundant beds are found in 2-8 meters of water on some of the lagoon slopes in the central lagoon opposite Eita. These beds are harvested by approximately 40 commercial divers. In some of these beds, the density reaches 40 per square meter. Commercial collectors skin dive from canoes and inner tubes.

The size and distribution pattern of *te bun* suggests a highly episodic recruitment pattern. Existing stocks appear healthy but the intensive harvest and irregular pattern of establishing new beds suggest that the resource could easily be over harvested in the future. Banning the use of SCUBA and hooka diving gear would not have an adverse impact on fishermen since no divers collects *te bun* with these types of gear at this time. But men are being trained to use SCUBA equipment at an ever accelerating rate on other Pacific islands and in Tarawa for the aquarium fish collection business. It is only a matter of time before trained divers decide to use this technology in the commercial harvest of *te bun*.

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4.5.2 *Te nouo*

Recommendations: None

Background

Te nouo (*Strombus luhuanus*), a small marine conch, is abundant throughout the lagoon on sandflats, shoals and bottom slopes. This conch is intensively harvested on the sandflats by subsistence gatherers on each low tide and is the most frequently taken shellfish. A large offshore population along the slopes and bottom of the lagoon provides an abundant brood stock and new recruits to migrate to the sandflats.

Most of the te nouo harvested are breeding size adults, since juveniles remain buried in the sands and muds of the lagoon bottom where they avoid detection by gatherers. Studies on this species in Papua New Guinea (Poiner and Catteral 1988) indicate this species can withstand a very high level of exploitation.

4.5.3 Giant Clams

Recommendation 1: Stop the harvest of giant clams. The Ministry should enact legislation and announce on radio that all giant clams around Tarawa are protected until further notice.

Recommendation 2: Save as many individuals for broodstock as possible for future clam culture.

Background

Te kima (*Tridacna gigas*), the giant clam, is in very serious danger of extinction around Tarawa. Munro (1988) surveyed Tarawa for giant clams and found the population was very depleted. His survey found only one giant clam on Tarawa. A survey by Paulay (this volume) at 50 sampling stations in the lagoon found only one specimen. The Fisheries Division is starting a giant clam culture project managed by an expatriate shellfish expert. The purpose of the program is to culture clams for seeding on the outer islands. Present management of the few remaining clams includes establishing a "clam circle" in which the few clams that can be found have been placed in a deepwater refuge accessible only by individuals with SCUBA gear. By clustering the clams, it is hoped that spawning will be more successful. Giant clams take many years to reach reproductive size, and two or more generations will be needed to restock the lagoon to the point where a limited harvest could be considered. The technology for a clam hatchery has been developed and can easily be transferred to Tarawa. The commercial culture of clams can join seaweed and black pearl

culture as viable, employment-creating activities. Present plans to limit giant clam culture activities to the outer islands should be reconsidered.

4.6 Species-specific Management Actions: Other Species

There are several species or groups of species that are important for managemennt of the lagoon, but for which no specific research was conducted during this study. Nevertheless recommendations have been developed based on observations in the lagoon, discussions with Tarawa residents, and information and experience from other tropical locations.

4.6.1 Marine Turtles

Recommendation: Institute a complete moratorium on all marine turtle harvest.

Alternative recommendations include:

1) Follow the general program of recommendations presented by the South Pacific Regional Marine Turtle Conservation Program (SPRMTCP) Marine Turtle Conservation Program.

2) Ban the taking of any sea turtle eggs laid on any beach in Tarawa.

3) Ban the export of any turtle products.

4) Ban all sales or purchases of turtles and turtle products.

5) Participate in "The Year of the Sea Turtle" activities for 1995.

6) Solicit funds to sponsor sea turtle tagging and public education programs in Tarawa in 1995.

Background

Marine turtles are endangered worldwide (International Union for the Conservation of Nature 1990) and have been placed on the red list of threatened animals (South Pacific Regional Environmental Program [SPREP 1993). The government of Kiribati has participated in regional marine turtle conservation program workshops sponsored by SPREP for the past several years. Mr. Rimeta Tinga, of the MENRD, Fisheries Division attended the 1993 SPREP meeting for the regional conservation of marine turties and presented a brief report on the green turtles in Kiribati. Much of the information he presented was from Onorio

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(1979) in an unpublished report prepared for the Fisheries Division. The legislation of the government of Kiribati related to marine turtles consists of a confusing and sometimes conflicting mixture of laws. These have been summarized in a preliminary report on environmental law in Kiribati prepared by Mere Pulea and Professor David Farrier for the National Marine Fisheries Service program, under sponsorship by SPREP (1992). This document points out that marine turtles are protected only in certain preserves and, at that, they are protected only on land, not in the water. Marine turtles are not protected in the Gilbert Islands or in Tarawa, either on land or in the water. The Fisheries Division is in the process of gaining more information from local fishermen about the marine turtle situation in Tarawa. A questionnaire was prepared and sent out to the fisheries representative in North Tarawa, but the results are not yet available.

Local fishermen capture marine turtles in several ways. In North Tarawa, some people set large-mesh (approximately 5 in.) gill nets supported by large floats. Although the nets may catch sharks, turtles are the main targets. Another method for catching turtles is by spearing them from boats. A third method is for divers to swim along the surface with goggles looking for turtles sleeping in coral crevices. When one is spotted, the diver drives a big hook through a flipper or ties a line around the head. The turtle swims away, pulling on a rope attached to a floating object (such as a log). When the turtle is exhausted, it is brought into the boat. Turtles are also captured on beaches, and eggs are regularly harvested by people looking for an alternative protein source.

Turtle fishing has been very poor recently. Most turtles are caught from October to November, which coincides with the blooming of the *"te Itai"* tree (*Callphylum inophyllum*) (Onorio 1979).

The generic name for all species of marine turtles is "*te on*" in the Kiribati language. In general, turtles are not widely harvested, partially because of their lack of abundance. When they are taken, they are used almost exclusively for local ceremonies. There does not appear to be any significant commercial market for turtles or turtle parts in Tarawa. The Fisheries Division was asked to export "*bekko*" to Japan in 1990, but they declined.

The government of Kiribati has expressed an interest in participating in all regional marine turtle conservation program activities, including research and tagging programs and establishing protected areas for turtle nesting. The main recommendations of the marine turtle conservation program are to (1) initiate an immediate and substantial reduction in the number of turtles killed throughout the Pacific region, (2) encourage countries of the region to ban international trade in turtles and turtle products, (3) encourage countries of the region to introduce a moratorium, or where possible, the permanent cessation of in-country commercial transactions of turtles and turtle products, allowing only cultural or subsistence takes, and (4) declare 1995 to be ceremonially considered the "Year of the Sea Turtle" in the

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Pacific region, and whenever and wherever possible and practical, on a voluntary basis, to restrain from killing turtles for any purpose.

4.6.2 Bêche-de-Mer

Recommendation: Engage a short term consultant to reassess the bêche-de-mer resources of Tarawa and set commercial size limits for export.

Background

World prices for bêche-de-mer have been at all time highs and climbing for several years. Throughout the Indo-Pacific, bêche-de-mer exploitation has followed the classic boom-and-collapse scenario caused by uncontrolled harvesting. The present price in Tarawa is so high that exporters are buying even the least valuble species. It is apparent that neither the collectors or buyers have a clear understanding of the population dynamics or basic biology of these species to make the fishery sustainable. There are two regulations that would be particularly appropriate. The first is a species-specific size-limit to be observed not only by fishermen, but also by exporters who are more easily regulated. The second is that the collection of bêche-de-mer with any type of underwater breathing apparatus should be prohibited. This provides them with a deepwater refugia for the maintenance of spawning stock.

Bêche-de-mer need to be boiled and dried before they are exported and this requires fuel which depletes the islands' limited wood resources. In some areas, the bêche-de-mer industry has caused serious degradation of mangroves and other sources of island wood. Obviously the outer islands are exceptionally vulnerable to this threat. This is not a problem on Tarawa because processors have access to petroleum-based fuel and gas.

4.6.3 Mangroves

Recommendation 1: Set a "no net loss policy." This means that whenever mangroves are destroyed, such as when trees are cut down for a construction project, a new area should be created or set aside as a protected mangrove area.

Recommendation 2: Provide information to the public and especially all planning groups on the importance of mangroves to the people and fish of Tarawa Lagoon.

Recommendation 3: Encourage people to plant mangroves along the lagoon beachfront.

At least three species of mangroves are found around Tarawa (Thaman 1990). The most common species in Tarawa is *Rhizophora mucronata* (*te tongo*). *Bruguiera gymnorhiza* (*te buangi*) is also found scattered throughout the mangrove areas. *Lumnitzera littorea* (*te aitoa*) is found only at Eita village. The islands also support some *Sonneratia alba* (Scott 1993).

Mangroves are traditionally important for construction since all local species of mangroves have a very dense hard wood that can be used in house construction, threading coconut shells for shark rattles, handles for scoop net, and stakes for fish traps. It is used whenever wood must be partly or completely immersed in water because it is resistant to dry rot and wood boring worms. The red flower is sometimes used in garlands. A red dye can be extracted from the roots and the bark is used to impart a perfume-like fragrance to coconut oil. Mangrove parts also are used to treat sore throats and gum diseases, and a canoe-caulking paste traditionally has been made by boiling mangrove fruits.

Mangroves are an essential part of the food web of many species of fish and shellfish. Mangrove forests are exceptionally productive. As leaves and stems fall into the water, they provide a significant amount of fixed carbon and nitrogen to the mangrove forest substrate. This detritus is slowly broken down by bacteria, protozoa and eaten directly by some types of small shrimp and crabs. The vertical root structure also provide a great deal of habitat for epibenthic organisms.

Tarawa's mangroves are especially important because they stabilize coastal soils. The people of Tarawa need more land, not less, and healthy mangrove systems help create more land. Mangrove roots create a structure that impedes and slows the movement of water. Slow-moving water can not hold suspended solids and consequently sand particles and mud precipitate out and create new muddy substrates that can eventually build-up into new land. Without mangroves, lagoon mud and sand tend to drift. One of the best ways stop the loss of beach sand and increase the build-up of new land along the lagoon edge is to encourage the growth of mangrove stands.

Many families that complain about the loss of land along their beach may not understand the direct relationship between cutting beachfront mangroves and the subsequent loss of beachfront property. The loss of sandy beachfront may take several years since most sand loss occurs during westerly winds.

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4.7 Fishing Methods and Fishery Improvements

This section describes several actions that could either improve conditions for the lagoon fisheries, or prevent further deterioration.

4.7.1 Fishing Methods

Recommendation: Prevent new destructive fishing methods and technologies from getting started on Tarawa.

SCUBA, hooka, and fins for collecting shellfish for commercial purposes should be prohibited before they get started. This element of the Lagoon Management Plan targets the protection of benthic organisms found throughout the slope and floor of the lagoon. These restrictions will protect giant clams, pearl oysters, bêche-de-mer, and deep water *te bun*. The intent is to limit diver efficiency and thereby protect populations in deeper water and thus maintain a reproductive reservoir for many species of shellfish. Some portions of this deep water populations would, of course, migrate into shallow water and be subject to harvest, but the intent is to maintain a perminent deep water reserve of all the major species. The best way to do this is to limit the ability of the fishermen to harvest in deep water reserves. Banning SCUBA gear will protect resources in the deepest part of the lagoon and limit a divers time on the bottom to his physical capacity. Hooka gear, involves a pump on a boat to support a team of divers connected by a hose. Hooka gear is widely used in commercial shellfish operations in many parts of the world. One hooka operation in Tarawa could remove virtually all commercially important resources in a few months. Swim fins allow a diver to go much deeper and cover more territory while on the bottom. Banning swim fins for commercial activities such as for the *te bun* harvesters will protect a greater fraction of the resources.

4.7.2 Aquaculture Development

Recommendation: Actively plan for the development of private sector aquaculture activity for many species in Tarawa Lagoon.

The history of aquaculture development in the Pacific Islands is for the most part a litany of failed projects. Uwate (1986) documented many aquaculture failures. Now, with the benefit of experience, appropriate aquaculture technology can be found in many Pacific islands. Kiribati has an impressive records of aquaculture success with its seaweed culture program. Other Pacific islands success stories include giant clams in Pulau, and black pearl oyster

culture in the Cook Islands. Giant clams and black pearl oyster culture technology are spreading rapidly throughout the Pacific. Sponge culture may be next. A natural sponge the size of a human hand sells for $20.00 in the U.S (Abbott, personal communication).

The *Bonnano N Tararua* should begin the process of determining how much aquaculture should be promoted in Tarawa Lagoon and then set aside specific areas as aquaculture parks. The goal should be to minimize the conflicts between fishermen, gleaners, and the aquaculturists so that the development of aquaculture can benefit the people of Tarawa in the form of hard currency from export products and jobs for people that want to enter the cash economy.

One approach would be to set up a leasing system, whereby an individual could lease approximately a hectare of lagoon area in which to culture seaweed, giant clams, pearl oyster, sponges, or other appropriate species.

The use of lagoon area for aquaculture will inevitably lead to conflicts. Having the rules governing the restricted use of lagoon tidelands, slopes and the waters colume fully aired in public meetings will both minimize confilits facilitate resolutions of conflicts.

4.7.3 Artificial Reefs

Recommendation: Establish and periodically evaluate several areas of artificial reef in the southeastern part of the lagoon.

The finfish survey (Beets, Volume II) indicated that there are almost no finfish resources in the souteast corner of the lagoon and that this is probably because of the absence of coral reef habitat. (Pauley, Volume II) observed that the few remaining dead coral heads found in the southeast corner were densly occupied by fish seeking cover or coal habitate for protection.

A systematic program to create artifical reefs in the southeast corner of the lagoon would lead to fuller use of uninhabited parts of the lagoon and benefit both north and south Tarawa fishers living adjacent to the artificial reefs. Government planners may wish to consider disposing of appropriate solid waste in the lagoon to create a series of artifical reefs. Villages might elect to build their own artifical reefs and negotiate with the *Bonnano N Tararua* to have excluse right to fish on an artifical reef that they create by their own labor.

Artificial reefs can be built of any material not containing toxic materials, although waste materials are usually used to keep costs down. Concrete is one of the best materials, but

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scrap steel works well too. Hulks of broken-down machinery, boats, and vehicles can be used if they are prepared properly. At a minimum, oil, petrol, and rubber must be removed before the equipment is dumped.

4.7.4 Shift Fishing Effort From the Lagoon to the Ocean

Recommendations: Support efforts by the Kiribati Development Bank and the Bank of Kiribati to stop making loans for boats or fishing gear that would be used in the lagoon and support their efforts to make loans for ocean fishing activities

One way to reduce fishing pressure in the lagoon is to increase near-shore ocean fishing. Ocean resources include tuna, flying fish, deepwater outer reef fishes, and other species of fish or squid found in deep oceanic waters. The cost of refitting boats and gear and retraining fishermen should be relatively low. Other measures needed to make ocean fishing successful include a commercial loan program for fishermen so they can buy appropriate boats and gear. Fishermen who receive loans should receive specific training in financial procedures such as budgeting and setting aside money for maintenance.

Studies have demonstrated that deepwater fishing with hand-reels on the outer reef yields extremely good catches(Crossland 1980; Crossland and Grandperrin 1980). Though deepwater reef resources are abundant, a recent assessemt by Fisheries Division indicates these resources are being heavily fished.

The effort to provide lagoon fishermen with access to the ocean fisheries should be coupled with other activities from the government fishing organization, Te Mautari, Inc. Fish-buying and ice-provision practices should be modified and a continuous training program should be implemented so that people interested in participating in the ocean fishery can learn how to do it and how to keep the quality of the fish high. See sections 4.8.3, 4.8.4, 4.8.5 and 5.6 for further discussion on the diversion of effort and expaning opportunities in the ocean fisheries sector of the economy.

4.7.5 Causeways

Recommendation 1: Open passages through the causeways

Recommendation 2: Consider a small boat passage over an area of the reef in the northern end of the Lagoon passage.

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There are many concerns about the environmental effects of causeways. The main reasons for opening passages through causeways are to allow the free movement of fish and fishermen betwen the lagoon and ocean. These two purposes suggest different solutions to the blockage of passes: the former would require replacement of causeways with bridges, while the latter requires only small culverts or short bridge segments.

Most of the islands are connected by solid-barrier-type causeways. One of our main recommendations is that of replacing large sections of these causeways with bridges such as that at Tanaea.

The computer simulation study reported in Volume II (See Kimmerer and Chen) conclude that opening the causeways will not significantly change water quality in the lagoon. However, passages will bring more larval fish into the lagoon and also allow the migration of adults out of the lagoon to spawn in the ocean.

The Betio-Bairiki channel silts up frequently and requires regular dredging. In addition, altered current patterns in the area may be responsible for the accelerated erosion seen on the seaward edge of Betio near the causeway. Fishermen from North Tarawa report physical changes that they associate with causeway closure, including erosion and accretion of coastlines and shallowing of the inner lagoon reef flat. In 1979, before construction of the Betio-Bairiki causeway, however, fishermen noted seasonal reversals in prevailing currents that they associated with accretion and erosion cycles. The report on coastal erosion by Howorth indicates that interannual variability in coastal erosion and accretion is a natural process of some significance in Tarawa. These additional variables make it difficult to determine what coastal erosional changes near the causeway are, in fact, due to the causeway.

The opening up of the causeways and the creation of channels so that fishermen can leave the lagoon and go out into the ocean will create jobs in South and North Tarawa. Wherever possible, these can become community-action public service projects. Of course, significant funding, technical assistance, and equipment support (e.g., heavy equipment from Public Works) from the government, bilateral multi-agencies, or bilateral donors may also be needed to open up the causeways.

Why don't bonefish use the passage in the Betio-Bairiki causeway? Bonefish may not enter the present causeway passage because of the strong currents generated there. Since the passage in the 2.4 kilometer long causeway is only 10 meters wide, the currents pouring through it on spring tides, which is when bonefish migrate to spawn, are very fast and turbulent. Before causeway construction there was a natural deep channel in the Betio-Bairiki pass. Bonefish entered this channel at low tide, waiting to migrate across the pass, but when the tide rose and the water currents became strong in the channel, the bonefish moved

laterally up into shallow, slower-flowing water, mainly on the Bairiki side of the channel, to continue their seaward migration. Legitimate arguments can be made not to open up the causeways. Opening causeways requires long-term planning, careful allocation of equipment and engineering skills, community involvement, long-term maintenance costs and a great deal of hard currency for the construction of culverts and bridges and for deployment of equipment.

The expense of opening the causeways, blasting out boat channels, and building metal bridges can be justified as an investment by the government in improved human productivity. The concept of good investment is based on the perception that opening the causeways will accelerate the rehabilitation of the lagoon's natural resources and create economic opportunities for fishermen. There would also be some small benefits to public health in the immediate vicinity of the causways. All these improvements can be seen as net benefits to the community and economy. A benefit/cost analysis would likely demonstrate:

- more people would be able to enter the ocean fisheries and earn higher incomes.
- more larval and juvenile fish and shellfish would enter the lagoon, accelerating the recovery of lagoon species and increase fish catch by subsistence and commercial fishermen

4.7.6 Recommendation: Create Fish Recovery and Protection Areas

Recommendation: Designate about 20% of the lagoon as a fish and shellfish recovery area.

The International Union for the Conservation of Nature (IUCN) uses the term "protected areas" to describe all types of natural resource-protected areas, including parks, sanctuaries, and preserves. The research conducted by Eeets, Johannes and Yeeting (Volume II) strongly suggests that the finfish resources of the lagoon need significant protection. There are many examples all over the Pacific of the benefit of creating protected areas for fish resource recovery. Figure 4.1 illustrates the relative size of such a fish sanctuary that included 20% of the lagoon area. The exact location and size shown are arbitrary and would be changed. The *Bonnano N Tararua* would have to lead the Tarawa community in a decision of how large an area should be set aside, where it should be, and how such an area would be managed.

The use of parts of the sanctuary for artificial fish habitats, aquaculture, and other types of non-fishing activities could be allowed, depending on the opinions of the *Bonnano N Tararua*. The essential feature of the protected area should be that a large population of the

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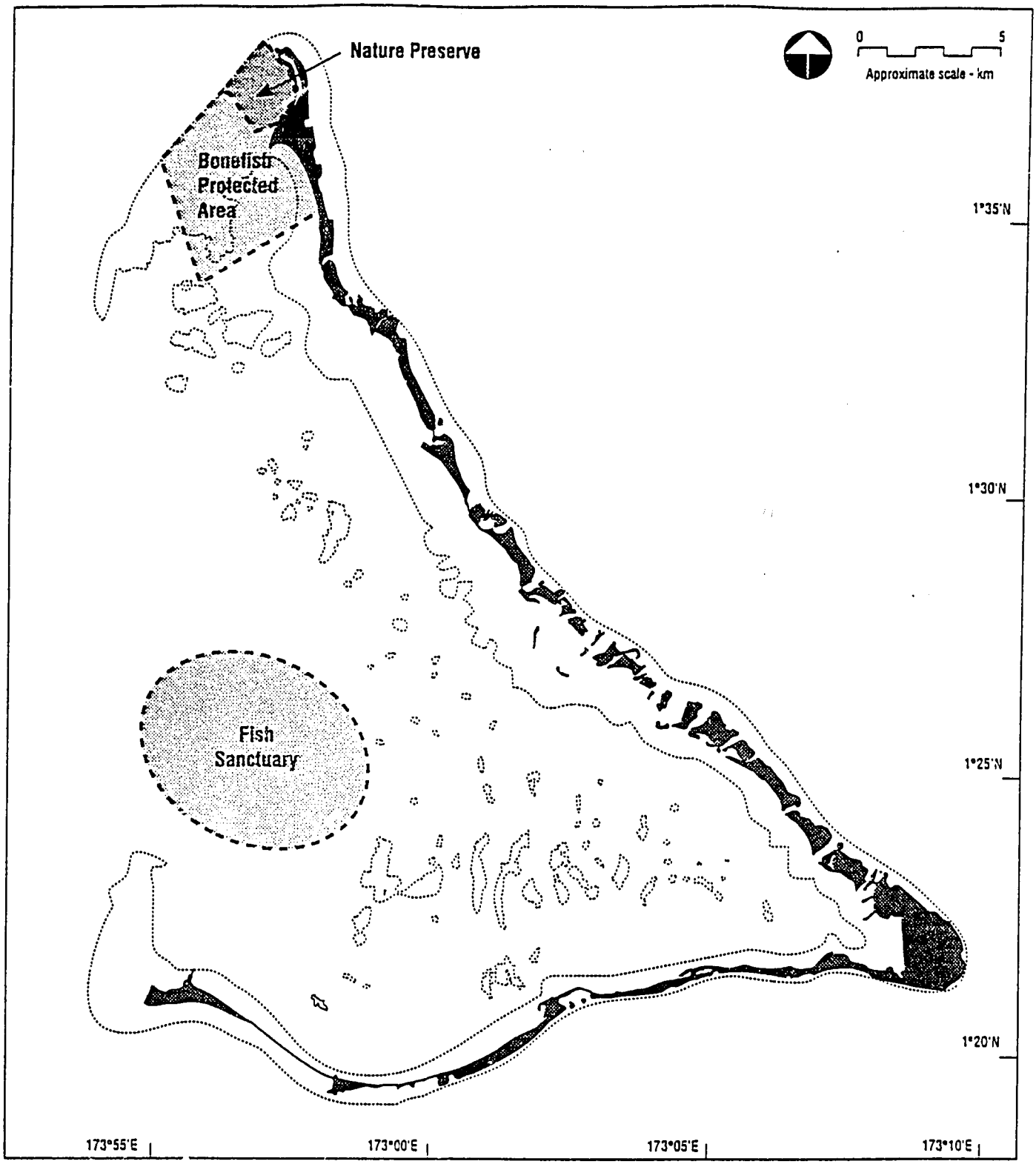

Prepared by BioSystems Analysis, Inc./1994

Figure 4.1 Possible Configuration for a Fish Sanctuary in Tarawa Lagoon.

fishes of the Lagoon would not constantly be the target of fishing pressure.

4.7.7 Allocation of Oceanic Resources to the People of Tarawa

Recommendation: Progressively reduce and eventually ban tuna fishing by foreign vessels within 200 miles of Tarawa.

Background

The government should begin the process of changing the rules by which large purse-seiners and long-liners can fish within the EEZ of Tarawa. It has taken years to institute the present set of programs that provide significant hard currency to the Government of Kiribati. Changes in treaties and contracts must be carefully considered and negotiated over several years. Progressive retention of the tuna resources around Tarawa for the benefit of the largest population concentration of people in Kiribati is not unreasonable. Present regulations do not allow these foreign boats to fish within 12 miles of the islands, but this rule should be gradually expanded out to the full 200 miles from Tarawa, while retaining the current limit around the other islands.

The primary reason is that once the migratory schools of tuna around Tarawa are intercepted, it may be months before another school will move into the area. Therefore, by excluding commercial fishing vessels from the entire 200-mile EEZ, more and bigger tuna schools will come into the waters around Tarawa and the people of Tarawa will be the main beneficiaries, instead of foreign fishing vessels. Tuna swim very rapidly; two hundred miles is only one day's travel for a school of tuna.

The large foreign vessels, especially the purse-seiners, have a very large impact on all other species. For instance, rainbow runners and some of the small mackerels that are consumed by the people of Tarawa are simply discarded by the purse-seiners. The loss of that resource to the people of Tarawa may be significant.

The main set of justifications behind this recommendations is to create a resource base for the local lagoon based fishermen that intend to enter the offshore tuna fisheries. It makes little sense to loan money to fishermen to buy boats and gear, set up extensions programs to train them and run a tuna purchase program if government policy is set up to guarantee the tuna around Tarawa to foreign nations.

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4.7.8 Fish Aggregation Devices (FADs)

Recommendation: Institute a program to install and maintain deepwater FADs around Tarawa.

Background

Oceanic fish aggregation devices (FADs) have been shown to constrain fish migration, especially tuna, when they are placed in deep oceanic waters (in excess of 100 fathoms). Our recommendation is that more FADs be constructed and maintained. There have been problems in the procurement of FAD parts and installation at sea. Many of the FADs that have been deployed in other islands have been lost. The reasons for these losses should be investigated, because other groups have kept FADs successfully deployed for long periods of time.

FADs decrease the amount of search time that the small skiffs need to locate tuna schools. Thus they could save Kiribati a considerable amount of money in hard currency that is currently spent to procure oil and petrol. Using FADs will also increase the earnings per unit effort of the skiff fishermen, since they will not have to spend so much time roaming the ocean in search of aggregations of tuna.

FADs also will increase the number and catchability of large tuna in waters accessible to local fishermen. Tuna in the 30-100 kilogram range are the most desirable. These tuna have a well-identified market in Hawaii and Japan. Therefore, the use of FADs will increase the availability of exportable tuna.

4.7.9 Tuna Fishing Technology

Recommendation 1: Introduce 7-10 meter fiberglass commercial fishing vessels.

Recommendation 2: Implement an extension program of training fishermen and providing them with easy loan terms for boats and gear to fish outside the lagoon for tuna, deep bottom fish, and other species.

Background

The existing small skiff fishy, using boats approximately 6m long and 40-horsepower outboard motors, should be seen as a transition stage to boats in the 7m to 10m size range, which should become commonplace in Tarawa in about 10 years. These larger boats have larger fish holds, carry more ice, and allow fishermen to greatly increase their income, especially in conjunction with FADs. It is recommended that a small vessel long-line

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program could also be initiated in Tarawa. Although the long-line catch rates for the Tarawa EEZ are not as high as in some of the other Kiribati islands, the rates are certainly high enough to justify the investment. Obviously the introduction of larger boats must follow the creation of a government backed lending program to enable business men to barrow funds to purchase the boats and gear to enable them to fish for larger tuna further from shore.

4.8 Public Health

The nearshore ocean and lagoon waters of the southern portion of Tarawa Atoll are polluted by sewage. Most waters exceed the currently-accepted standards for contact activities (see Danielson et al., Volume II). Shellfish taken from near shore and along the seagrass beds are unfit for human consumption. This is significant because the consumption of contaminated shellfish is one of the major links in the spread of human gastroenteritis (diarrheal diseases). Therefore, it is urgent that the lagoon be managed to inhibit or prevent recurring incidence of gastrointestinal disease.

The improved health of the people of North and South Tarawa must be one of the highest priorities of the *Bonnano N Tararua*. Gastrointestinal illnesses are so commonplace in the lives of many people that it is not even seen as abnormal (Phillips, Volume II). In fact, the incidence of gastrointestinal ailments is so high that it drains community resources and affects the ability of people to be productive at their jobs and take care of their homes.

4.8.1 Lack of Toilet Facilities

Recommendation: The sewage system described in the Kiribati Seventh National Plan (1992) should be implemented as soon as possible

Recommendation: Adapt the existing concrete flush units to systems acceptable to the people.

Recommendation: Install stand-alone compost toilets (various energy alternatives).

Recommendation: Consider constructing as many as 100 over the water tempory type latrines along the ocean side of south Tarawa.

Recommendation: Provide a deeper outfall for the untreated sewage discharge system to prevent the backwash of disease-causing pollutants.

The lack of adequate toilet facilities in the homes of the majority of people living in South Tarawa, and public attitudes towards the use of toilets, are major constraints in reducing the use of the lagoon as a toilet. It is important for all residents of South Tarawa, and particularly the leaders who will be members of the *Bonnano N Tararua*, to bear in mind that another major disease outbreak is likely in South Tarawa. A new epidemic could be worse than the cholera outbreak in 1977. Without immediate measures to deal with this problem, the government will be subject to grave criticism.

No one ministry, agency, NGO, or person can change the practices and concepts of all the people of South Tarawa in a short period of time. It will take the efforts of many ministries, many public educators, and many community leaders to make the necessary change in toileting practices in the lagoon.

Shifting populations to the use of toilets has been a long, slow process in other countries. One of the main factor that has led to the universal use of flush toilets in other countries was laws, zoning and public health laws, that stipulated that each dwelling had to have an approved toilet system.

A functional sewage system represents the greatest challenge for success because of the enormous cost, cultural constraints, and logistical difficulties involved. It is, however, key to disease prevention on Tarawa. We strongly recommend that the sewage system described in the Kiribati Seventh National Plan (1992) be implemented as soon as possible. Until people have more desirable alternatives, they will continue to pollute the lagoon and ocean reef.

The remaining options are appropriate technology solutions to part of the problem. When a regular sewage system can be constructed, the over-reef systems and other temporary facilities can be removed.

It is already law in Kiribati that people should not use the lagoon as a toilet, and there are signs advising people not to do it. More signs are needed as well as articles in the newspaper. Public health education officers must make a concerted effort to get people to not use the lagoon but to walk to the ocean. In most cases the ocean is only several hundred yards away. If people choose not to go to the ocean side, then they should use sealed trenches with lime, toilets installed in homes, or other methods so that the lagoon does not become the primary recipient of fecal material.

4.8.2 Contamination of Water and Shellfish

Recommendation 1: Continue monitoring of water and shellfish for fecal contamination.

Recommendation 2: Obtain equipment to be used in analyzing contamination.

Water and shellfish sampling by the Ministry of Health, as well as several non-government studies, has documented the extent of contamination in the water table and lagoon. It will continue to be necessary to monitor the extent of the contamination until remediation practices have demonstrated that they have worked. Data must be collected and analyzed annually to measure the severity of contamination. The extent of pollution along the ocean reef from the two point-source discharges has not been defined. A short-term priority should be given to collecting ocean reef samples near these discharges to discover the extent of their influence.

The government must be able to measure accurately the level of contamination. This will require an expansion of the current water and shellfish monitoring program in both total number of sites measured and the frequency of measurement. It may also entail upgrading laboratory capabilities, including the acquisition of new equipment and expanded training for more technicians. Surveys also are required to identify those areas contributing non-point-source run-off of fecal pollution. Until water quality improves markedly, sanitary surveys should be conducted at least annually.

The government may wish to solicit donors to send public health professionals to assist in the compilation and analyses of data. Alternatively, donors may be willing to sponsor graduate student/interns to analyze the data collected or conduct sanitary surveys. These technicians could also train Kiribati nationals for future data analyses. Increased sampling will require increased resources for equipment and training. See the following sections and 5.6 for additional information.

4.8.3 Separate Waste Disposal and Food Collection Areas

Recommendation: Post contaminated areas to restrict shellfish collection

By continuing sampling for a year, it should be possible to identify those areas that are the least affected by contamination in the lagoon. Steps should then be taken to restrict the use of these areas to limit the amount of pollution introduced. For example, areas may be designated for recreation and/or fishing but not for toileting. Once they are made aware of

the restricted areas, local councils could enforce these restrictions. It will be up to the local authorities to see to the administration of restriction enforcement.

4.8.4 Public Health Educational Programs

Recommendation: Oncrease public health education on the cause and prevention of gastrointestinal diseases

Many resources are currently available for educational purposes. Almost all donors participate in education and appear eager to help in this area. One approach may be to hold a workshop for the teachers on the atoll so that they can have access to the most up-to-date information. The government should start non-formal community education on the cause and prevention of gastrointestinal illness.

People need to be trained to thoroughly cook all shellfish but most importantly the government should send a very positive message that people should stop using the lagoon for their toileting.

4.9 Research

4.9.1 Fish Larvae

Recommendation: Initiate a study of the migration of fish larvae into the lagoon through existing passes and over the western reef.

Background

A preliminary study of the migration of juvenile and larval fish through lagoon passes indicates many species use the passes (Abbott and Yeeting, volume II). Additional studies should be conducted to determine the movement of larval fish into and around the lagoon so that meaningful management plans can be developed for target species. This research is long overdue for atoll and lagoon passes since this subject has implications for marine resource management in many parts of the tropical Indo-Pacific. Sampling should take into consideration the likelihood that ingress rates for some species will have a pronounced lunar periodicity and the distribution of larval fish will be vertically stratified. The movements of larval fish across Tarawa's western reef should be compared with movements through those passages that remain open.

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4.9.2 Fishery-Dependent Sampling

Recommendation: Implement an improved sampling program of fishermen landings, based on sound sampling design.

Fishery-dependent sampling should be continued indefinitely. This sampling is essential for assessing the recovery (or lack thereof) of important fish stocks. Enumerators should measure the length and weight of all fish present in complete catches to provide long-term data for future stock assessments.
Collection of total catch per unit effort data is very important. However, in the future these activities must not be confined to data-gathering alone. Data must be thoroughly analyzed using modern fishery management techniques. This may require the assistance of outside expertise. See section 5.6.

4.9.3 Research Program on Important Species

Recommendation: Encourage studies to provide information needed to develop future management strategies.

Not much is known about the movements, life history, and habits of important species in the lagoon. Research in these areas should be encouraged through the establishment of ties with major research laboratories in tropical regions, and through grant funds obtained from donor nations.

Some examples of research topics include:

- Spawning location and larval development of bonefish
- Behavioral traits of bonefish, particularly around structures and people
- Larval development, dispersion, and recruitment of *te bun*
- Movement of sediments in the southeastern corner of the lagoon and through passes
- Effectiveness of artificial reefs in attracting fish to the southeast corner of the lagoon

4.9.4 Effect of Sewage Outfall Pipes on the Lagoon

Recommendation: Conduct a sampling program to determine whether outfalls cause significant fecal contamination in shallow water.

Data from the ocean side is needed to determine the plume of the outfalls at Bikenibeu and Betio. This is vital public health information that can be used to restrict access to heavily contaminated areas along the oceanside of South Tarawa during outbreaks of disease. This has been a consensus concern of the Ministry of Health, Ministry of Environment, Foreign Commissioner Offices and other aid donors.

For example, water samples could be taken and analyzed for fecal coliform concentration. Sample transects should extend across the ocean reef (three per transect), from shore to reef edge, at roughly 1,000-meter intervals.

Since the laboratory in Tarawa already has the capability to measure coliform, this would be a continuation of the current effort. However, the laboratory would need to upgrade its quality assurance (QA/QC) program to ensure the credibility of the data.

If it is found that significant contamination is washed back from the outfalls into areas where people bathe and collect food, redesign may be necessary. Engineering studies would determine the depth and distance from shore needed to remove the waste from the vicinity fo the atoll.

4.9.5 Rainfall Effects

Recommmendation: Determine effects of rainfall on microbiological water quality of the lagoon.

Background

Danielson et al., (Volume II) suggested that heavy rainfall could result in substantial increases in contamination, particularly in urbanized areas such as Bikenibeu.

In accordance with the internationally-accepted guidelines of the National Shellfish Sanitation Program (NSSP), the effects of heavy rainfall on shellfish growing waters should be defined. The results may show which areas are most affected by contamination contained in runoff.

It would then be possible to determine which areas are most safe to harvest shellfish after strong rains. This information could be provided to people through the education programs

recommended in section 4.9.

4.9.6 Pathogen Depuration of *Te Bun*

Recommendation: Conduct a study of the rate of depuration of enteric viruses or pathogens from *te bun*.

Background

A pathogen depuration study using *te bun* is important to determine the relevance of the bacterial depuration study to infectious viral agents. The procedure should be to export several *te bun* to a laboratory capable of conducting a microcosm study of the depuration of enteric viruses from the clam. An *in situ* environment that replicates the temperature, pH, sunlight, salinities, sand grain size, etc., could be created for the clams. Initial conditions would have to be measured at Tarawa for replication. Vaccine strain Polio virus would be introduced into the tank and viruses retention could be measured at various time intervals to determine depuration rates.

4.9.7 Indicator of Bacterial Contamination for Tropical Atoll Waters

Recommendation: Determine the best indicator of human fecal pollution in Tarawa Lagoon.

Background

Microbiological surveys of Tarawa Lagoon have shown very high levels of fecal coliform bacteria near shore. Until recently, the major source of this pollution was thought to be the human population. A recent sanitary survey identified a large number of swine being raised by the water's edge that may release significant waste into the lagoon. If remediation programs are to be instituted, there will have to be an environmental measure by which to evaluate any improvements. Other indicators have been proposed as better evaluators of human fecal pollution in tropical waters.

The Australian Water Board (Sydney, Australia) reports that sewage effluent is better characterized using the *Aeromonas hydrophila* organism. This is a relatively rapid test and could be conducted at the University of South Pacific Atoll Research Programme. Parallel water analysis with the standard method, coupled with detailed sanitary surveys of human and animal activities, would be required. Existing nearshore sample sites could be employed. Sanitary surveys may employ one or two more part-time technicians for gathering data.

4.9.8 Ciguatera

Recommendation: Institute a ciguatera test program.

In order for people to eat some types of fish, it will be necessary to maintain an ongoing program to test for the presence of the ciguatera toxin in fish caught in certain areas. The technology to test for the ciguatera toxin is changing rapidly, and we recommend that a program be funded to take advantage of the latest changes in the technology and to institute a public testing program.

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5.0 Implemtation

The implementation of the proposed plan depends on the combined actions of the Bonnano N Tararua, and many government ministries.

This section of the Plan gives some suggestions on ways Plan recommendations can be put into action. We have no doubt that the way they will be implemented will in fact be I-Kiribati way. But in general we see the process flowing as follows:

Bonnano N Tararua set goals and priorities
Bonnano N Tararua would lay out public service activities
MENRD design implementation plan, set budget, allocate staff
Bonnano N Tararua representatives enlist their village's support
Government solicit donor financial and technical assistance
Bonnano N Tararua and MENRD define private sector activities
Other ministries provide technical support, budget, equipment
Village provide people to do certain tasks

As described in the preceding sections, the Annual Bonnano N Tararua conference main objective would be to identify specific strategies and management projects to be undertaken in the comming year.

5.1 Public Service Projects

Perhaps the easiest way to undertake projects where a workforce is the main requirement would be through community or church group or *maneaba* based public service projects.

For example, projects to stop the fishing of bonefish pre-spawning aggregations could be organized to include groups of men and wormen who would serve as Deputy Fisheries Constables. They could remain in the area keeping fishers and poachers away. Perhaps they could also focus on fishing for barracuda, big jacks and sharks with handlines or longlines to reduce the number of large predators preying on the bonefish aggregation.

Similarly, public service projects could include joint undertakings between the men of villages and the Department of Public Works to open boat passages or install culverts in the causeways.

Community efforts to build FADs is another example.

5.2 Private Sector Projects

New job opportunities and enterprise potential exists in implementing some of the projects that are needed. These opportunities probably will not develop if the government simply carries out the actions. For example, earlier in this Plan an opportunity is described to protect and increase the present population of giant clams through a small business approach. The government could continue to protect the clams but at the same time it could encourage the private sector to start a giant clam hatchery or growout farm. With a small shift in perspective, and a little help, a small business might be created and possibly do a better job than the government.

New opportunities exist in new gear and fishing methods as they are discussed throughout the Plan. Opportunities exist to re-manufacture gillnets, manufacture FADs, make long-lines and lures, and refit or build boats. Job opportunities also exist to assist government in management activities, data collection, research and monitoring, and development projects.

In order for these opportunities to take full form and in order for them to be developed by the private sector several steps need to be taken.

- The Bonnano N Tararua planning process, along with workshops should focus on how each management activity could produce jobs and income without relying on government to carry out every activity.
- Each management activity should be analyzed to identify the technical support that will be needed to carry out the project in the private sector.
- Any needed training should also be identified
- Someone should be assigned to organize the training or technical assistance.
- Each management activity should be analyzed to identify the appropriate financial support (loans or grants) that might be needed to carry out the project in the private sector (e.g., assistance purchasing the necessary equipment to manufacture FADs). Similarly, the most appropriate form of the financial assistance should be identified such as loans, grants, or direct contributions of equipment.

5.3 Government Agency Projects

Most of the actions required to implement the Plan require government participation at some level. But it is strongly recommended that as many of the actions as possible be implemented by private individuals or companies other than the government. Instead, the various government

agencies could serve as a source of support and technical assistance to individuals and groups from the public who desire to carry out projects. Government has considerable resources that it could mobilize to support such efforts including people, equipment, technical assistance, and assistance in raising funds from international donor agencies to support community projects.

5.4 Technical Assistance

Foreign technical assistance to implement parts of the Plan will be essential for several more year. Implementation will be smoother if the government and the communities are supported with a team of technical experts with experience implementing community and public participation programs, designing economic incentives, and facilitating government-private sector cooperation. In addition, there is a long agenda of scientific information that still needs to be collected, analyzed, and communicated to the public in ways that will contribute to a sound Plan.

The UNDP, South Pacific Regional Environmental Program, South Pacific Commission, Asian Development Bank, and the World Bank are examples of the multi-lateral development assistance agencies which may provide financial support. Bilateral organizations from the U.S., New Zealand, Australia and Japan also have the potential to provide significant financial and technical assistance.

5.5 Enforcement of Regulations

Most of this Plan contains recommendations not requiring the institution of regulations or enforcement. But some elements of the plan do require imposition of restriction on lagoon user activities. Enforcement of any proposed set of regulations will be difficult for many social, cultural, economic and political reasons. Enforcement must be within the constraints of the law and penalties must be reasonable. In addition, regulations must be imposed in such a way that public support is broad, so enforcement becomes a matter of community compliance and policing, not totally a government enforcement problem. The Bonnano N Tararua must openly discuss enforcement, identifying those who will be authorized to enforce regulations and what penalties might be imposed. Possible enforcement authorities include:

- A fisheries court with specially trained judges operating under the authority of the Attorney General.
- A voluntary Fishery Constable Corps set up by the Island Councils
- An enforcement department within the Fisheries Division
- A fisheries enforcement division within the Police Department

5.6 An Integrated Implementation Team

The implementation of the management plan would take many kinds of specialists. Brief job descriptions for some key individuals are listed below.

- INSTITUTION SPECIALIST
  The institution specialist would spend approximately two months per year in Tarawa assisting the MENRD and the executive committee of the Bonnano N Tararua in preparing an agenda and organizing the annual conference.

- EDITOR/PROPOSAL MANAGER
  The person holding this position needs to be a skilled technical editor with English as a first language. The technical editor would assist in the production of documents, proposals and reports. This person would also serve as an on-the-job trainer for technical writing, editing and document management.

- COMPUTER GRAPHICS SPECIALIST
  This position could be filled by an local Kiribati citizen knowledgeable about computers. They would assist the various groups within the ministry in producing the figures, tables, and illustrations used in reports and newsletters and especially in the community education effort.

- COMMUNITY EDUCATION SPECIALIST
  The community education specialist would be an expert in special training programs and in coordinating the non-formal community education projects.

- PUBLIC SPEAKER
  The public speaker would be a senior kiribati man with exceptional ability as a communicator and facilitator in village maneaba meetings. His task would be to inform the community about government activities and listen to village comments about the lagoon. He would help carry the message of the Bonnano N Tararua to village and from the village back to the government.

- SONGWRITER/CHOREOGRAPHER
  The songwriter/choreographer would be a Kiribati master of the songs and dances of Kiribati. This person would transcribe the message of the Bonnano N Tararua into humor, song and dance with the grace and insight needed to inspire community understanding. The songwriter/choreographer would supervise a troop of at least six performers.

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- FINFISH EXPERT
  The finfish expert would be a part-time fisheries scientist charged with providing specialized technical advice as required to help implement the fisheries related recommendations of the Plan.

- FINFISH FIELD ASSISTANTS
  Two kiribati field assistants would work under the direction of the finfish expert collecting data.

- SHELLFISH EXPERT
  The shellfish expert would be a part-time shellfish scientists specifically charged with providing an annual report on the status of the shellfish resources of the lagoon.

- SHELLFISH FIELD ASSISTANTS
  Two kiribati field assistants would work under the direction of the shellfish scientists to collect information on the status of the lagoon's shellfish resources.

- PUBLIC HEALTH EXPERT
  The public health expert would be charged with conducting the series of studies recommend in the research and public health sections of the Plan.

- FIELD ASSISTANTS/LABORATORY TECHNICIANS
  Two kiribati field assistants would be hired to collect samples and run laboratory tests related to the recommendations in the public health and research sections of the Plan.

- FISHERIES EXTENSION
  The fisheries extensions experts job would be to assist and enable fishermen presently earning their livelihood from commercial fishing in the lagoon, to start fishing in the ocean. Thus this person would work closly with the MENRD, the Kiribati Development Bank, Bank of Kiribati, bilateral development agencies and fishermen to mobilize funds, equipment and training programs. The basic scope of activities would be similar to those detailed in the Plan relating to decreasing effort in the lagoon and increasing effort in the ocean.

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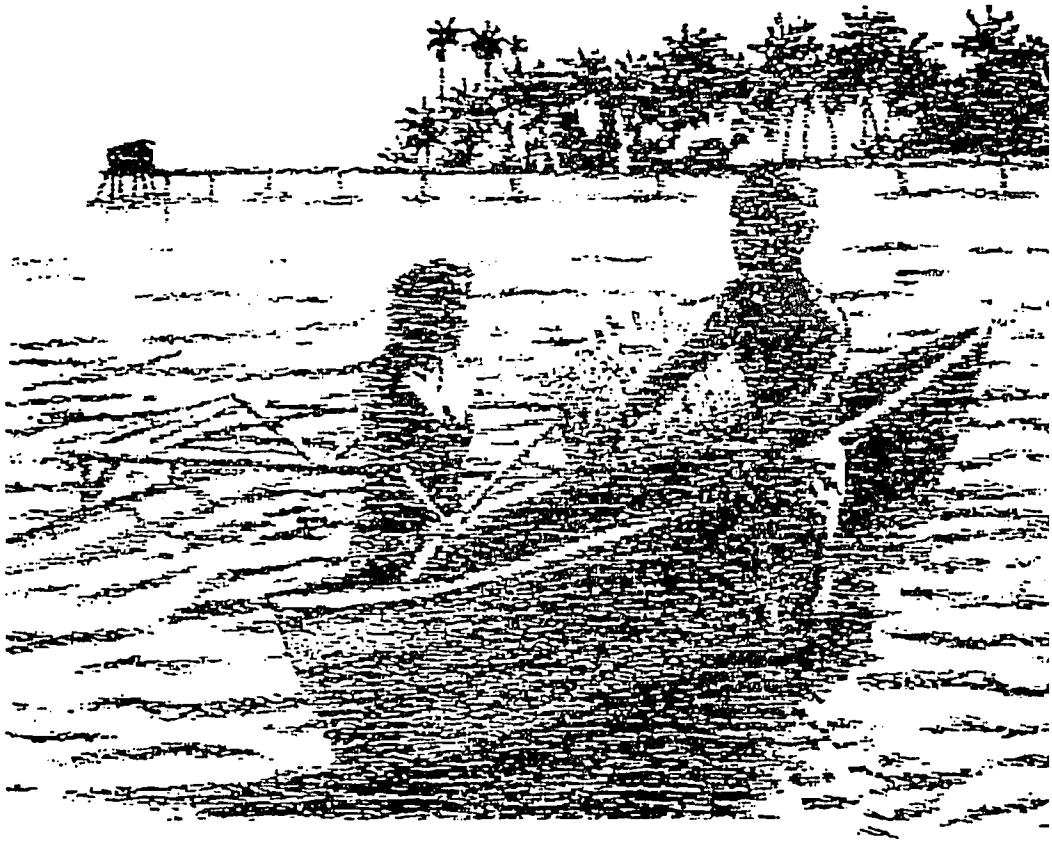
TARAWA LAGOON MANAGEMENT PLAN

Volume III

The Management Plan

February 1995



BioSystems

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Volume III: Management Plan

Pacific Islands Marine Resources
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Acronyms

APHA . . . . . American Public Health Association
CMT . . . . . customary marine tenure
CPUE . . . . . catch per unit effort
CTD . . . . . Seabird Seacat conductivity-temperature-depth recorder
ENSO . . . . . El Niño – Southern Oscillation
FAD . . . . . fish aggregation device
FFA . . . . . Forum Fisheries Agency
GPS . . . . . global positioning system
IMR . . . . . University of the South Pacific Institute of Marine Resources
LW . . . . . low water
MENRD . . . . . Ministry of Environment and Natural Resources Development
RCYBP . . . . . radiocarbon years before 1950 A.D.
SOPAC . . . . . South Pacific Applied Geoscience Commission
SPREP . . . . . South Pacific Regional Environmental Programme
SPRMTCP . . . . . South Pacific Regional Marine Turtle Conservation Program
TML . . . . . Te Mautari Limited

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List of Abbreviations

μm	microns
amsl	above mean sea level
cal	calories
cm	centimeter
d	day
FC	fecal coliform
g	gram
g-at	gram atoms
μg-at	microgram-atoms
h	height
hr	hour
kg	kilogram
km	kilometer
L	liter
m	meter
mb	millibars
min	minute
ml	milliliter
mm	millimeter
MPN	most probable number
msl	mean sea level
ppm	parts per million
ppt	parts per thousand
psu	practical salinity unit
SD	standard deviation
SL	standard length
sec or s	second
y	year

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Kiribati Terms

aba . . . . . submerged sand shoals
bubuti . . . . . cultural practice of asking for another's property
Kain Tawara . . . . . Tarawa landowners
Kainga . . . . . a cluster of households
maneaba . . . . . meeting house
mronron . . . . . informal enterprise activity
Nei Teba . . . . . a rock formation
te bun . . . . . *Anadara* sp., species of bivalve
te bauamaran . . . . . species of mullet
te bauataba . . . . . species of mullet
te ikabuti . . . . . periodic lunar spawning migration
te ikanibong . . . . . paddletail snapper
te ikari . . . . . bonefish
te kima . . . . . giant clam
te koikoi . . . . . popular species of shellfish
te maebo . . . . . species of goatfish
te morikoi . . . . . spangled emperor, species of snapper
te nimimai . . . . . pets of a ghost
te ororo . . . . . splash fishing method
te rou . . . . . species of snapper
Te tao . . . . . lagoon area near Buariki
te tarabuti . . . . . goldspot herring
te tewe . . . . . species of goatfish
tinaba . . . . . a special gift given to a woman
unimwane . . . . . traditional leaders
utu . . . . . extended family

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Preface

This report is one of three volumes on the development of management strategies for Tarawa Atoll lagoon, Republic of Kiribati. This project was conducted by BioSystems Analysis Inc., the Atoll Research Programme of the University of the South Pacific, and the Government of Kiribati, with primary funding from the U.S. Agency for International Development.

Tarawa Lagoon is an important resource to the growing population of the atoll. However, high population density and rates of resource exploitation, alteration of the coastline, and disposal of human waste have led to several significant environmental problems. Most important among these are a severe depression of several food sources, particularly bonefish, and severe contamination of nearshore waters and shellfish beds with fecal bacteria.

The principal objectives of this project were:

- To identify opportunities to improve harvests from or conditions in the lagoon
- To assess the status of the lagoon and determine the extent and severity of problems
- To develop a management strategy to take advantage of opportunities and address the environmental problems

The three volumes of this report are:

I. **Summary of the Tarawa Lagoon Management Plan** This volume summarizes the major points of the management plan. It is designed as an extended executive summary of the plan and the principal results of the underlying scientific studies.

II. **An Environmental and Resource Assessment of Tarawa Lagoon** This volume reports on the scientific research conducted on the lagoon, including investigations of human activities, circulation, water quality, food chain, reefs, and harvestable resources, including fish and shellfish. It includes a summary of the principal findings of the scientific research as they relate to management.

III. **Management Plan for Tarawa Lagoon** This volume contains the plan itself, including a description of the issues and opportunities, a summary of the recommended actions, and a proposed action plan for implementation.

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Summary

This report describes results of a study of environmental and ecological conditions of Tarawa Atoll Lagoon, with particular emphasis on the relationship of the human population to the lagoon.

Three characteristics of Tarawa Lagoon are central to its ecological function and productivity. First, Tarawa Atoll is in the equatorial upwelling region, an area in which biological productivity is higher than in the rest of the tropical Pacific. Second, Tarawa Lagoon is open to the ocean along its entire western boundary, resulting in rapid exchange with the ocean. Third, as the capital of the Republic of Kiribati, Tarawa's human population is large, with a high population density in south Tarawa and in particular on Betio Island.

Our study examined circulation, water chemistry, trophic ecology, reefs, finfish production, and shellfish production. In addition, we examined the interaction of humans with the lagoon in two ways, by a formal household survey, and through informal, unstructured interviews with knowledgeable fishermen. This combination of methods gave us complementary information on the lagoon and on people's use of and perceptions about the lagoon. Much of our information is based on field studies conducted between April 1992 and July 1994.

Circulation in the lagoon is due mainly to tidal flow through the large western entrance and through passes between islets in north Tarawa, and to a lesser extent to wind. The southeastern corner or "elbow" of the lagoon has the poorest circulation, in that it is least connected with the ocean. We studied circulation by the use of a computer model, which was calibrated using data on tidal height and salinity in the lagoon. Residence time of the lagoon, which is the average time that a particle of water would remain in the lagoon, was calculated at 9.5 days using the model, and 3-12 days (median 5 days) using salinity data. This short residence time means that contaminants entering the lagoon are removed rapidly by exchange with the ocean. Although the passes between islets in north Tarawa contribute substantially to circulation in the central lagoon, installing or removing causeways would do little to alter the exchange of water into the elbow. We calculated that exchange of sediment was not altered much by the construction of causeways in southeast Tarawa, and that therefore the high turbidity of this region is probably due to longer-term processes that result in deposition of sediments. Model calculations of the distribution of enteric bacteria and nutrients agree reasonably well with observations. Using the model, we calculated that most of the nutrient in the lagoon was from the ocean rather than from human inputs.

Measurements were made of salinity, dissolved oxygen, phosphate and total phosphorus, and on one occasion a full suite of nutrients. These measurements indicated that water quality in the lagoon is high, even in the eastern elbow, although nutrient concentration can be elevated near lagoon sand flats. Planktonic productivity is higher than in the surrounding ocean, and higher than in most atoll lagoons, owing mainly to the relatively high nutrient concentrations in the ocean water. Biomass and production varied throughout the year but had no seasonal pattern. Based on estimates of ecological

efficiency, the contribution of the zooplanktonic food web to fishery yield of the lagoon is small. Most of the fishery yield is apparently based on benthic production, much of which is based in turn on phytoplankton produciton.

Microbiological water quality of nearshore waters continues to be poor, owing to use of the lagoon as a toilet, and possibly to runoff from pigpens along the shore. Bacterial contamination of nearshore waters exceeded International Public Health standards for waters used to grow shellfish on eight of nine transects. Samples from four of the nine transects exceeded human bathing water standards. By contrast, water from the open lagoon had consistently low or nondetectable levels of contamination. Model studies suggested that these low levels could be expected because of strong tidal circulation and rapid mortality of these indicator bacteria. All shellfish (*te bun*) collected close to shore exceeded the currently accepted standard for shellfish meat, whereas shellfish collected farther out on the lagoon shoals contained no measurable contamination. Bacterial contamination might be reduced by maintaining the shellfish in clean water for several days, but cooking provides a surer method of reducing contamination.

The distribution of coral reefs in Tarawa Lagoon reflects the unusual shape and bathymetry of the lagoon. Coral cover and diversity increases from west to east and also from north to south, as a consequence of the one-sided opening of the atoll. Algae are abundant in much of the central lagoon, probably as a result of high productivity. Reefs in general appeared healthy, except for some mortality along the barrier reef and substantial mortality of corals in the southeast lagoon. This mortality occurred within the last few hundred years, possibly this century. If this dieback is recent, then the urbanization of Tarawa could have been responsible for the reef kill. As a consequence of this mortality, much of the habitat and associated communities on the shoals of the southern lagoon have been lost.

The abundance and species composition of finfish were examined using a variety of methods, and results were compared with similar studies done in 1977. Fish are much less abundant in the southeastern part of the lagoon than in the northern or western portions. Many of the species have declined since 1977. In particular, bonefish have declined in abundance, size distributions have shifted to smaller mean size, and the sex ratio has changed to 7:1 (male:female). These results suggest that the spawning stock of female bonefish within Tarawa Lagoon is very low. Many of the bonefish caught in Tarawa Lagoon are pre-spawning individuals, and the larger females have been depleted. Besides bonefish, there have also been severe declines in other species, including some baitfish (e.g., *te tarabuti*) that have been collected for commercial fishing.

Benthic resources including shellfish were examined on the lagoon sand flats, slopes, and the deep lagoon bottom. Population densities of mollusks and echinoids (sea urchins) are unusually high for an atoll, the result of phytoplankton productivity high for an atoll. Seagrass beds on the reef flats support an intense fishery that takes about 1,000 tonnes of shellfish per year in South Tarawa, mainly of the two preferred species, a bivalve (*te bun*) and a small conch (*te nouo*). Off central South Tarawa, a limited but very intense commercial fishery removes about 1,000 tonnes of *te bun* per year from dense, localized beds on the lagoon slope. Most of the deep lagoon floor holds few

shellfish. Marked west-east and north-south zonation in all aspects of the benthos, similar to that seen for reefs and finfish, is probably related to patterns of water exchange.

The household survey revealed that the lagoon is considered a very important resource, mainly because of its uses for collecting food, bathing, and toileting. Respondents indicated that catching fish has become more difficult in the last 3 years, and the composition of the catch has changed away from preferred species. Finfish are caught most often by gill netting, and second by the "splash" method of gill nettinhg. Most fish are consumed by the fisher's family, but a substantial fraction is sold. Shellfish are collected by family groups in large quantities, but the average size has become smaller, according to respondents in South Tarawa. Respondents believed causeways exerted a negative effect on fish, but seemed to believe that the advantages outweighed the loss of fish. Respondents indicated a lack of willingness to reduce their own catches to improve stocks, but supported broad regulations that would require everybody to reduce catches.

Interviews with knowledgeable, usually older, fishermen in villages of North and South Tarawa were very revealing about the habits of fish and the methods used now and in the past to capture them. In particular, information about bonefish, the most valued lagoon fish, was very revealing, and gave further indication of a steep decline in abundance of these fish. Bonefish have a characteristic spawning migration behavior by which they aggregate in the lagoon, migrate through the passes to spawn in the ocean, then return through the passes. This behavior was used in the past to capture huge numbers of bonefish in rock traps at strategic locations on the ocean reef flats. However, blockage of migration pathways by causeways, and efficient fishing methods such as the use of gill nets and the "splash" method of fishing, have eliminated most of the runs; the last remaining known spawning aggregation has failed to appear for the last 2 years. Spawning runs of other fish such as goatfish and mullet have also greatly declined.

To summarize, main findings of the study were:

- The base of the food chain, and the chemistry of the latgoon's water, are characteristic of a healthy ecosystem
- Nearshore lagoon waters are contaminated to an extent that causes a health risk for people bathing and collecting shellfish
- Fish populations are depleted because of blockage of migration by causeways, use of efficient fishing methods, and overfishing
- In particular, bonefish are in a precarious state, and could be lost within the next decade
- Shellfish populations are being heavily exploited but so far are not in danger, except for giant clams
- Causeways have severely damaged many of the important fisheries in the lagoon, but probably have not had much effect on water quality

Introduction to the Study

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Introduction to the Study

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This volume of the Tarawa Lagoon Management Plan describes the scientific results of a 2-year study of Tarawa Lagoon conducted in 1992-1994 in support of the development of a lagoon management plan, which is presented in Volume III.

Tarawa Atoll

Tarawa is the capitol of the Republic of Kiribati[1] (Figure 1 inset), which comprises the atolls of the Gilbert, Phoenix, and Line island groups and Banaba Island, spread over 4,400 km of the central Pacific.

Tarawa Atoll, centered at lat. 1°25'N, is roughly triangular and about 30 km (north-south) by 25 km (east-west). The eastern and southern margins are delineated by low islands, and the western margin consists of a submerged reef. Most of the human population lives on South Tarawa where the islands have been linked by causeways. The major population centers are at Betio, Bairiki, and Bikenibeu (Figure 1).

The Lagoon Environment

Several previous reports on the physical characteristics of Tarawa Lagoon provide a background for this study. Most of these are technical reports prepared by consultants for various branches of government, or are reports of the South Pacific Applied Geoscience Commission (SOPAC), South Pacific Commission (SPC), Forum Fisheries Agency (FFA), University of the South Pacific Institute of Marine Resources (IMR), or Atoll Research Programme (ARP, formerly Development Unit, ARDU). Because relatively little of this work has been published in the widely available literature, we summarize this material below.

[1]In the Gilbertese language, or Kiribati, the "ti" combination of letters is pronounced "s" or "sh," as in the English word "negotiate." Thus, "Kiribati" is pronounced as if it were spelled "Kiribass."

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General Description

Tarawa Lagoon is shallow, with numerous patch reefs and intertidal sand flats, and a wide fringing reef on the ocean side of the islands. Mean depth is 6 m (deeper if the patch reefs are excluded), and the maximum is 25 m. Intertidal sand flats extend along the lagoon margins of the islands. Most of the islands of the atoll are narrow (100-700 m wide), and all the islands are less than 2 m above sea level. Passes between the islands are shallow, generally no deeper than the fringing reef, and are dry at low tide.

The atoll is commonly divided into North Tarawa, the sector north of the airport, and South Tarawa. The lagoon is also divided into northern and southern sectors by a line of large patch reefs that transverse the lagoon at about 1°30′N (Figure 1). Parts of the western reef are exposed at low tide, but a 30-m-deep natural channel is used for shipping traffic.

All the passes between the islands in South Tarawa and many of those in North Tarawa have been blocked by causeways. Because of the high cost, only one of the channels has been spanned with a bridge (Figure 1). The longest causeway, between Betio and Bairiki, was completed in 1988. This causeway has a single bridge segment large enough for small boats to pass, except at low tide. Where no causeways have been constructed, access between islands is by boat or by wading at low tide.

Climate

Tarawa is located in the tropical convergence where warm, moist air rises into the stratosphere, resulting in substantial rainfall in most years. Meteorological data were obtained from the New Zealand Meteorological Service and the Tarawa weather station. Mean annual rainfall is 1.5 m, most of which falls in the northern winter. Trade winds blow from the east about 81% of the time, particularly during the northern summer (Figure 2). Typhoons are rare, but westerly winds associated with storms occur frequently, particularly in June-November (Figure 3).

Air temperature in Tarawa is high, varying by only a few degrees throughout the year from a mean of 29°C (Figure 4C). Water temperature (Kimmerer, this volume) also does not vary much from a mean of 32.3°C (Figure 4F). Mean relative humidity during our study was 79% (Figure 4D); May-July 1992 was relatively dry but humidity remained high for the rest of 1992-1993. The weather during our study was somewhat unusual in that heavy rainfall was frequent throughout 1993, with no dry season. Rainfall totaled 3.3 m for the year beginning April 1992, and 4.4 m for the year beginning October 1992. Solar radiation averaged 390 cal cm^{-2} d^{-1}, although it was not measured during the entire period. Mean wind speed was 3.6 m s^{-1}, and mean direction was northeast.

Westerly winds were more frequent during our study than indicated by the longer record (Figure 5). Although monthly mean wind vectors were from the west only 41 times during 1948-1992, mean westerly flows occurred during 4 months of our study.

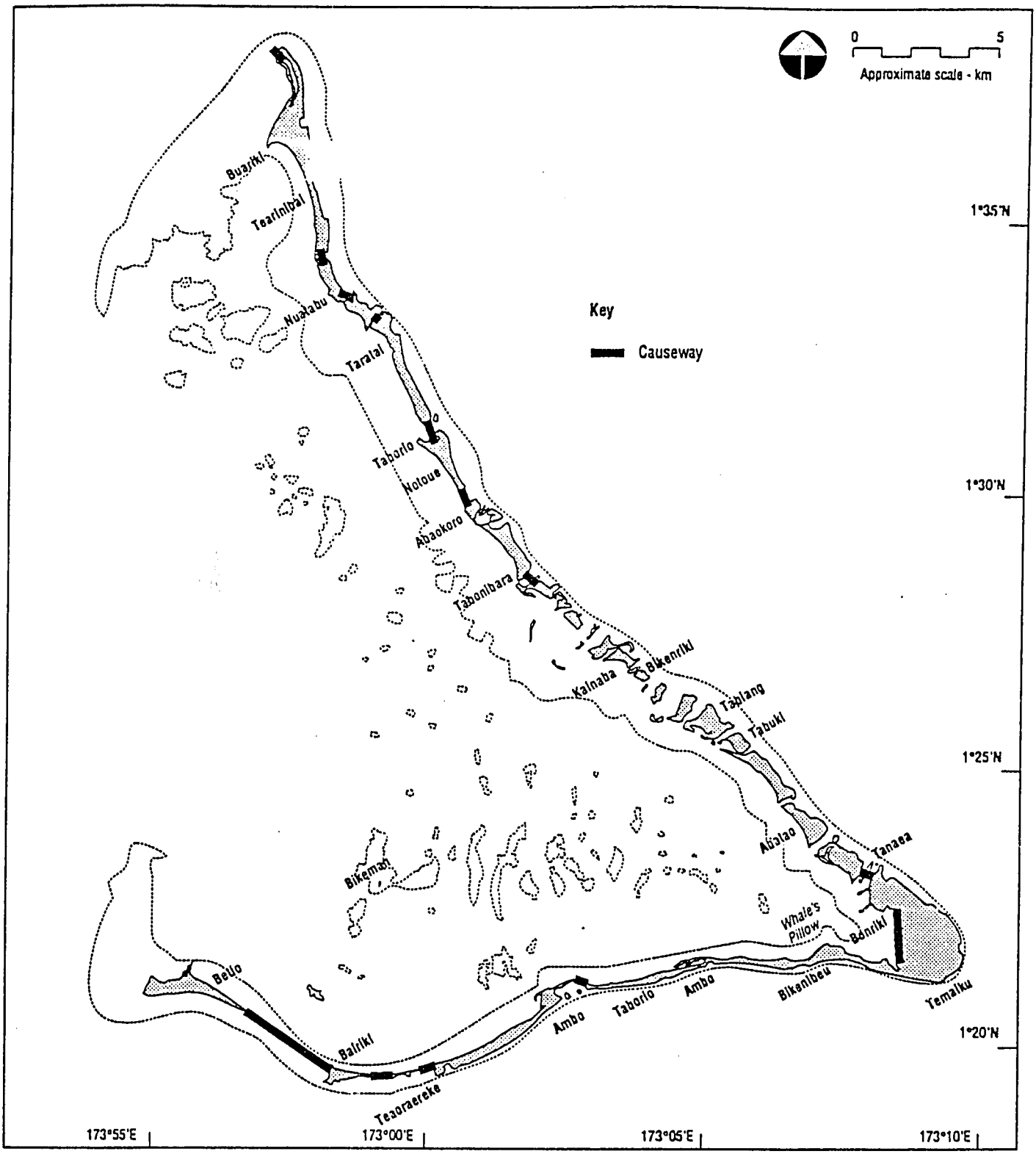

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Figure 1 Map of Tarawa Lagoon showing location of villages and causeways.

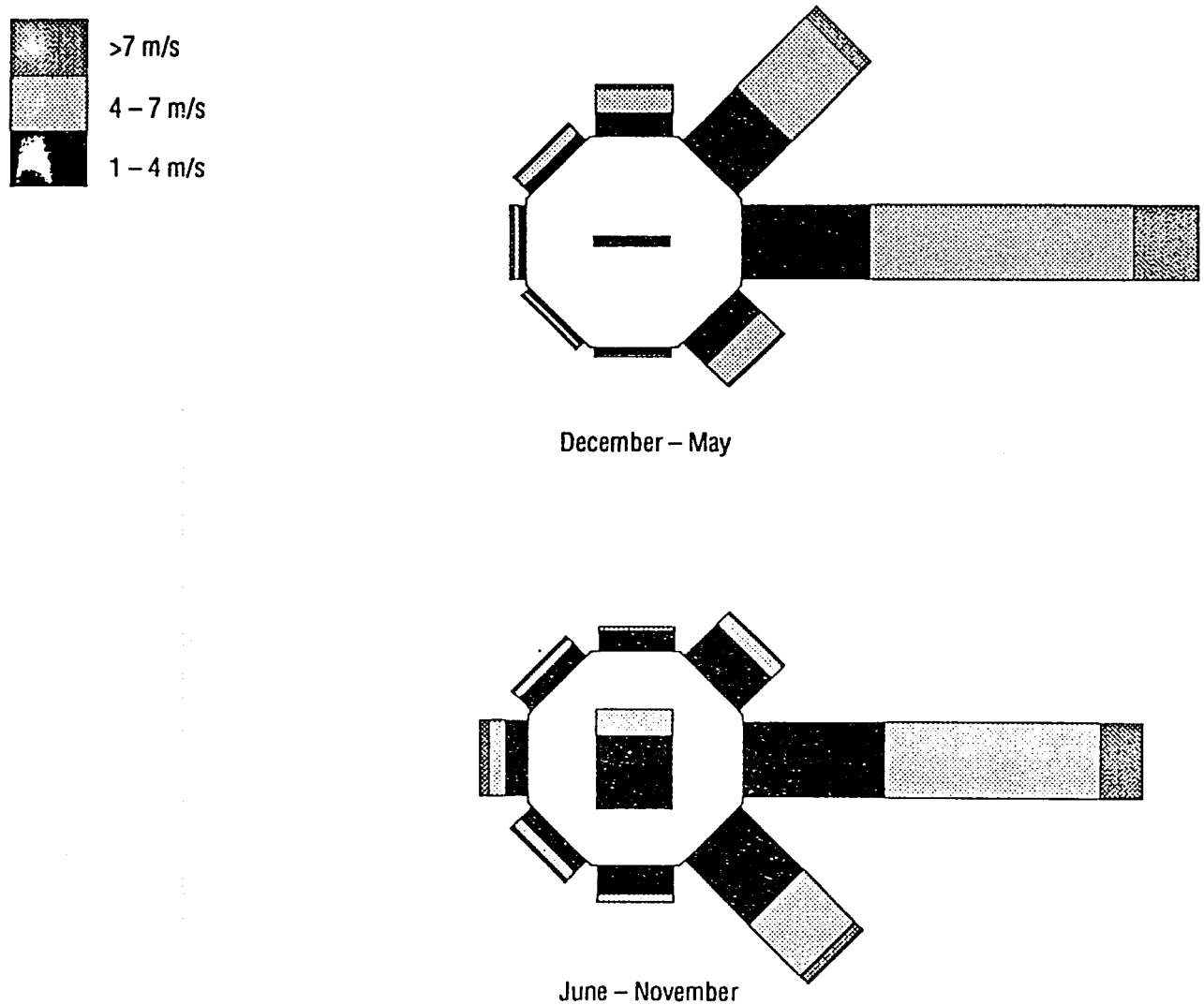

Figure 2. Wind roses for December-May and June-November.

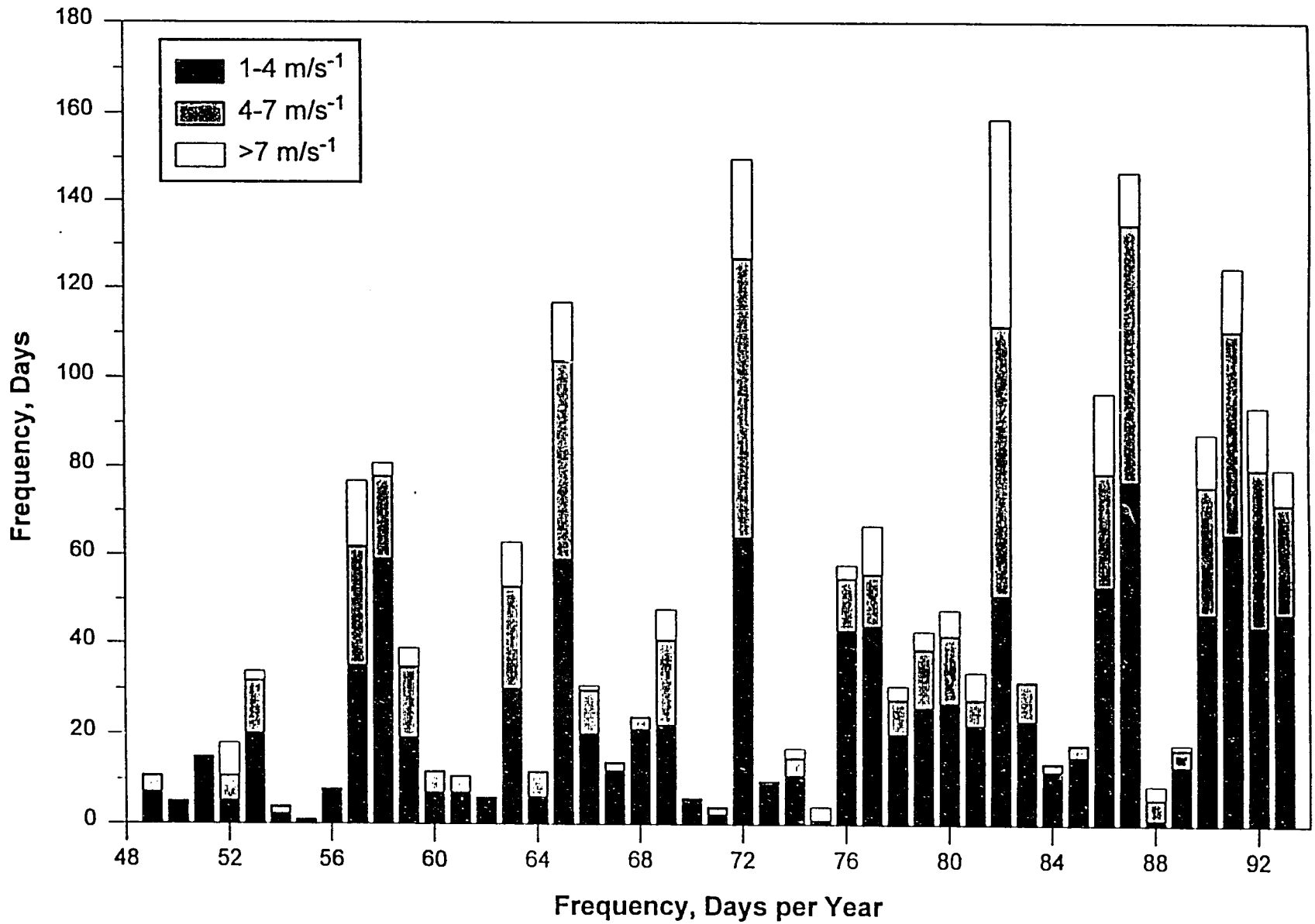

Figure 3 Frequency of westerly wind by year, 1948-1993.

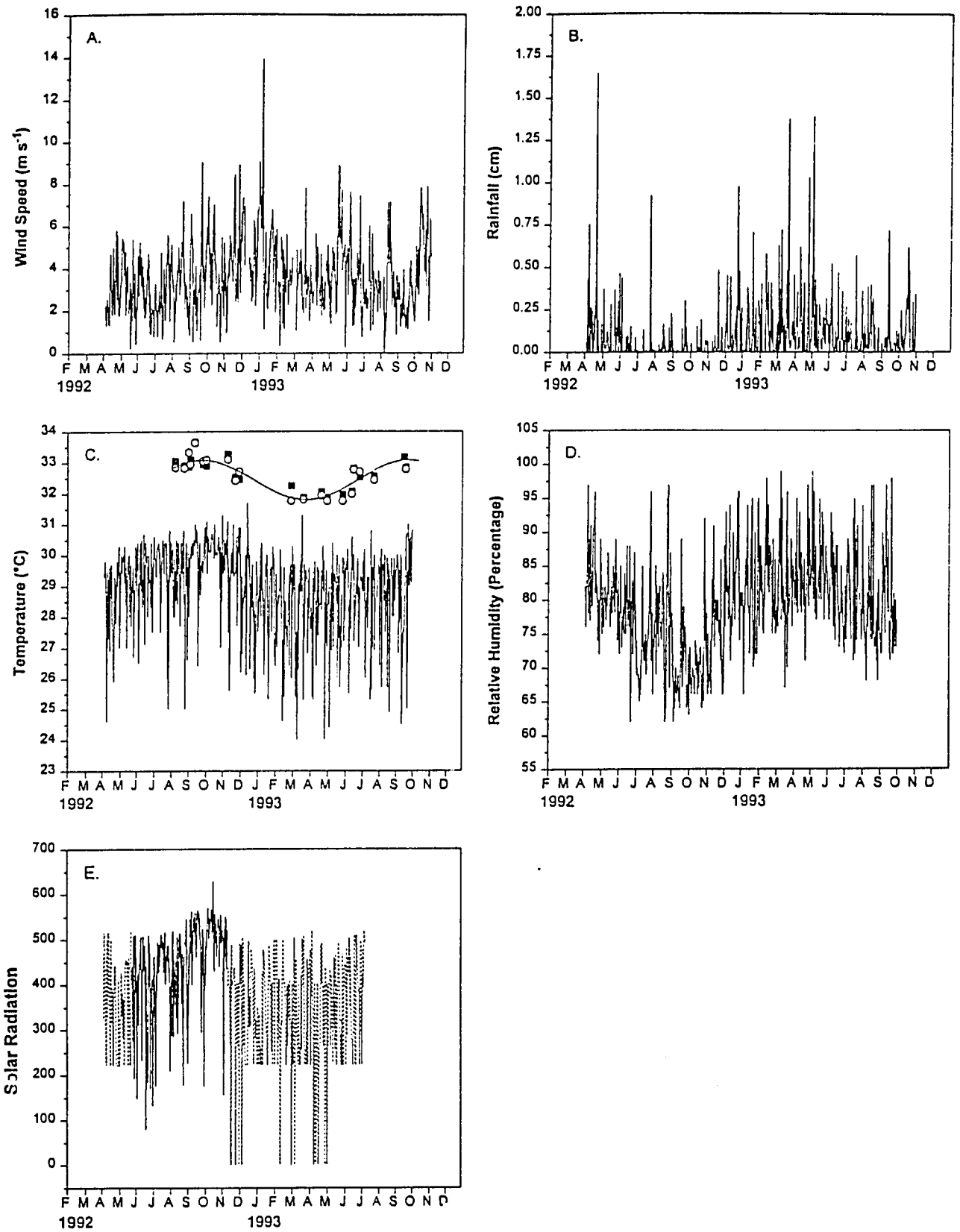

Figure 4 Climate data for the period of the study. A) Wind speed; B) rainfall; C) air temperature and water temperature at two lagoon stations with fitted curve (data from water quality Stations 1 [filled square] and 8 [open circle] (Figure 1); D) relative humidity; and E) solar radiation (dashed line is estimated from hours of sunshine.

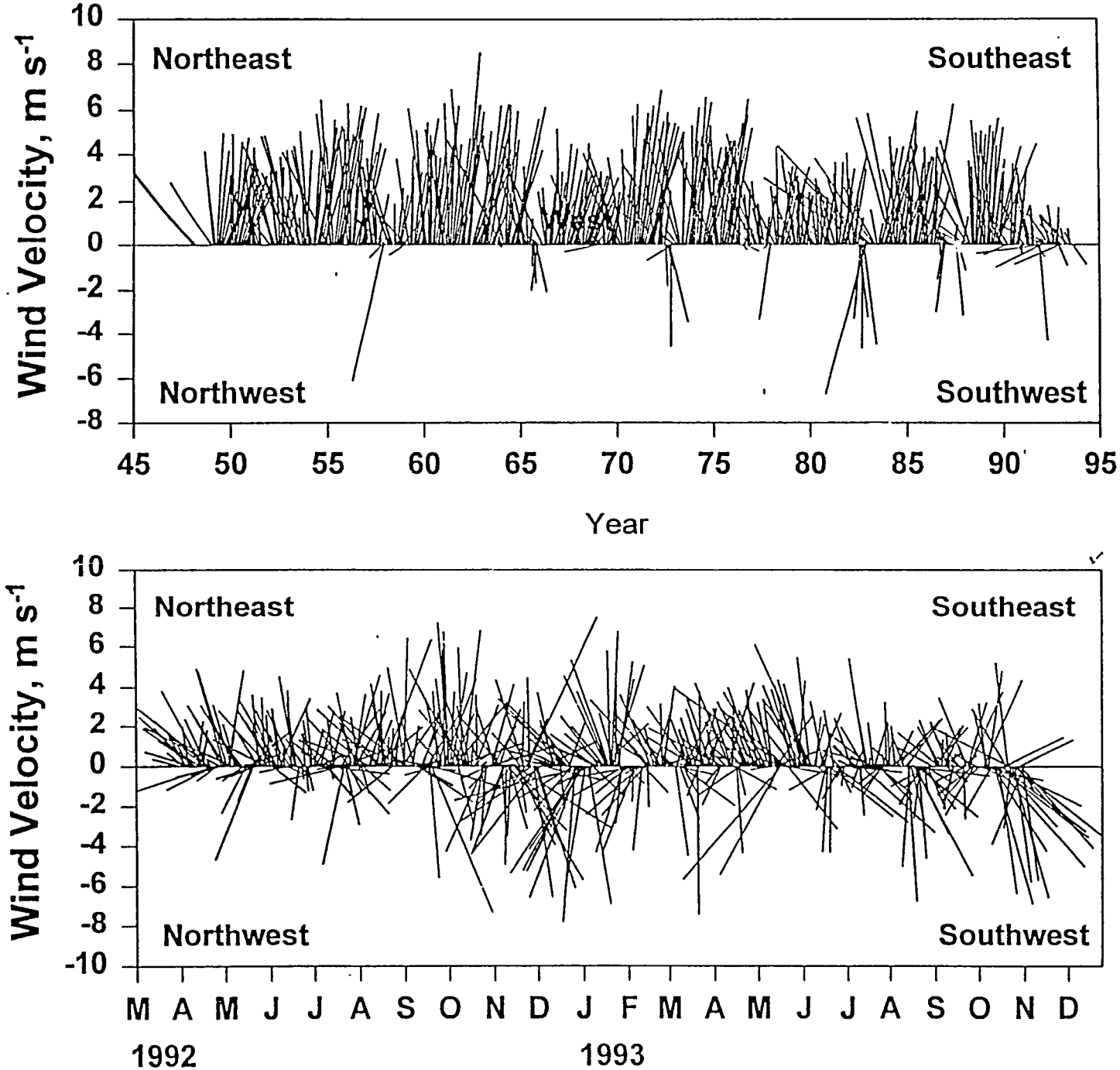

Figure 5 Wind vector diagrams: each line represents a vector oriented with north at the left and east at the top so that the principal direction can be seen. Monthly mean vectors for 1948-1993 (top); daily vectors for 1992-93 (bottom).

Regional Oceanography

Tarawa is in the region of equatorial upwelling. Relatively cool, deep, nutrient-rich water rises to the surface as the warmer surface water moves poleward under the influence of the trade winds and the earth's rotation. Currents in the top 100-300 m flow generally toward the west, although these currents can reverse with shifts and meanders in the equatorial countercurrent that flows in the opposite direction north of Tarawa. The equatorial undercurrent flows eastward below the surface along the equator just south of Tarawa.

Tides

The tides of Tarawa Lagoon are semidiurnal with a mean amplitude of about 1.5 m (Figure 6). Tidal data are collected at Betio by the University of Hawaii and, since 1991, by the National Tidal Facility at Flinders University, South Australia, as part of their global sea level measurements. Tidal currents tend to be weak, except in the deep channel through the western reef where current speeds of 24 cm s^{-1} (0.5 knot) have been recorded (Johannes et al. 1979). At times, however, currents can be considerably stronger (Chen et al., this volume).

Currents through the passes vary over the tidal cycle and with wind direction. Flows in Tanaea and nearby channels are predominantly inward because of wave setup on the ocean reef (Johannes et al. 1979; Consulting Environmental Engineers 1986). Westerly winds, however, can cause a reversal of these currents (Chen et al., this volume).

Sediment Geology

Several studies of sediment type, composition, and movement have been conducted (e.g., Weber and Woodhead 1972; Harper 1989; Gauss 1982; Richmond 1990; Byrne 1991). Most of the sediments in Tarawa Lagoon are biogenic calcium carbonate, predominantly aragonite (Weber and Woodhead 1972). Sediment composition follows an east-west gradient, with sediment originating as coral toward the west and sediment derived from the alga *Halimeda*, mollusks, and echinoderms increasing to the east. This pattern is consistent with the observation that live coral cover increases to the west (Johannes et al. 1979; Paulay and Kerr, this volume).

Sediment grain size also decreases to the east, with the greatest proportion of aragonite mud slightly west of the easternmost corner of the lagoon. As a result, the eastern part of the lagoon tends to be turbid, particularly during strong winds. The lagoon bottom is muddy compared to other atolls (Weber and Woodhead 1972). Lagoon sand flats are a depositional feature, unlike the ocean reefs, which may be erosional (Richmond 1990). The sources of sediments in the lagoon differ with location. Sources include lagoon and patch reefs, in situ production, and, to a lesser extent, ocean reefs through channels.

Beach profiles taken in Betio and Bairiki from 1982 to 1988 have revealed considerable sediment movement, with erosion and accretion occurring at different times and places (Harper 1989). Sediment movement in the lagoon depends on wind speed and direction. The most substantial movements were attributed to the increased frequency of westerly winds that occur during El Niño-

Southern Oscillation (ENSO) events such as those that occurred in 1982 and 1987 (Harper 1989). The completion of the Betio-Bairiki causeway in 1988 was not associated with major changes in sediment movements, except for localized erosion and accretion (Harper 1989, 1991).

Bikeman Island, a small sand island atop one of the larger patch reefs in the lagoon, has moved eastward by roughly 100 m during the last decade. Although some have attributed this movement to the construction of the Betio-Bairiki causeway, a more likely cause is an increase in westerly wind. The depth of the lagoon between patch reefs and lagoon sand flats would preclude movement of sand between them (Richmond 1990). The currents that flowed over the Betio-Bairiki sand flat before the causeway was constructed were not forceful enough to transport sand any distance from the edge of the sand flat (Johannes et al. 1979). Furthermore, the sediments of this island are predominantly derived from foraminifera (Richmond, pers. comm.), unlike the primarily coral sands of the causeway area. Finally, currents around Bikeman Island have likely not been affected much by causeway construction (Chen et al., this volume).

The history of sediment movement has been inferred by examining depositional features in aerial photographs (Byrne 1991). These features indicate that when passes in South Tarawa were open, the sand tended to move westward. In Bikenibeu, near the eastern edge of the lagoon, Byrne inferred that the movement of sand tended to be eastward because this area is sheltered from easterly winds; therefore, waves from the northwest would be responsible for most sediment movement.

Byrne (1991) also inferred that recent erosion on the ocean side of Temaiku, at the easternmost part of the atoll, is related to the interruption of an intermittent sand supply from within the lagoon. Closure of the Temaiku Bight eliminated the source of sand once available during westerly winds. Active erosion in several other areas may be the result of causeway construction.

The Human Environment

Tarawa Atoll has been inhabited by humans for at least 3,000 years. The I-Kiribati are known throughout the Pacific for their expertise in building and sailing canoes, and are accomplished fishers (Teiwaki 1988).

The Gilbert Islands came under British rule in 1892, and in 1916 became part of the Gilbert and Ellice islands colony. British authority over the Gilberts was interrupted during the Japanese occupation in World War II, which ended with the bloody battle of Tarawa in November 1943. Relics from that battle are still prominent on Betio, the largest, westernmost island (Figure 1). In 1979, the Gilbert, Phoenix, and Line islands and the island of Banaba were granted independence as the Republic of Kiribati.

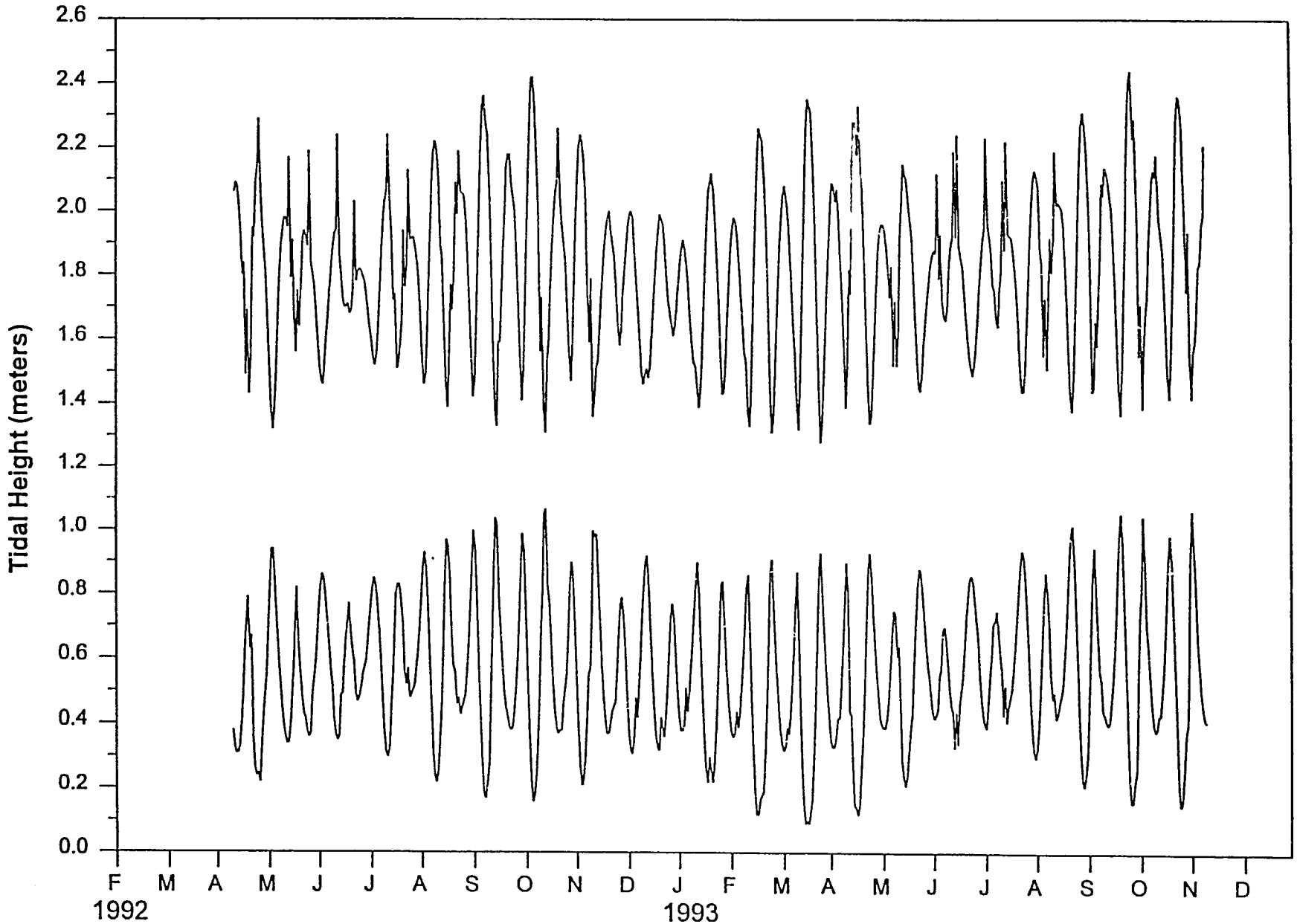

Figure 6 Calculated tidal stage (daily high and low tides) for Betio during the study period, based on tidal constants obtained by National Tidal Facility of Flinders University, Australia.

Population and Economy

The land area of Tarawa is approximately 31 km^2 and the population in the 1990 census was 28,802. Most people live in South Tarawa (Table 1). The population density per square kilometer in North Tarawa is 239, in South Tarawa is 1,596, and on Betio is over 5,000, making Tarawa the most densely populated atoll in the equatorial Pacific. The annual population growth rate has averaged 3.2% per year since 1985, based on census data; most of this growth is the result of immigration from other islands (Cheung 1993).

Table 1 Population of Tarawa Atoll, including major villages and areas (1990 census).

Area		Population
Total North Tarawa		3,648
South Tarawa		
Bikenibeu	5,055	
Eita	1,182	
Teaoraereke	1,677	
Bairiki	2,226	
Other villages	5,788	
Total South Tarawa		15,928
Betio		9,226
Total Tarawa Atoll		28,802

A subsistence economy predominates throughout Kiribati, except in South Tarawa where employment by government and private organizations results in a vigorous cash economy. As a result of employment opportunities in South Tarawa, a large proportion of the residents are not native to Tarawa.

Foreign exchange is supported by the export of labor and copra, the sale of fishing rights, investment income, and foreign aid. Many I-Kiribati citizens train at the local maritime academy and seek employment on foreign merchant fleets as merchant marine seamen. Significant income is also provided by I-Kiribati employed in other countries. Several tuna-fishing nations, notably the United States, Korea, and Japan, pay for access to these rich fishing areas. In the past, sales of phosphate mined from Banaba Island provided substantial income, which is now maintained in income-producing investments.

Local commercial fishing activities include small-scale fishing for tuna, sharks, billfish, and other ocean fish, and lagoon fish including bonefish, silverbiddies, and reef fishes. Additional commercial

fisheries are based on bêche-de-mer, sipunculan worms, the bivalve *Anadara* sp., and several other mollusks.

Data from the 1990 census provide information about the use of the lagoon by Tarawa residents. Table 2 summarizes assets held by households in North and South Tarawa that affect the lagoon. Table 3 summarizes the location of toilet facilities, and Table 4 summarizes the reported places of fishing activity.

Table 2 Assets owned by households in South and North Tarawa.

Asset	Number in South Tarawa	Percentage of Total	Number in North Tarawa	Percentage of Total
Households	3,297	100	552	100
Canoes[1]	810	25	167	30
Boats[2]	385	12	20	4
Skiffs[3]	70	2	11	2
Outboard motors	443	13	26	5
Nets	1,572	48	392	71
No nets	2,264	69	308	56
Coolers	456	14	17	3
Households with pigs	2,578	78	419	76
Households with chickens	1,035	31	336	61

[1]Traditional lagoon canoes.
[2]Outboard motor boats.
[3]Modern versions of traditional canoes, capable of holding motors.

Table 3 Facilities used as toilets by households in South and North Tarawa.

Facility	Number in South Tarawa	Percentage of Total	Number in North Tarawa	Percentage of Total
Households	3,297	100	552	100
Toilet block/communal/homeflush	2,239	68	37	7
Water latrine	392	12	54	10
Lagoon beach	938	28	493	89
Ocean beach	1,059	32	275	50
Other	298	9	179	32

Table 4 Locations of fishing activities engaged in by households in South and North Tarawa.

Location	Number in South Tarawa	Percentage of Total	Number in North Tarawa	Percentage of Total
Households	3,297	100	552	100
On lagoon flat	2,105	64	446	81
In lagoon	1,859	56	497	90
On ocean flat	1,583	48	372	67
In open ocean	768	23	88	16

Cultural, Institutional, and Socioeconomic Context of Tarawa

This section discusses several aspects of the culture of Tarawa that are useful in interpreting the results of our studies. In addition, these aspects are essential to consider in preparing management plans for the lagoon.

Cultural Aspects

The culture of modern Tarawa is a complex amalgam of traditional Kiribati culture and western influences. The ways in which these various influences interrelate varies among families and villages, with pronounced differences between North and South Tarawa.

Kiribati society "is dominated by an ethic of absolute egalitarianism; it is utterly impossible for one person to place himself above another outside the family context" (Geddes et al. 1982). Similarly, attitudes toward externally imposed rules reflect this egalitarian perspective: "There seems to be no such thing as individual crime: everything was seen as a family matter. People were supposed to mind their own business, and in this sense nobody was in any position to tell someone to do this and not do that. To reveal another's misdeeds was a dangerous matter" (Batana et al. 1985).

The basic organizational unit in Kiribati society for management, decision making, and rules has always been the family. The *maneaba*, a council of families represented by respected family elders (*unimwane*), addresses issues outside the family.

Historically, the close knit family served many beneficial purposes, such as joint fishing/collecting expeditions, defense from attack, and efforts to prevent starvation and disease. Another effect, however, was a tendency to be isolated from the external world, including events that might affect the family directly. As a result, news may not be communicated beyond the relatively closed family or *maneaba* society.

With the arrival of Europeans, additional layers of organization were superimposed on the traditional family and *maneaba* structure. Today, the people of Tarawa have elected island councils, a

parliament, and a president. These institutions serve a vital role in linking the people to the external, nonfamilial world of education, health care, financial assistance, development projects, and governance of individual islands and all the islands. These institutions, however, seem to remain external to the family and to the individual. The cultural adaptation to these broader government structures reflects a paternalistic history. The role of these institutions is perceived as simply to provide for the needs or desires of the residents. Beyond this, the activities of the institutions are viewed as separate and of little direct interest to the individual or family (Geddes et al. 1982).

The local Island Councils, likewise, are viewed as merely messengers through which the family can tell the government what it wants or the family can be told about the latest projects "others" are going to do. Since government is separate, it has no obligation to solicit or listen to the views of the people (Geddes et al. 1982). More cynically, many people believe government exists to benefit the people in government and any benefits to the family are incidental (Geddes et al. 1982).

In this context, planning and management must take into account the separation between the individual or family and all other formal structures. The government plans and manages its activities and individuals carry out their own activities. The attitude toward government and government projects also may manifest itself in apathy toward the planning and management efforts of others. An exception to this is *mronron*, a form of temporary cooperative enterprise in which a family or larger group can pool resources for a specific purpose (Geddes et al. 1982). *Mronrons* may offer an opportunity to organize people and capital for enterprise projects as part of the lagoon management plan.

Another aspect of the tradition of individualism and the effect of decades of paternalistic colonial management is a strong tendency to rely on foreign experts (Geddes et al. 1982). The position of the foreign expert is enhanced by his or her familiarity with Western institutions, such as Kiribati's own governmental structure (Geddes et al. 1982).

Institutional Aspects

The government provides technical expertise through a small number of professionals in its agencies. Certain elected officials also have technical expertise. Though most government officials have little background in natural resource planning, the Ministry of Environment and Natural Resources Development (MENRD) has an active environmental planning unit. New, young university graduates are joining the government and providing valuable technical and planning expertise.

The Fisheries Division of MENRD is directly responsible for the fisheries of Tarawa Lagoon and elsewhere in the Republic. The Fisheries Division has been managing the government's programs in the lagoon, and attempting to improve the ability of commercial and subsistence fishers to improve their catch. Fisheries Division programs have been extended to fishing activities in the lagoon and ocean. The Fisheries Division has been active in assisting the fishers to obtain gear, gill nets, boats, and motors, and has been developing offshore fish aggregation devices (FADs) to

improve ocean harvest. In some cases, the Fisheries Division has assisted fishers directly with equipment, technical assistance, or subsidies for costs of new gear, or has supported loan programs, such as that of the Kiribati Development Bank, for gear, boats, and motors.

Socioeconomic Aspects

In the past, accumulating wealth or maximizing cash income was of little interest to the people of Tarawa, because little wealth existed in the economy to accumulate and the people had virtually no material goods on which to spend income (Geddes et al. 1982). That situation is changing as more consumer goods become available for purchase. People who accumulate wealth or high income, however, are often viewed negatively as "trying to be better than the people" (Catala 1957). Another disincentive against individual entrepreneurial or commercial efforts is the cultural practice of *bubuti*, whereby an individual can simply ask for the property of another (the pressure is great to give it). Local people have little experience with the development of individual entrepreneurial efforts, even with substantial technical support from Western-trained advisors. The *mronron*, however, offers a culturally acceptable way of creating enterprise because it typically puts all participants on an equal footing and is intended to help all members get something, rather than allowing one person to gain by making a profit from all others. In Tarawa, enterprises resembling *mronron* include fishers associations organized to pool resources to buy boats or set up other projects.

All these features are undergoing rapid change, especially in South Tarawa. Rapid population growth is increasing population density and weakening historical family structures. This trend is particularly true where many immigrants reside who do not have the same historical connection to the family or the land. Similarly, families or communities with individuals who have been abroad, either for work or education, are being pressured to change from family governance to increased independence.

Returning foreign workers and development assistance projects increase the amount of cash in the family and in the community. The accumulation of consumer goods is taking on new importance as the opportunity for land ownership, the historical measure of wealth, has decreased. As a result of these factors, more cash is available to buy such things as fishing gear. The Kiribati Development Bank and other sources lend money with which to buy boats, motors, and gill nets, so the opportunity to start a commercial fishing enterprise has increased. Today, although commercial fishers make up only 10% of the population, they catch 50% of the fish (Tearo 1993).

The future of Tarawa is uncertain. Although the government has policies intended to shift development and population growth to other islands, immigration continues. Government policies are directed toward reducing family size and fertility rates have decreased, but the population continues to grow. Projections are that South Tarawa's population will swell to roughly 35,000-46,000 in the next 15 years. Even if government population control policies are effective, South Tarawa's population will grow to as many as 43,000 residents (Cheung undated). The already high

pressure on the lagoon will likely increase, not only as the population increases, but also as the population adopts ever higher levels of technology and becomes less bound by traditional restraints.

Environmental Issues

Most of the environmental problems of the lagoon have been recognized for a long time. The goal of our research program was to refine our understanding of these problems and to reveal, if possible, opportunities for solutions. This section briefly discusses some of the major problems identified in previous reports.

Bacterial Contamination

Several reports have described high levels of bacterial contamination in the nearshore waters of the lagoon, caused by defecation on the beach or in the water (Johannes et al. 1979; Naidu et al. 1992. Edible shellfish also are highly contaminated (Johannes et al. 1979). Efforts to control this contamination by installing sewage systems or land-based latrines have met with limited success. The high incidence of diarrhea, other gastrointestinal ailments, and infections may be a result of contact with lagoon water or ingestion of contaminated shellfish, although contaminated water from wells or catchment cisterns is probably the main cause of these diseases.

Overexploitation

Many people are concerned about excessive harvesting of lagoon fish and shellfish. This concern has manifested itself in several ways, including support for this study. A steady increase in the population and in the availability of outboard motor boats and gill nets has significantly contributed to increased effort and total catch. Catching efficiency has also increased substantially with the introduction of gill nets that are more than 1 km long. The splash fishing method (*te ororo*), in which fishers drive fish into long gill nets by splashing the surface of the water with heavy iron bars, may be particularly efficient.

Problems Associated with Causeways

Although causeways have been blamed for several environmental problems, Johannes et al. (1979) did not believe that they had a major influence on circulation or the distribution of pollutants. They predicted, however, that closing the Betio-Bairiki causeway would interrupt the spawning migrations of certain fish, notably bonefish. Because of the importance of this fish in the Tarawa diet, and the apparent reduction in stocks, this topic is given particular attention (Chen et al., this volume; Kimmerer, this volume; Paulay and Kerr, this volume; and Johannes and Yeeting, this volume). In addition, causeways have apparently caused local changes in sediment distribution and have blocked fishers' access to the sea.

Overview of the Research Program

The objectives of the research program were to:

- Assess the status of shellfish and finfish resources in the lagoon
- Identify environmental problems in the lagoon and the possible causes
- Identify opportunities to improve harvests from the lagoon
- Determine the beliefs, attitudes, and use patterns of the human population
- Provide input to the management strategy for the lagoon

The research program included elements that directly addressed potential or known environmental problems, including bacterial contamination and overexploitation of finfish and shellfish resources. It also included supporting elements to permit interpretation and extension of these results, assess the general health of the lagoon, and predict the outcome of management activities. These elements included a circulation model; an assessment of water chemistry, lower trophic levels, and reefs; a household survey; and interviews with experienced fishers.

The research program was conducted by a team of local and expatriate scientists and technicians. The local team, hired for the duration of the project, was trained in most aspects of the project and conducted most of the field work. The expatriate members of the team supervised aspects of the work of the local team, conducted specialized investigations in Tarawa, and were largely responsible for data analysis and reporting results. A laboratory was established at the Atoll Research Programme of the University of the South Pacific facility in Teaoraereke.

Field work was conducted using a 5-m outboard boat equipped with a global positioning satellite (GPS; Trimble TransPac II) receiver for accurate (ca. 30 m) navigation. The correct datum was not available for the Tarawa chart at the beginning of the study. Therefore the positions determined by GPS had to be corrected so that they would accurately match chart positions. We used the Guam 1966 datum in the GPS receiver and determined the correction by comparing charted and GPS positions of the Bikeman navigation beacon and the Betio and Bairiki piers. Positions for routine sampling are given in Table 5.

Table 5 Corrected GPS positions of samplins stations, Tarawa Lagoon.

Sample Type		Latitude	Longitude
Beach seine	B01	1°21.61′	173° 5.01′
Beach seine	B05	1° 21.39′	173° 3.17′
Beach seine	B10	1° 20.82′	172° 57.27′
Beach seine	B13	1° 19.77′	172° 59.16′
Beach seine	B18	1° 20.28′	173° 1.73′
Beach seine	B22	1° 21.87′	173° 8.18′
CTD	C	1° 25.95′	172° 55.16′

Table 5 Corrected GPS positions of samplins stations, Tarawa Lagoon (cont.).

Sample Type		Latitude	Longitude
Datasonde 2	D2-14	1° 23.29′	173° 5.85′
Datasonde 2	D2-15	1° 25.01′	172° 55.54′
Datasonde 2	D2-16	1° 22.81′	172° 59.18′
Datasonde 3	D3-14	1° 24.55′	172° 55.94′
Datasonde 3	D3-15	1° 23.31′	173° 5.87′
Datasonde 3	D3-16	1° 23.41′	173° 6.23′
Finfish	F1	1° 32.54′	172° 54.95′
Finfish	F2	1° 32.54′	172° 57.95′
Finfish	F3	1° 27.54′	172° 54.95′
Finfish	F4	1° 27.54′	172° 57.95′
Finfish	F5	1° 27.54′	172° 0.95′
Finfish	F6	1° 23.04′	173° 56.95′
Finfish	F7	1° 22.54	173° 0.45′
Finfish	F8	1° 23.54′	173° 4.95′
Shellfish	H1	1° 23.04′	173° 7.2′
Shellfish	H2	1° 35.79′	173° 58.01′
Incubation	I	1° 20.93′	172° 58.87′
Plankton	L02	1° 22.48′	173° 7.74′
Plankton	L03	1° 22.15′	173° 7.43′
Plankton	L05	1° 22.1′	173° 6.73′
Plankton	L10	1° 20.12′	173° 0.67′
Plankton	L8	1° 20.98′	173° 2.17′
Plankton	L9	1° 20.54′	173° 1.48′
Microbiology	MA0	1° 19.84′	173° 0.57′
Microbiology	MA1	1° 20.21′	173° 1.6′
Microbiology	MA2	1° 20.15′	173° 1.43′
Microbiology	MA3	1° 20.11′	173° 1.35′
Microbiology	MA4	1° 20.08′	173° 1.32′
Microbiology	MA5	1° 20.04′	173° 1.25′
Microbiology	MA6	1° 20.01′	173° 1.13′
Microbiology	MA7	1° 19.96′	173° 1.03′
Microbiology	MA8	1° 19.92′	173° 0.83′
Microbiology	MA9	1° 19.89′	173° 0.73′
Micro time ser	MB1	1° 19.94′	173° 0.93′
Microbiology	MC0	1° 21.75′	173° 7.34′
Microbiology	MC1	1° 21.89′	173° 8.2′
Microbiology	MC2	1° 21.91′	173° 8.09′
Microbiology	MC3	1° 22.06′	173° 8.03′
Microbiology	MC4	1° 22.08′	173° 7.91′
Microbiology	MC5	1° 22.08′	173° 7.73′
Microbiology	MC6	1° 22.01′	173° 7.62′
Microbiology	MC7	1° 21.85′	173° 7.64′
Microbiology	MC8	1° 21.9′	173° 7.49′
Microbiology	MC9	1° 21.78′	173° 7.34′
Bairiki pier	N1	1° 19.76′	172° 58.78′
Bikeman	N2	1° 23.07′	172° 59.67′

Table 5 Corrected GPS positions of samplins stations, Tarawa Lagoon (cont.).

Sample Type		Latitude	Longitude
Plankton	P01	1° 22.34′	172° 59.95′
Plankton	P02	1° 23.04′	172° 57.45′
Plankton	P03	1° 25.54′	172° 55.45′
Plankton	P04	1° 29.04′	172° 55.45′
Plankton	P05	1° 34.04′	172° 57.25′
Plankton	P06	1° 31.04′	172° 58.45′
Plankton	P07	1° 28.24′	172° 59.45′
Plankton	P08	1° 25.54′	172° 59.95′
Plankton	P09	1° 23.04′	173° 7.35′
Plankton	P10	1° 22.04′	173° 3.45′
Reef Survey	R01	1° 27.86′	172° 54.96′
Reef Survey	R02	1° 27.87′	172° 56.96′
Reef Survey	R03	1° 27.92′	172° 58.34′
Reef Survey	R04	1° 25.83′	172° 55′
Reef Survey	R05	1° 23.54′	172° 55.35′
Reef Survey	R06	1° 23.18′	172° 58.53′
Reef Survey	R07	1° 23.33′	172° 59.21′
Reef Survey	R08	1° 23.34′	173° 1.3′
Reef Survey	R09	1° 23.2′	173° 3.39′
Reef Survey	R10	1° 23.3′	173° 5.17′
Shoal 1		1° 23.30′	173° 5.172′
Shoal 2		1° 23.04′	173° 7.203′
Shoal 3		1° 23.20′	173° 3.393′
Shoal 4		1° 22.54′	173° 5.402′
Shoal 5		1° 21.44′	173° 2.221′
C1		1° 27.856′	172° 54.962′
C2		1° 27.87′	172° 56.96′
C3		1° 27.917′	172° 58.339′
C4		1° 25.829′	172° 55.001′
C5		1° 23.542′	172° 55.354′
C6		1° 23.18′	172° 58.527′
C7		1° 23.326′	172° 59.205′
C8		1° 23.343′	173° 1.297′
C9		1° 23.196′	173° 3.393′
C10		1° 23.304′	173° 5.172′
C11		1° 23.037′	173° 7.203′
C12		1° 25.337′	173° 5.355′
C13		1° 26.362′	173° 2.906′
C14		1° 27.881′	173° 1.279′
C15		1° 27.848′	172° 59.902′
C16		1° 30.526′	172° 59.76′
C17		1° 32.478′	172° 58.089′
C18		1° 32.46′	172° 56.931′
C19		1° 34.183′	172° 57.547′
C20		1° 35.206′	172° 54.804′
C21		1° 37.104′	172° 56.496′

Table 5 Corrected GPS positions of samplins stations, Tarawa Lagoon (cont.).

Sample Type	Latitude	Longitude
C22	1° 32.487′	172° 54.234′
C23	1° 32.538′	172° 55.354′
C24	1° 20.185′	172° 54.299′
C25	1° 23.036′	173° 5.72′
Transect 1	1° 19.947′	172° 59.454′
Transect 2	1° 20.115′	173° 0.454′
Transect 3	1° 20.597′	173° 1.454′
Transect 4	1° 21.269′	173° 2.454′
Transect 5	1° 21.638′	173° 3.454′
Transect 6	1° 21.831′	173° 4.454′
Transect 7	1° 22.104′	173° 5.454′
Transect 8	1° 22.23′	173° 6.454′
Transect 9	1° 22.107′	173° 7.454′
Temaiku	1° 22.343′	173° 9.078′
Bikenibeu	1° 21.917′	173° 7.608′
Bangantebure	1° 21.846′	173° 6.14′
Abarao	1° 21.78′	173° 5.672′
Eita E	1° 21.771′	173° 5.204′
Eita W	1° 21.541′	173° 4.704′
Tangintebu	1° 21.38′	173° 4.294′
Ambo	1° 21.391′	173° 3.147′
Banraeaba	1° 20.591′	173° 2.254′
Antenon	1° 20.191′	173° 1.504′
Nanikai	1° 19.913′	172° 60.134′
Betio	1° 21.268′	172° 56.604′
L3	1° 22.88′	172° 56.529′
L4	1° 22.869′	172° 58.221′
L5	1° 22.858′	172° 59.919′
L6	1° 22.93′	173° 6.794′
L7	1° 22.898′	173° 1.66′
L8	1° 22.883′	173° 3.353′
L9	1° 22.822′	173° 4.964′
L10	1° 26.752′	172° 56.181′
L11	1° 26.749′	172° 57.776′
L12	1° 26.744′	172° 58.511′
L13	1° 26.744′	173° 0.998′
L14	1° 30.622′	172° 55.64′

Circulation and the Value of Passage Channels to Water Quality of Tarawa Lagoon

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Circulation and the Value of Passage Channels to Water Quality of Tarawa Lagoon

By

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Abstract

A link-node circulation and water quality model was used to simulate the movement of water and substances in the lagoon. The model was calibrated against measured tidal stage, flows through passes between islets, and salinity. The mean residence time of lagoon water as estimated by the calibrated model was 9.5 days. This value is in good agreement with other estimates.

We used the model to estimate the distribution of phosphate and enteric bacteria in the lagoon, assuming that the human population was the only source. Resulting phosphate concentrations in the lagoon were well below observed concentrations, supporting previous estimates that human inputs are a minor contribution to the nutrient budget of the lagoon. To match the data collected in the lagoon in 1993, phosphorus uptake rates in the lagoon on a per-unit-area basis must sometimes be positive and sometimes be negative (indicating release), possibly because of changes in equatorial upwelling. Simulated concentrations of enteric bacteria agreed reasonably well with measured concentrations. Concentrations were highest on sand flats adjoining heavily populated islets and were below detection limits in the lagoon more than 1 km from the sand flat.

We used simulated tracers to investigate the importance of passes to circulation in the lagoon. Closing all of the passes in North Tarawa had only a minor effect on bacterial contamination on nearby sand flats, because strong tidal flushing and die-off of bacteria are the principal modes by which concentrations are reduced. Removing causeways to open old passes in the southeastern corner of the atoll or along South Tarawa would improve water quality of the relatively isolated southeastern region by no more than 11%. Closing passes in northern islands may not reduce water quality, but may harm fish migration. We argue that the effect of these passes on water quality and on the movement of sediments is minor compared to the influence of the large opening along the western margin of the lagoon.

Introduction

The water quality and productivity of Tarawa Lagoon are controlled largely by tidal exchange with the ocean (Kimmerer and Walsh 1981). The ocean serves as a source of nutrients to the lagoon biota and as clean water for flushing the lagoon. Ocean water enters the lagoon over the western reef and

through the passes that remain open between the atoll islands. Kimmerer and Walsh (1981) estimated that the contribution of these passes to flushing of the lagoon was slight, but this estimate was based on a single measurement of flows in the channels and a single estimate of lagoon residence time.

In this study, a circulation and water quality model of the lagoon was developed based on information from various field studies. The model was used to depict the general patterns of circulation in the lagoon and to calculate the expected concentrations of nutrients and enteric bacteria from the human population. In addition, it was used to quantify the importance of the passage channels on lagoon water quality, especially in the southeastern sector.

The southeastern sector of the lagoon was of particular concern because it is isolated from the central lagoon by a series of reefs and flow restrictions. This sector of the lagoon is the most turbid, has the highest plankton concentrations, and is most likely to be contaminated with bacteria (Kimmerer, this volume; Danielson et al., this volume). In addition, this region has numerous dead reefs, which suggests that the turbidity of the lagoon water may have increased in the past (Paulay and Kerr, this volume). We used the model to determine whether the closure of two passes in this area (Bonriki-Tanaea and a small, meandering pass through the apex of the atoll at Temaiku) (Figure 1) might have had a significant effect on water quality.

Mathematical Model

Model Description

We used the link-node model described by Chen and Orlob (1975). The basic assumptions of the link-node model are that the water body is vertically mixed and that Coriolis force is negligible. Vertical salinity gradients were uncommon except after a heavy rainfall, which can lead to as much as a 1 practical salinity unit (psu) difference between the surface and bottom (Kimmerer, this volume). Therefore, the assumption that the lagoon is vertically mixed is reasonable for neutrally buoyant substances. The Coriolis parameter is small because of the low latitude. Low flow velocities also reduce the effect of the Coriolis force.

The model represents a water body as a series of nodes connected by links. Figure 2 shows the grid system adapted for Tarawa Lagoon, which has 193 nodes and 444 links. The model has two modules: hydrodynamic and water quality. The hydrodynamic module calculates the flows occurring in the links. It solves the Saint-Venant equations, written for a link as:

$$\frac{\partial u}{\partial t} + \frac{u\partial u}{\partial x} + g\frac{\partial h}{\partial x} + gS_e - gS_w = 0 \qquad (1)$$

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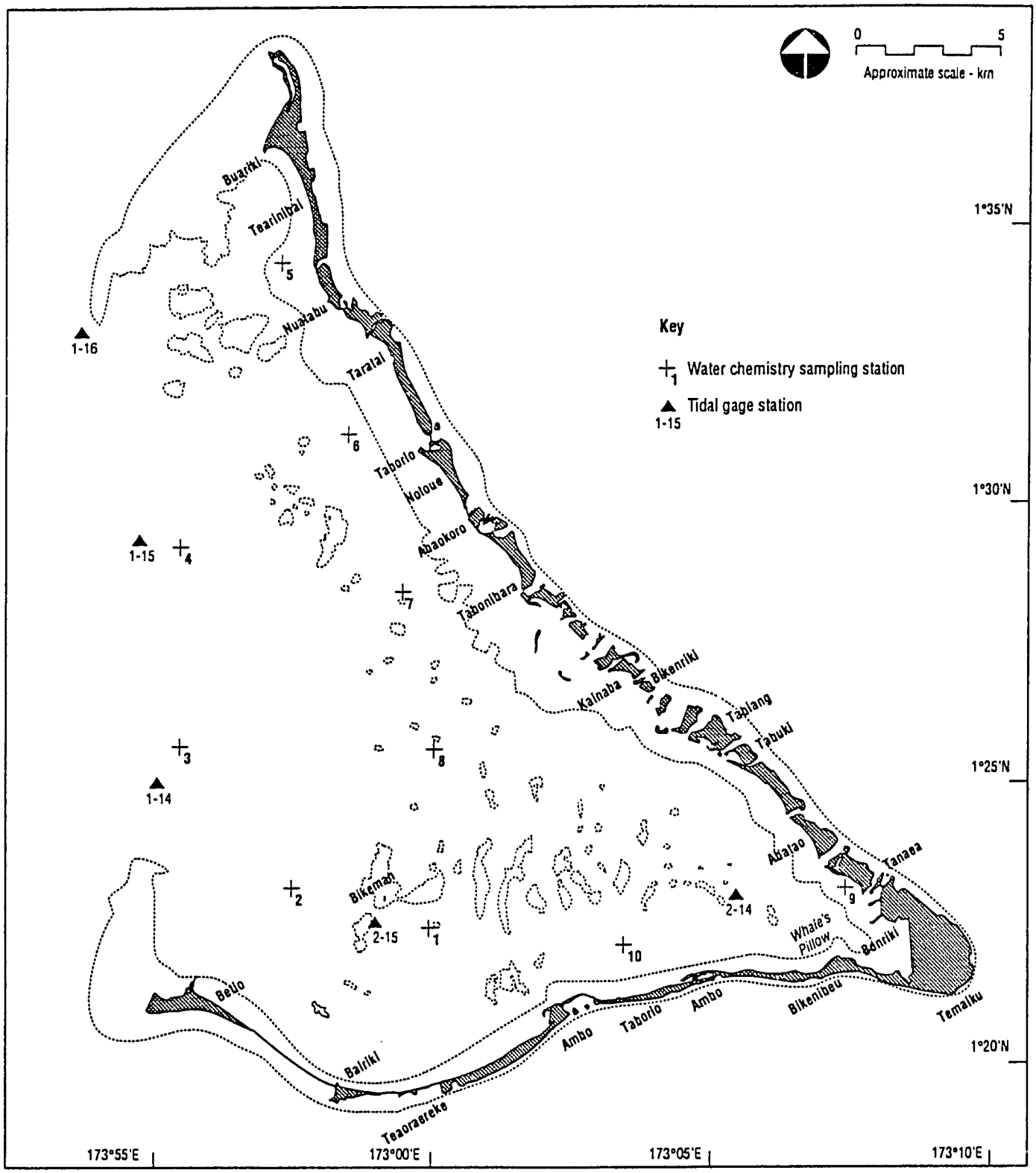

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Figure 1 Map of Tarawa Lagoon showing location of villages, passes, tidal gages, and sampling stations used for circulation study in 1993. All locations are approximate. Station coordinates are given in Introduction to the Study (this volume).

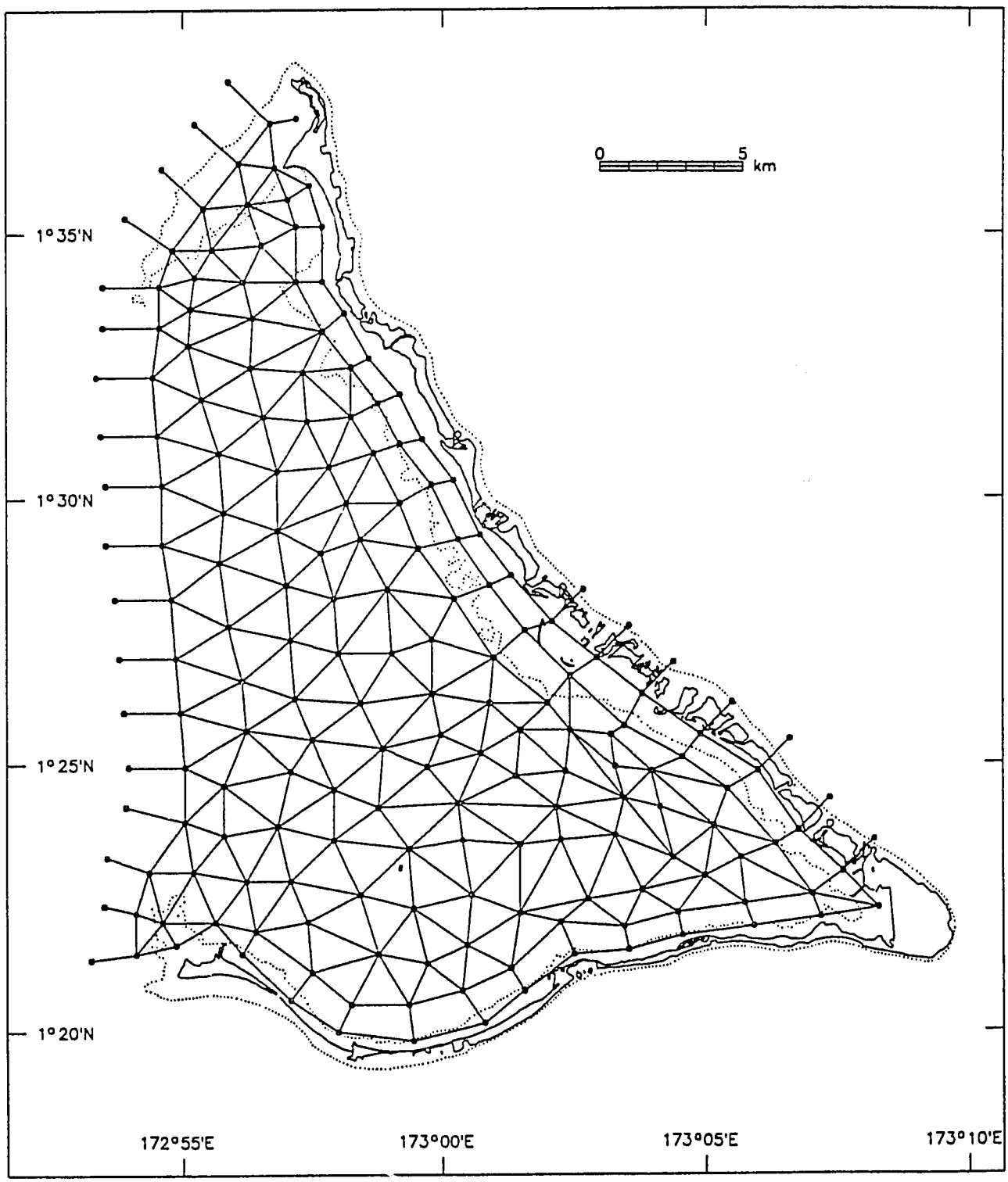

Figure 2 Grid system used for link-node circulation model of Tarawa Lagoon.

where u is vertically integrated mean velocity in the x direction, x is distance along the link, g is acceleration of gravity, h is height of water surface above a reference plane (i.e., mean sea level [msl]), S_e is channel resistance (a function of Manning's friction coefficient), and S_w is wind stress. This equation was transformed into a form for numerical solution as detailed in Chen and Orlob (1975). The solution of the equation provides the current velocities in all links at a given time step. The current velocity multiplied by the cross-sectional area of the link gives the flow in the link. A mass balance (continuity) equation is then solved to determine the new water elevation for the node:

$$h_j(t) = h_j(t-1) - \frac{\Sigma q}{A_j \, \Delta t} \qquad (2)$$

where $h_j(t)$ is water surface elevation of node j at time t, $h_j(t-1)$ is surface elevation of node j at time $t-1$, $\sum q$ is the sum of flows entering or leaving a node in the links, A_j is the surface area of node j, and Δt is the time step of calculation.

The calculations were performed with a time step of 20 sec. The outputs are time series of flows in each link and surface elevations at each node. These data were integrated over 0.5-hr periods and saved in a hydrodynamic file for subsequent water quality calculations.

The water quality module uses flow data to calculate the advection of pollutants from one node to another. It calculates the dispersion of pollutants between nodes, and sink and source terms of substances associated with chemical and biological reactions occurring in nodes. The output is the time concentration of water quality variables for each node every .5 hr. The model was calibrated by adjusting exchange with the ocean to match mean salinity in the lagoon and adjusting dispersion coefficients to match the observed salinity distribution.

The basic model as described by Chen and Orlob (1975) has been modified for this application. The program can now accept multiple boundary nodes (i.e., the nodes along the western reef of the lagoon) and can run for an extended period to incorporate several neap-spring tidal cycles. The model allows the nodes near shore to go dry at low tide.

Input Data

Input to the model includes the following: 1) the positions and dimensions of links and nodes, 2) the tide specified at the boundary nodes along the western reef, 3) tide and wave setup on the ocean side of passage channels, 4) wind speed and direction at the water surface, 5) net precipitation (i.e., precipitation – evaporation), and 6) loading rate of substances to receiving nodes.

The positions and dimensions of links and nodes were determined from the bathymetry of the lagoon. The bathymetry for the southern two-thirds of the lagoon was taken from a chart updated in 1959 by the Defense Mapping Agency Hydrographic/Topographic Center. A less detailed British

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Admiralty Chart was used for the northern one-third of the lagoon. For navigation safety, the depths were purposely underestimated according to Gilmour and Colman (1990).

Meteorological and tidal data are presented in the Introduction to the Study. Tidal constants for Betio Harbor were obtained from the National Tidal Facility at Flinders University, Australia. These constants were used to generate tides in the model at Betio Harbor.

Hydrolab Datasonde 3® recorders, which measure changes in water level, were deployed at stations along the western reef during 16-30 September 1992. Because the time lag in tides between these stations was negligible, the tidal stage at Betio was imposed on all nodes on the western boundary of the lagoon.

The wind waves are typically from the east (80%) and will increase the water elevation when they break on the seaward reef of North Tarawa. This wave setup is typically between 5% and 10% of the significant wave height (Consulting Environmental Engineers 1986). Wave heights can vary considerably; 78% of the time the height is between 0.1 and 1.5 m. For modeling, a 10-cm setup was assumed to represent the average wave climate in the ocean. During periods of westerly winds, however, the wave setup on the seaward side of North Tarawa may be reduced to nearly zero.

Precipitation and other meteorological data were obtained from the New Zealand Meteorological Service. Precipitation was assumed to apply equally over the entire lagoon. Other freshwater inputs to the lagoon are negligible; groundwater enters from the islands following heavy rain, but the area of islands is so small compared to that of the lagoon that groundwater input can be adjusted.

Evaporation rate was calculated according to Sverdrup et al. (1942):

$$E = 0.142\ W\ (e_w - e_a) \tag{3}$$

where e_w is vapor pressure (mb) of water at sea surface temperature, e_a is vapor pressure (mb) of the air, and W is wind speed in meters/second. Water vapor pressure was calculated from sample data on sea surface temperature averaged over the lagoon. Pan evaporation data from the weather service did not correlate well with the calculated evaporation rates, but averaged 5.0 mm compared with 5.7 mm by the above method. The monthly net precipitation was negative in the latter half of 1992, whereas in 1993 it was positive (Introduction to the Study).

Model Calibration

The objective of model calibration is to match the simulated results to the observed data as closely as possible. The model coefficients adjusted for calibration are Manning's friction coefficient for hydrodynamics, and dispersion, exchange, and decay constants for water quality.

Rigorous calibration could not be performed because the data were not synoptic. Not all of the boundary conditions were measured during the current velocity and water quality measurements. Reasonableness of the results was judged by comparing the pattern of spatial variation, maximum and minimum values, and theoretical considerations. The available field data were from Kimmerer and Walsh (1981), Groves and Yeeting (1981), Consulting Environmental Engineers (1986), and measurements of channel velocities and distributions of salinity, nutrients, and bacterial contamination made for this study from April 1992 to October 1993.

Tidal Propagation

Figure 3 compares the simulated and measured tides at Station 2-14 (southeastern corner) on 14 June 1993. The bottom half of Figure 3 is a comparison between the tide predicted at Betio and the simulated tide at Station 2-14. The phase lag as the tide propagates from west to east is about 14 min. The tide amplified as it moved inward, causing the high water to increase by 5 to 10 cm.

Current Velocities

Figure 4 presents simulated flood and ebb current velocities during a spring and neap tide. A large portion of the tidal prism is supplied through the 20-m-deep shipping channel where the currents are strongest. The maximum currents predicted here during a spring tide are 100 cm s^{-1}. This number is near the 80 cm s^{-1} maximum currents measured by Gilmour and Colman (1990). Kimmerer and Walsh (1981) recorded current velocities of up to 29 cm s^{-1} in the channel on 10 October 1978.

The currents in the southeastern sector are considerably less. The maximum current simulated near Station 9 was 9 cm s^{-1}. In this vicinity, Consulting Environmental Engineers (1986) and Gilmour and Colman (1990) measured peak velocities of 13 cm s^{-1} and 10 cm s^{-1}, respectively. The tidal excursion (i.e., the distance traveled by a water particle over a tidal cycle) at this location is about 1.6 km during a spring tide and 0.9 km during a neap tide.

Flows in Passes

The passes between the islets are dry at low water and submerged at high water. They slope downward from the ridge on the seaward side to the lagoon side of the islets. The ridge is about 10 cm above msl (amsl) (Gilmour and Colman 1990), so flow is possible only when the water surface has exceeded this elevation.

For modeling, the passes were considered links. One end is connected to a seaward node that has the same elevation as the ridge, and the other is connected to a node located on the lagoon sand flat.

We assumed that the passes are 1 km long with bottoms that drop evenly from the seaward side to the lagoon. The bottom edge of the lagoon sand flat is assumed to be at mean low-water spring tide, which is 0.85 m below msl. This assumption means that the flats will drop 0.95 m from the ocean to the lagoon side. The sand flats are wider toward the north and have smaller slopes. Using these dimensions and elevations, an average depth, referenced to msl, was computed for the section between the islets.

The passes were assumed to be rectangular channels. Multiple adjacent channels were lumped together. Hydraulic radius equaled channel width because the width was much larger than the depths. The Manning's coefficients of bottom friction were set to 0.020.

Several investigators have measured flows in the passes between Tanaea and Buota, and between Betio and Bairiki before the causeway was constructed. Groves and Yeeting (1981) measured current speed and flow rate in the Tanaea-Buota channel during a spring tide on 4 February 1981, when wind came from the east. The data were compared with simulated currents in the passage channel during a spring tide and a neap tide (Figure 5). A wave setup of 10 cm on the ocean reef was assumed.

The speeds of the observed and simulated currents were similar, with maximum speeds of both near 50 cm s^{-1}. Both curves followed the same pattern. During the flood tide, water initially flowed from the ocean into the lagoon. After the high tide propagated from the western boundary to the passage channel, the water level in the lagoon side of the channel was high enough to slow the flow and at times reverse it. During the neap tide, all simulated currents flowed from the ocean to the lagoon (Figure 5). The water level in the lagoon was not high enough to cause a flow reversal. Consulting Environmental Engineers (1986) also measured maximum speeds of 40 to 50 cm s^{-1} in the Tanaea-Buota channel with flow stopping at high water.

The simulated volumetric flow rates were close to measured values. During a spring tide, the simulated volume transport into the lagoon over a tidal cycle was 0.77×10^6 m^3 for the high high tide, close to the measured value of 0.7×10^6 m^3 (Groves and Yeeting 1981). The measured volume transport during the neap tide was 1.1×10^6 m^3, while the simulated volume transport was 0.64×10^6 m^3 for the higher of the two high tides.

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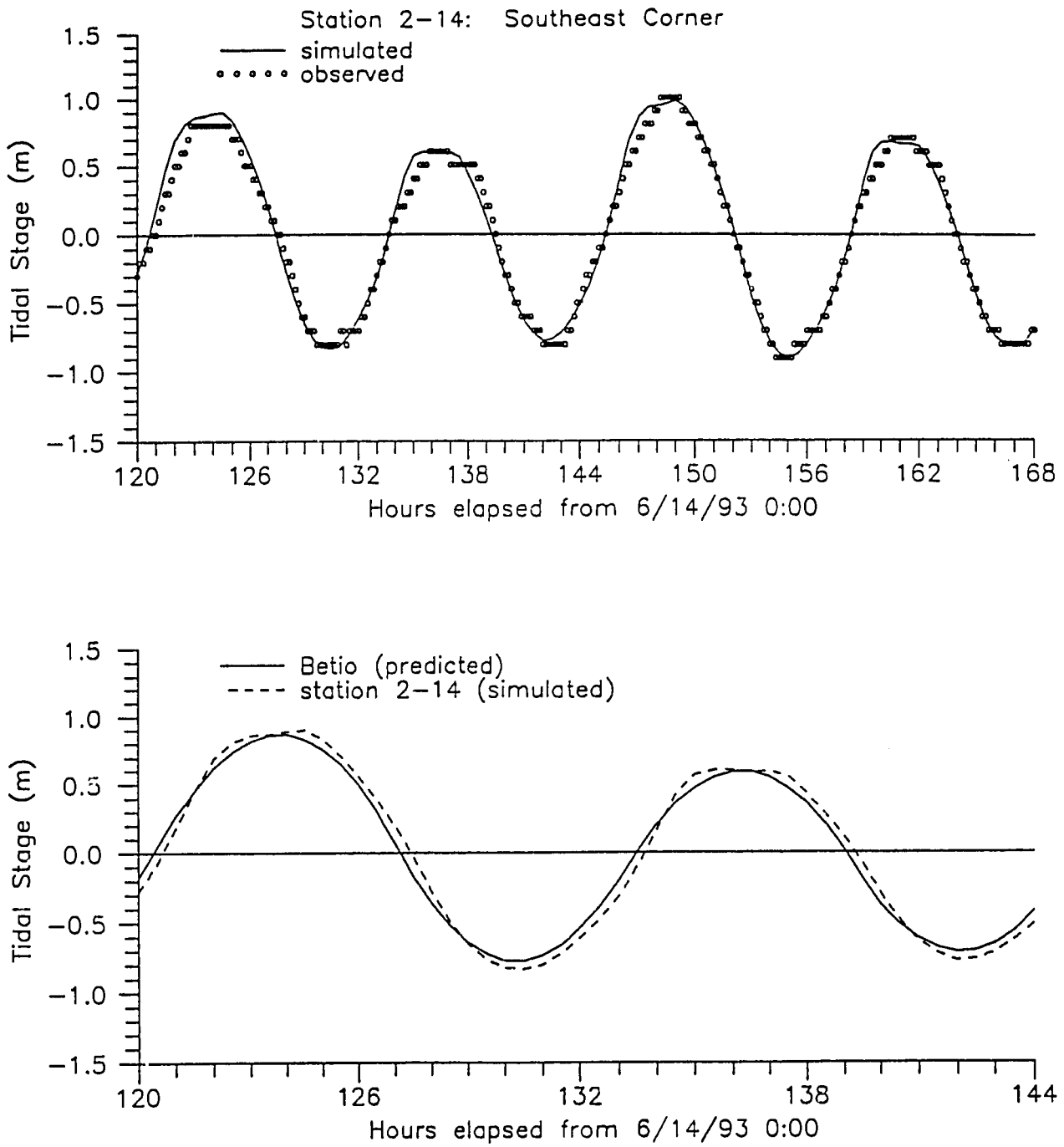

Figure 3 Comparison of simulated tidal stage at Station 2-14 (Figure 1) in the southeast corner with (top) observed tidal stage at Station 2-14 and (bottom) the ocean at Betio.

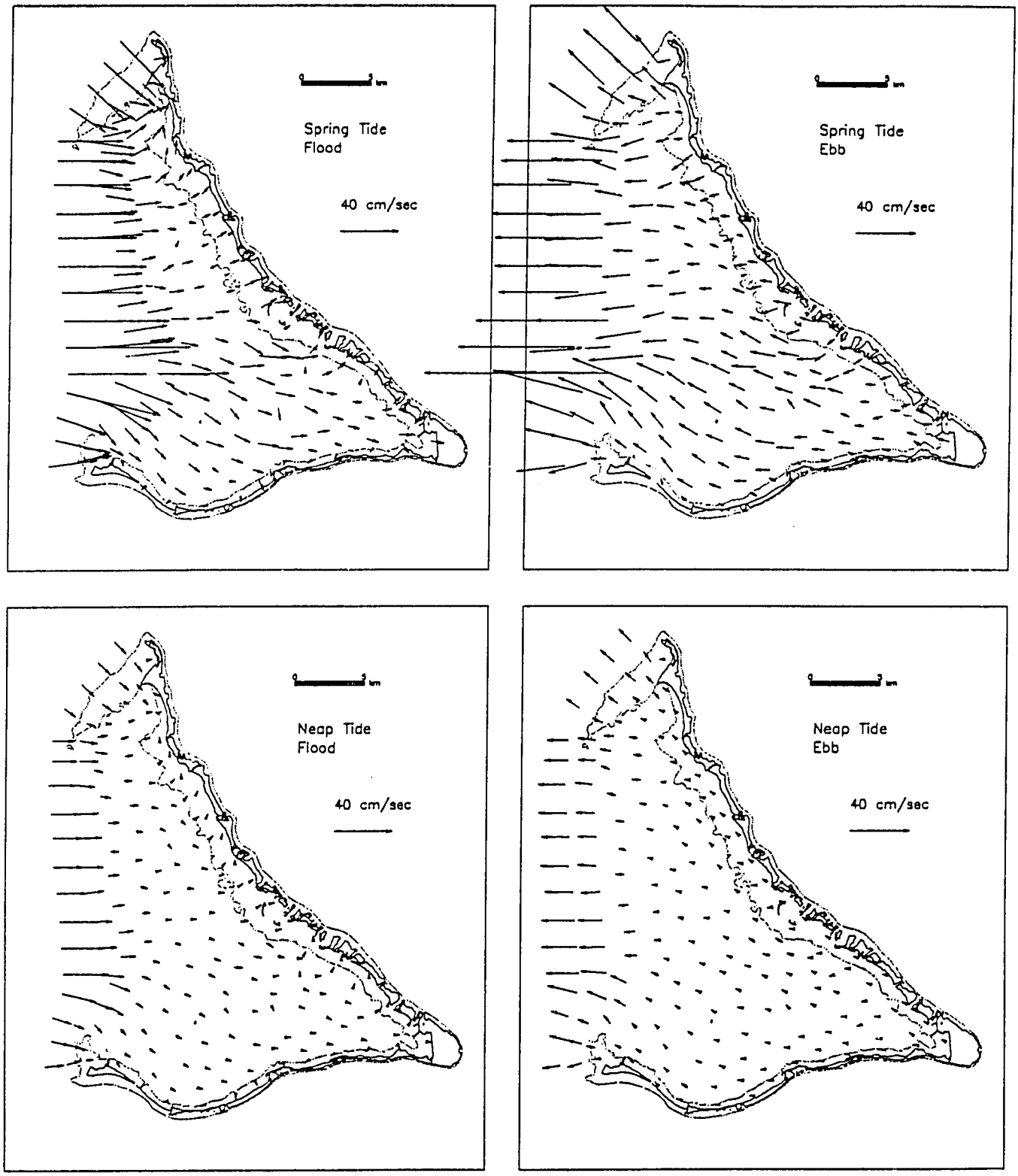

Figure 4 Simulated current patterns for spring and neap tides in Tarawa Lagoon.

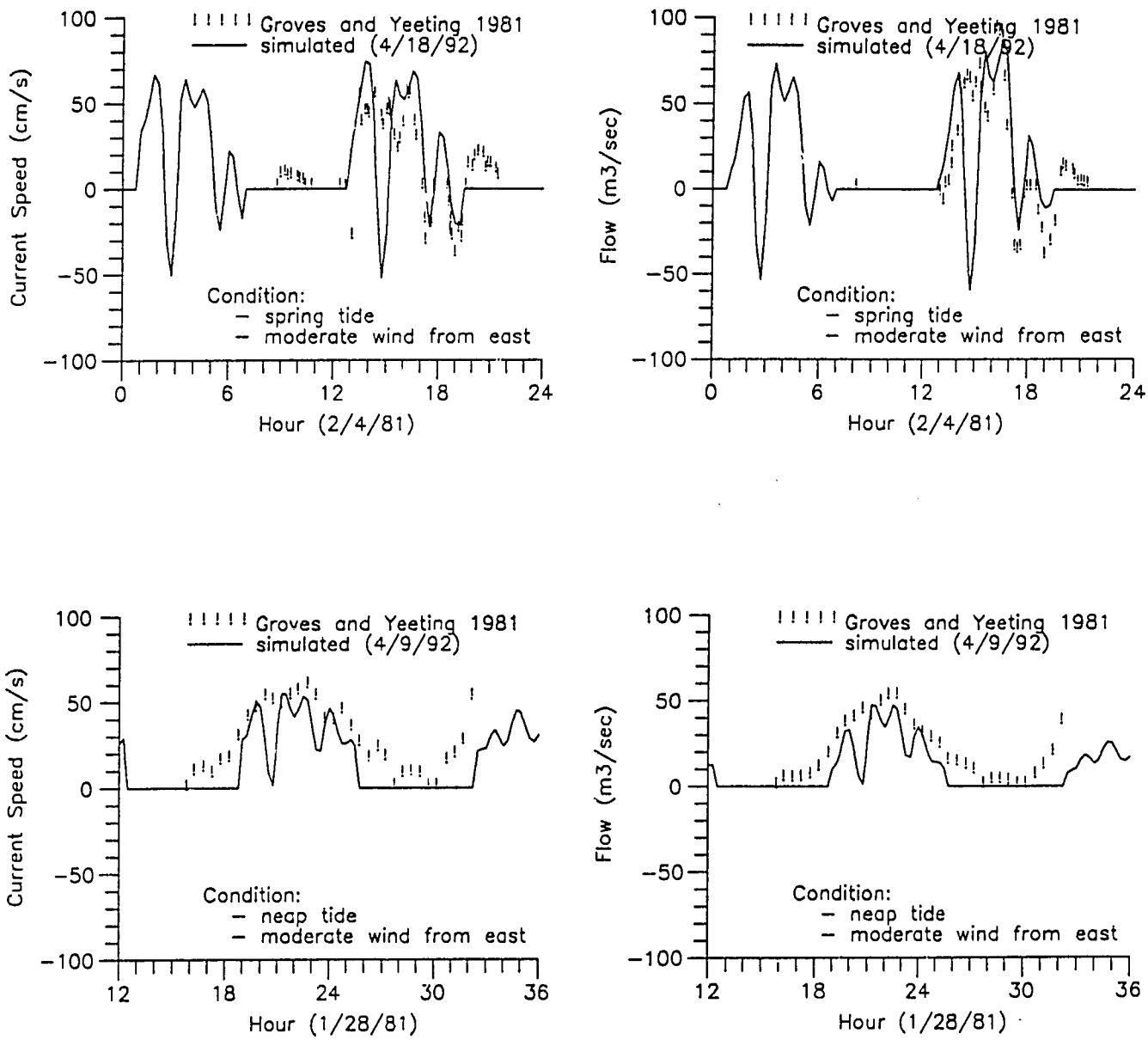

Figure 5 Simulated (line) and observed (symbols) (Groves and Yeeting 1981) current speed and flow rate in Tanaea-Buota channel for spring and neap tides with moderate wind from the east. Positive values are flows and negative values are outflows.

On 17 October 1993, currents were measured in the Tanaea-Buota channel (75 m wide) when the prevailing wind came from the west at about 5 m s^{-1} during the morning high tide, and during the afternoon high tide, when the prevailing wind came from the southwest at about 3.4 m s^{-1}. Currents were measured using a recording flow meter and volume fluxes calculated according to Maragos (1978). The flow in the morning moved uniformly from the lagoon to the ocean, with a maximum current of 80 cm s^{-1}. The estimated volumetric flow was 1.3 x 10^6 m^3. The maximum current in the evening tide, after the wind abated, was 75 cm s^{-1} from the ocean to the lagoon for the first 1.5 hr, then 60 cm s^{-1} from the lagoon to the ocean for the next hour. Net fluxes were 0.25 x 10^6 m^3 in and 0.26 x 10^6 m^3 out.

For the model to generate a net flow from lagoon to ocean on the order of 1.3 x 10^6 m^3 per high tide, a westerly wind of 4.5 m s^{-1} and no wave setup on the oceanside reef were required. This is qualitatively consistent with the observation of uniform outward flow in the morning and reversing flow during the afternoon of 17 October 1993.

Before the causeway was constructed, flows were measured over the Betio-Bairiki channel in 1978 by Kimmerer and Walsh (1981) and in 1981 by Kimmerer (unpublished). Both sets of measurements used movements of drogues and visible plumes of discolored water to estimate water velocity. Under prevailing winds from the northeast, this channel has little wave setup. In 1978, the volume transport was estimated at 2 x 10^6 m^3 into the lagoon during a spring tide. In 1981, it was estimated at 3 x 10^6 m^3 during a spring tide and 1.2 x 10^6 m^3 during a neap tide, both out of the lagoon. These fluxes are low for this wide (3.25 km) channel, as compared to estimates for the much narrower channels of North Tarawa.

Table 1 summarizes the simulated volume fluxes for all the northern channels averaged over a neap and spring tidal cycle. The total inflow averages 9.8 x 10^6 m^3 per high tide. The general tendency for tidal influx to be higher than outflow through passes may be important for fish migration. Ocean-spawned fish larvae, which have limited swimming ability, may require this flow to drift into the lagoon.

Table 1 Simulated mean volume fluxes per high tide for northern channels.

Link	Into Lagoon (million m^3)	Out of Lagoon (million m^3)
940 (Tabonibara)	1.72	0.03
942 (Kainaba)	1.76	0.06
944 (Nabeina)	3.32	0.10
946 (Tabiang-Tabiteuea)	0.96	0.06
948 (Tabiteuea-Abatao)	0.47	0.04
950 (Abatao-Buota)	1.05	0.08
951 (Buota-Tanaea)	0.53	0.04
Total	9.81	0.40

Salinity

Salinity in the lagoon is controlled by net precipitation (i.e., rainfall - evaporation) and exchange with the ocean. We used salinity to check model calibration and calculate residence time. Dispersion coefficients in the model were adjusted to obtain a match with the observed salinity. An accurate simulation of the salinity distribution means that the model can correctly simulate the transport of any other dissolved substance in the lagoon. The accuracy of simulation of particulate matter (sediment, bacteria) depends on the sinking rate of the particles; movement of free-living bacteria in the water is probably fairly close to that of dissolved substances, while movement of sediment is probably poorly represented.

Figure 6 presents the simulated daily average salinity distribution on 26 May 1993; observed depth-averaged salinity data are shown in parentheses. The observed data are not synoptic, having been taken throughout most of the day. In this sampling program, most samples were taken over the western reef during the flood tide and in the interior lagoon during an ebb.

Agreement is good for most portions of the lagoon. The largest error is in the northern area, where the model overpredicts the exchange. This error may be due to the poor resolution of bathymetric data. Evidently the northwest end of the barrier reef is intertidal, not submerged as indicated in the bathymetric data. The circulation in that section of lagoon is restricted to almost the same degree as in the southeastern elbow.

Salinity distribution patterns observed on other dates during this study for other dates were similar. Figure 7 shows the paired comparisons of simulated and observed salinities for seven dates. Data collected on 26 November 1992 were not used because the salinity gradient reversed as rainfall increased, bringing observed and measured salinity close to oceanic values. On three of the dates, samples were taken at all ten stations. On the other four dates, detailed transects were taken across the southern half of the lagoon; four to five evenly spaced data points were taken from this series to avoid unduly weighting the results by the southern sector. The correlation coefficient for salinity prediction is 0.7, and the standard error of the estimate is 0.2 practical salinity units (psu). The largest source of error may be the approximation used to estimate the evaporation rate.

Model Applications

Residence Time

Residence time is defined as the mean time that a dissolved tracer remains in the lagoon or in a subarea of the lagoon. Long residence times suggest poor flushing characteristics and sluggish exchange with the ocean. If residence time is long, nutrients from the ocean are more likely to be depleted and pollutants will remain in the lagoon longer.

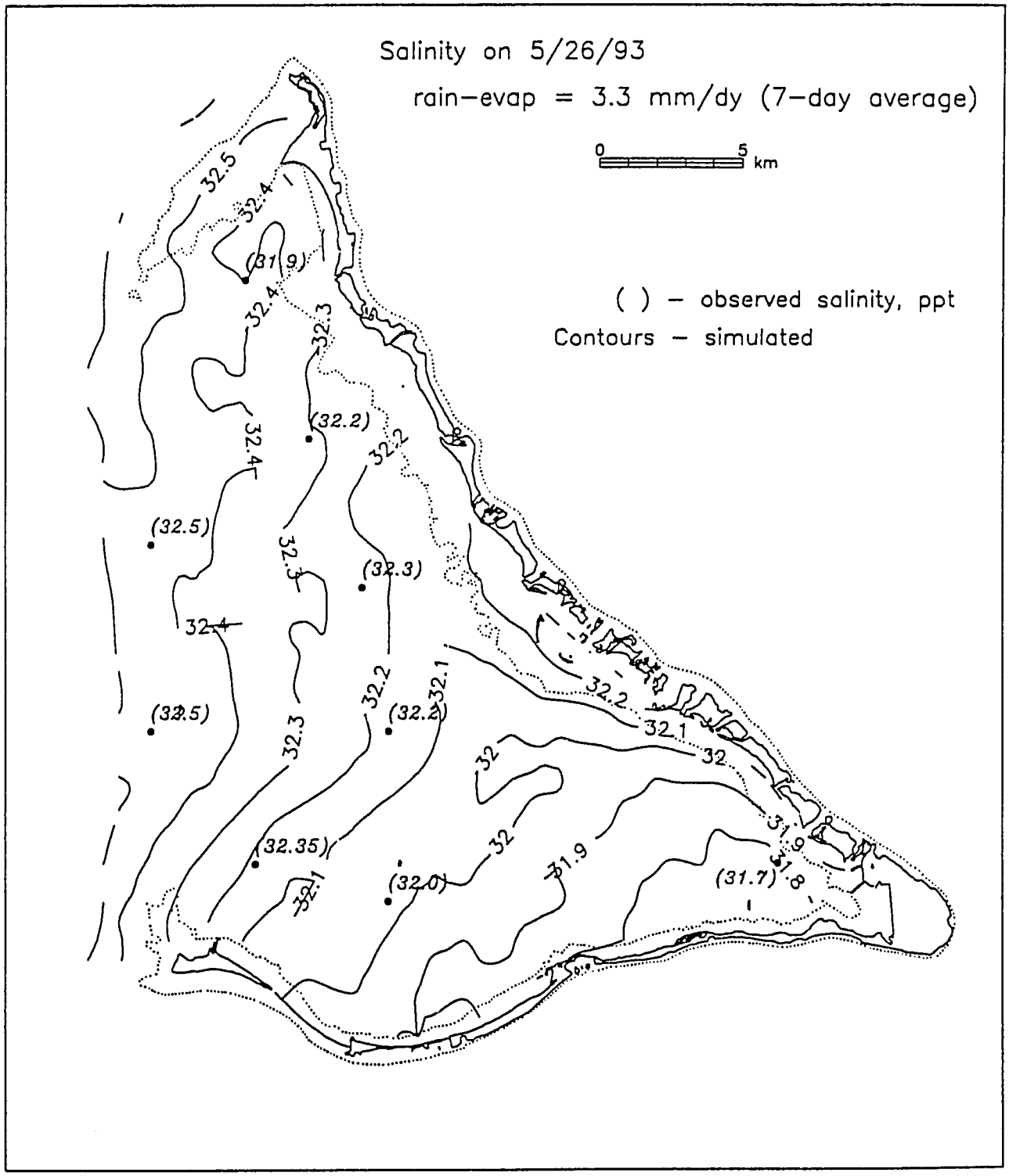

Figure 6 Observed and simulated salinity distribution in Tarawa Lagoon on May 26, 1993.

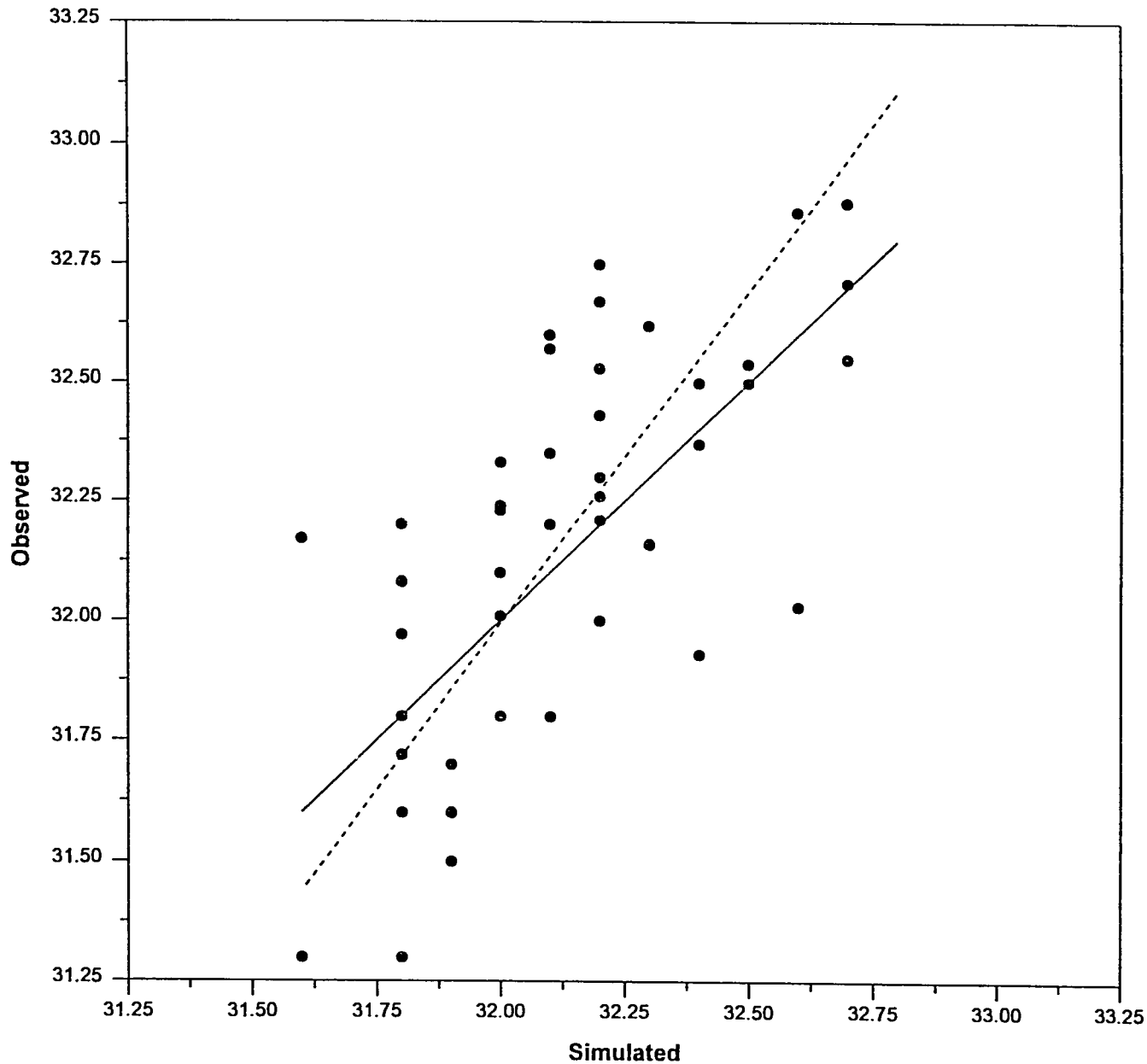

Figure 7 Composite comparison of observed and simulated salinities at various stations and times. Solid line, geometric mean regression, r=0.69; dashed line, 1:1.

A simulation was used to calculate the freshwater residence time for the entire lagoon. The principal assumption is that freshwater mixes vertically and does not alter lagoon circulation. Residence time was determined by dividing the total volume of fresh water in the lagoon by the volumetric rate at which rain is deposited to the surface:

$$RT = \frac{Z\,(S_o - S)}{(r-e)\,S_o} \tag{4}$$

where Z is the mean depth in meters, r is rainfall in meters/day, e is evaporation in meters/day, S_o is ocean salinity, and S is the average salinity calculated by the model.

The residence time calculated from the model was 9.5 days. Using the standard error of 0.2 ppt in model predictions of salinity, the uncertainty in residence time is from 6 to 13 days.

Similar calculations were made using the salinity data averaged volumetrically over the lagoon for each sampling date (Kimmerer, this volume). These data were used iteratively in a non-steady-state version of equation 4 to estimate residence time for each date. Values ranged from 3 to 13 days with a median of 5 days. Thus, the model calculations are in substantial agreement with calculations based on the data.

Phosphate

The model was used to evaluate phosphate uptake rates of the lagoon. The first step was to calculate the potential contribution of phosphate from human waste. For this simulation, the phosphate concentration of ocean water and uptake rate in the lagoon were set to zero. The per capita phosphorus load was assumed to be 22.5 mg-at d^{-1} or 0.70 g P d^{-1} (Feachem et al. 1983), and the phosphorus from human waste was assumed to be in the form of dissolved phosphate. The Tarawa population was projected to 30,000 for 1992. Half of the population was assumed to use the beaches on the lagoon side for defecation or to use toilets on the lagoon side, contributing to groundwater input. Half of the 1992 population of each island was multiplied by the per capita load, and the result was input to the nearest node of the model grid. The total phosphate load amounted to 673 g-at d^{-1} (21 kg P d^{-1}).

The simulated phosphate concentration in the lagoon was generally less than 0.006 μg-at L^{-1} (0.19 μg P/L) for distances greater than 2 km offshore. This concentration is less than 4% of the observed average lagoon concentration (Kimmerer, this volume). We conclude that phosphate in the lagoon came from the ocean rather than from human waste.

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The next step was to estimate the phosphate uptake rate that would result in a reasonable match between the simulated and observed phosphate concentration in the lagoon. For this simulation, the phosphate concentration of ocean water was estimated from the concentrations measured at Stations 3 and 4 on the western reef and was assumed to be constant for the month preceding the sampling date. Fluctuations in ocean phosphate probably indicate variability in equatorial upwelling. Concentrations ranged from 0.08 to 0.26 μg-at L^{-1} (2.5 to 8.1 P μg/L) (Table 2). Two uptake rates, one for all nodes south of latitude 1 25'N and one for the northern nodes, were entered as parameters and then adjusted until simulated concentrations in each sector matched observed values.

Table 2 Phosphate concentration of ocean and lagoon and estimated biological uptake rates of phosphate in Tarawa Lagoon.

	PO_4, μg-at L^{-1}			Uptake, mg-at $Pm^{-2}d^{-1}$	
Date	Ocean	Lagoon	SE Lagoon	South Nodes	North Nodes
26 Nov 1992	0.24	0.08	0.00	0.130	0.130
18 Mar 1993	0.26	0.23	0.15	0.040	-0.030
16 Apr 1993	0.09	0.17	0.14	-0.010	-0.060
26 May 1993	0.20	0.18	0.14	0.030	0.010
17 Jun 1993	0.11	0.10	0.13	-0.002	0.025
1 Jul 1993	0.08	0.25	0.29	-0.100	-0.070
Average	0.16	0.17	0.15	0.015	0.001

The calculated uptake rates of phosphate were positive for some periods and negative (indicating release) for other periods (Table 2). On average, the uptake rates are near zero, indicating that the lagoon is neither a significant sink nor a source of phosphate. Note that phosphorus is probably not the limiting nutrient; it therefore can be useful in tracing water masses (Kimmerer and Walsh 1981). In contrast, nitrogen is difficult to deal with because it is often reduced below detection limits, has numerous forms, and is usually altered by N- fixation and denitrification, neither of which was measured.

Coliform Contamination

The inhabitants of Tarawa customarily defecate along the beaches (Danielson et al., this volume), which contaminates lagoon waters and shellfish. To simulate the fecal coliform levels in the lagoon, coliform emission to the lagoon was estimated using the same population data used for phosphate loading. The emission rate was 2.5 x 10^{10} most probable number (MPN) per capita per day (Feachem et al. 1983). The total fecal coliform input to the lagoon was 7.5 x 10^{14} MPN/day.

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The coliform concentration of the ocean water was set to zero. The die-off rate was 0.11 hr^{-1} (or 2.4 d^{-1}) according to Kelley (1993), which means 50% of the coliform will die in 6 hr. This rate falls within the range of 0.48 to 8 d^{-1} reported in a review of other studies (Bowie et al. 1985). Figure 8 compares the simulated and observed coliform distribution on lagoon sand flats. The levels were as high as 1,700 MPN/100 ml at localized areas of Teaoraereke and as high as 5,000 MPN/100 ml at Bikenibeu.

The observed data show that the level of coliform bacteria away from the sand flats is less than 20 MPN/100 ml, the detection limit. Simulated data also indicate that coliform contamination is low in the lagoon away from sand flats, and that high concentrations occur mainly at nodes along the shore of southern islands with high population densities. Because of the low population and, therefore, the low coliform input, the nodes along the shore of the north island chain were not as contaminated. The coliform concentration of nodes about 1 km offshore of the south island chain was reduced to nearly zero, as observed, by dilution, dispersion, and die-off.

Importance of Passes

The model was used to calculate the percentage of water contributed by the passes between islands at various parts of the lagoon. For this simulation, a tracer concentration of 100 mg L^{-1} was imposed on the water entering the lagoon through all passage channels in the north island chain. Other water had a tracer concentration of zero.

Approximately 25% to 30% of the water in the southeastern sector is derived from the channels (Figure 9). The contribution of channel flows to the sand flats bordering the northern channels can be as high as 50%.

The model was used to evaluate the impact of opening or closing the northern channels on fecal coliform concentrations on northern sand flats. Opening a channel would reduce the concentrations by about 10% or less according to simulations (Figure 10). Apparently, the flushing action provided by the channels is small compared to the mixing provided by ebbing and flooding of water over the sand flats and the natural die-off of coliform bacteria.

The model was also used to evaluate how the local residence time of the elbow at the southeastern corner of the lagoon could change for four different channel configurations. The first case considered was the existing configuration, where the northern channels from Tabonibara to Tanaea are open, and the Tanaea-Bonriki and southern channels are closed. The other three cases considered were all channels closed, the Tanaea-Bonriki channel and an old channel at Temaiku at the southeastern apex open (total width of 225 m), and all South Tarawa channels open (total width of 4,725 m). Zero wave setup was assumed for the Betio-Bairiki passage, which is oriented away from prevailing waves, and a 10-cm setup was assumed for all other channels.

A tracer was introduced at a constant rate to the node in the southeastern corner, and the model was run to a steady-state condition. The residence time was then determined by dividing the total tracer mass within the southeastern area by the dosing rate.

Table 3 presents the simulation results. Closing all the channels would increase the residence time by 0.4 days, reducing the local circulation and increasing the concentration of pollutants in the area by about 6%. Opening the channels near the apex of the atoll would improve local circulation slightly, reducing pollutant concentrations by about 11%, whereas opening the channels in South Tarawa would have little effect.

Table 3 Simulated residence times and contaminant concentrations at elbow for different passage channel configurations.

Case	Residence Time in Days	Normalized Contaminant Concentration
1. Base Case (existing configuration)	6.4	1.00
2. Close all channels	6.8	1.06
3. Open channels near apex	5.7	0.89
4. Open south channels	6.2	0.97

Sediment Movement

While using this model, we did not directly address the movement of sediments. We can, however, address sediment transport by using the results of the modeling and field studies. The major concern is whether closing passes near the southeastern elbow has had a significant impact on sediment accumulation in that region (Paulay and Kerr, this volume).

In general, sediment movement is affected by wind-driven stirring and mixing. We have shown that the effect of these causeways on residence time in the elbow is small, implying that closing these passes probably has not significantly affected the westward movement of sediments under tradewind conditions. Flows in the passes reverse with westerly winds, however, which also have the greatest fetch and therefore the greatest effect on resuspension in the elbow.

We therefore calculated the amount of sediment exported annually through the Tanaea-Bonriki and Temaiku passes in the elbow under westerly wind conditions. The sediment is assumed to be mostly calcium carbonate. Particulate inorganic carbon concentration in the elbow had a maximum value of 40 μg-at L^{-1}, or about 13 ppm calcium carbonate, in 1978 (Johannes et al. 1979). Maximum extinction coefficient at Station 9 was about 0.6 m^{-1}, corresponding to a total particulate content of 2.5 ppm from a study of an enclosed bay in Hawaii (Smith et al. 1981, Figure 31). Under westerly winds the sediment content of the water might be higher, and we consider 25 ppm a conservatively high value.

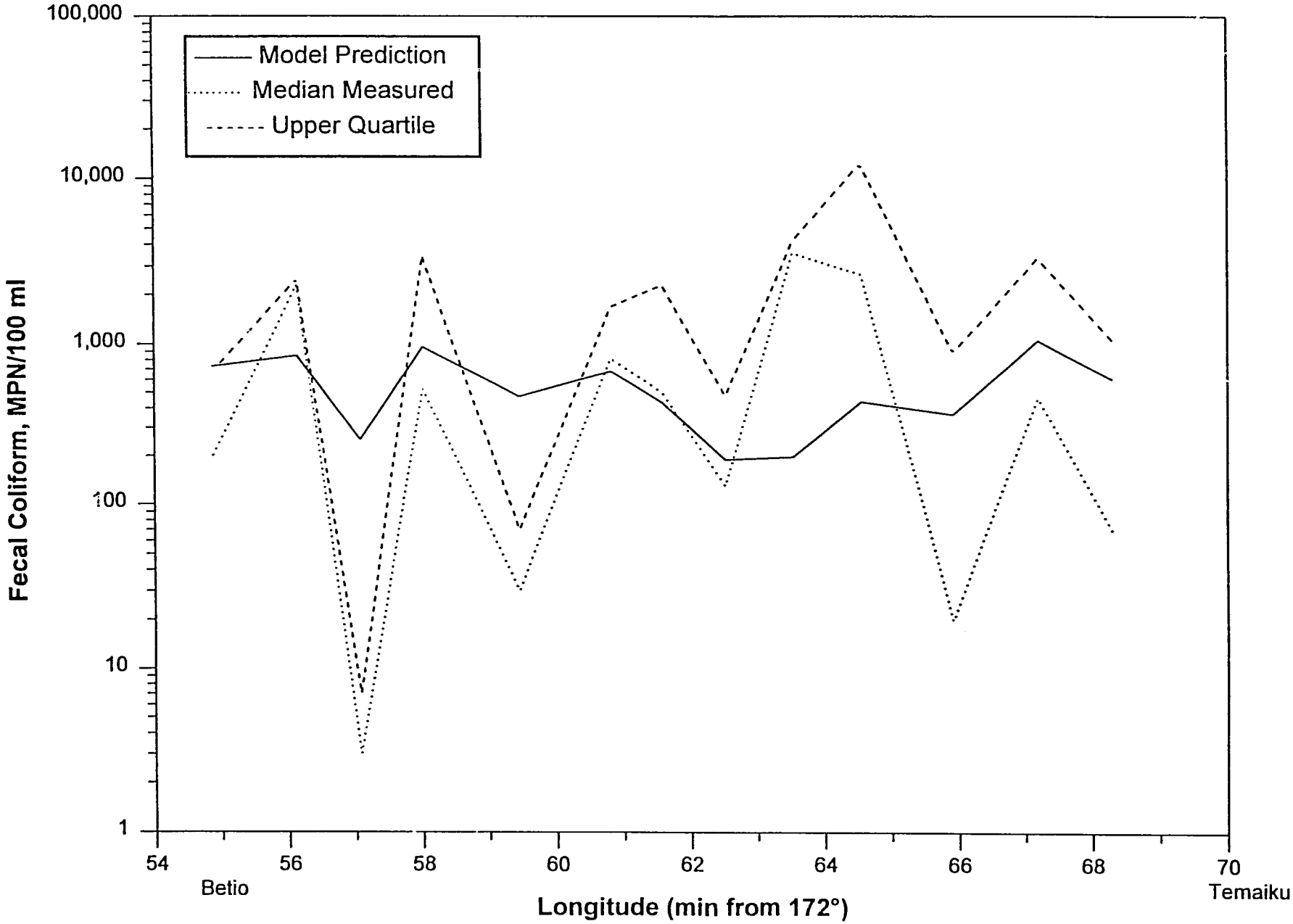

Figure 8 Observed and simulated coliform distribution west to east along the South Tarawa middle lagoon sand flat.

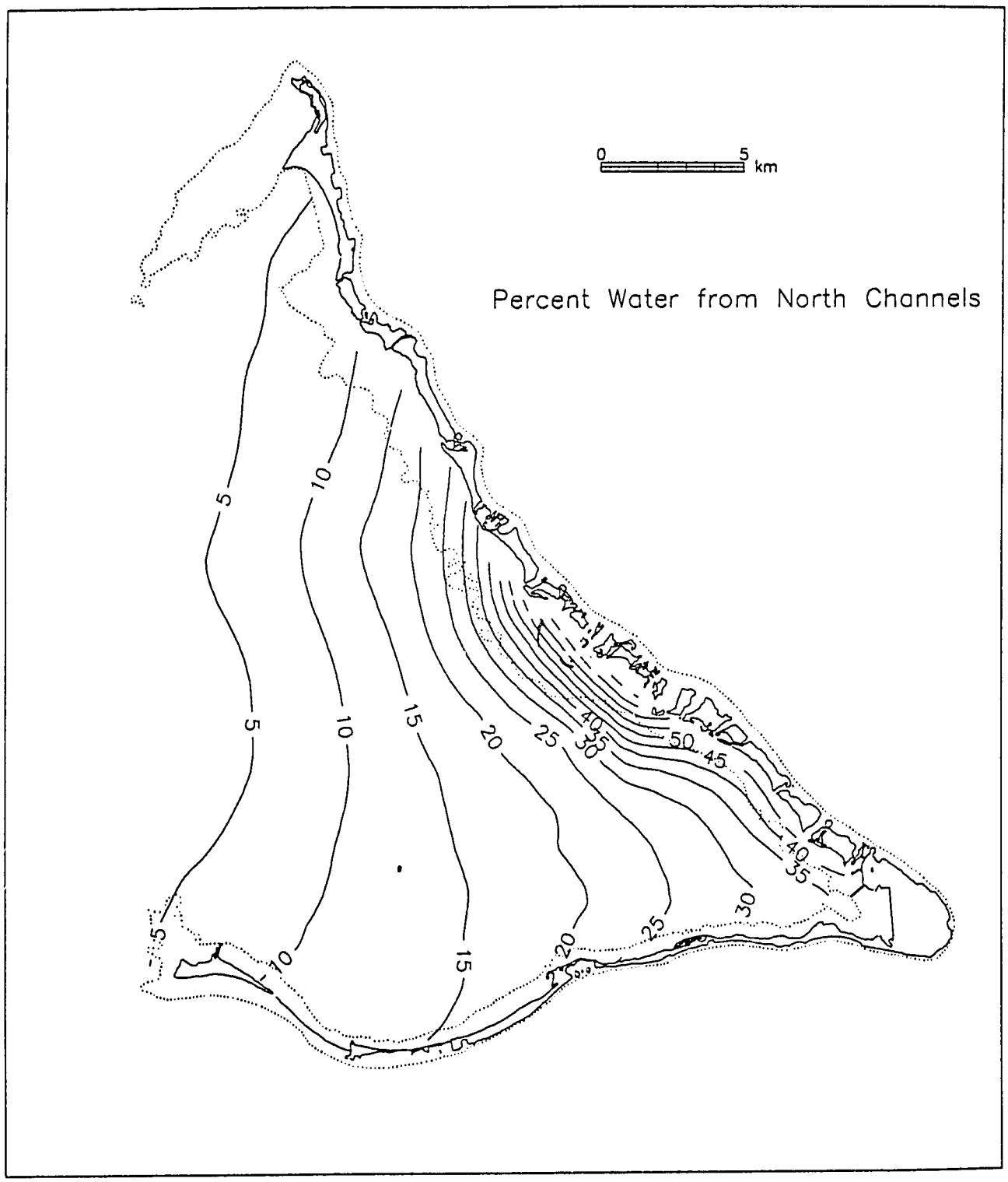

Figure 9 Percentage of contribution of water from flows through the northern passage channels.

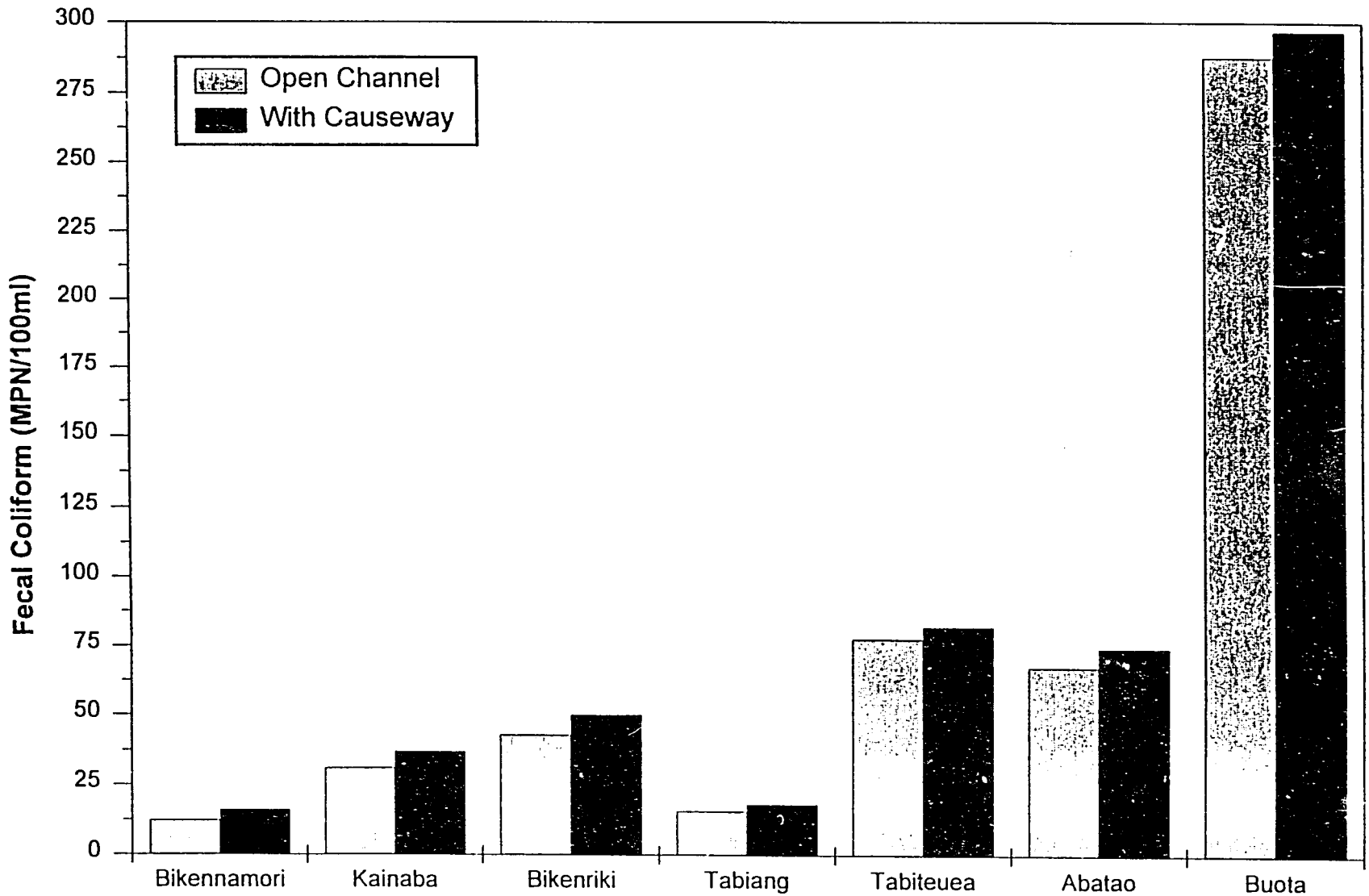

Figure 10 Effects of blocking northern passage channels on coliform levels on the northern Tarawa Lagoon reef flat.

About 10^6 m^3 would be exchanged per tidal cycle, and the area of this region is about 25 x 10^6 m^2. Westerly winds at speeds of more than 4 m s^{-1} occurred on an average of 16 d y^{-1} during 1948-1992. We assume a sediment density of about 50%. If no sediment were produced, the mean excess rate of removal of sediment would be equal to the sediment load in the outflowing water divided by the surface area affected. This calculation gives about 0.06 mm per year, or about 3 mm of removal in 50 years.

This rate of sediment removal would be equivalent to the accumulation that has resulted from blocking these passes. The total amount is inconsequential and would be undetectable if the area were resurveyed. Therefore, we conclude that the closure of these passes during the last 50 years has not caused significant shoaling or increased suspended sediment.

Discussion

Model calibration, particularly against salinity, gave a reasonable degree of confidence in model outputs related to mixing. The residence time determined using the model, 9.5 days, agreed within measurement error with that determined directly from the salinity data. It is also close to the value of 11 days determined during dry season measurements in 1978 by Kimmerer and Walsh (1981).

One of the greatest concerns in Tarawa Lagoon is the effect that causeways may have had on the lagoon, particularly on water quality in the southeastern corner. Our model simulations showed that opening passes near the elbow that were previously blocked by causeways would reduce residence time by only about 11%, and that opening up southern passes would have even less effect. The reasonable match of modeled and observed salinity data strongly suggest that residence time calculations are sufficiently accurate to reach this conclusion. Thus, tidal currents over the western reef are the dominant source of ocean water to the lagoon, even in the southeastern corner.

We have concluded that most of the phosphate in the lagoon comes from the ocean, not from human input. This conclusion also applies to nitrogenous nutrients and reinforces the conclusion of Kimmerer and Walsh (1981) that human waste has a minor influence on the nutrient budget of the lagoon (Kimmerer, this volume).

The variability in calculated phosphate uptake rates contrasts with the results of Kimmerer and Walsh (1981), who reported high uptake rates based on measurements during 1 week of the dry season. The difference may be caused by large variations in rainfall, variation in uptake related to reduced primary productivity resulting from high cloud cover, or variability in oceanic supply rate.

Measurements of enteric bacterial contamination in nearshore and offshore waters (Danielson et al., this volume) indicate low concentrations in lagoon water and high concentrations onshore, particularly in densely populated areas. Model results are in qualitative agreement with these calculations. The main reasons for the steep gradient in bacterial concentrations from the shore to the lagoon are the intense mixing that occurs on each tide and the die-off of bacteria in lagoon water.

Closing channels has no effect on bacterial concentration because of this strong mixing, and lagoon water and ocean water are equally uncontaminated. Thus, opening existing causeways would have little influence on bacterial contamination in any area.

Water Chemistry and Lower Trophic Levels

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Water Chemistry and Lower Trophic Levels

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Abstract

Water chemistry and plankton abundance and biomass were determined during 1992-1993 at stations throughout Tarawa Lagoon. Residence time in the lagoon based on salinity measurements is in agreement with values determined using the circulation model. Measurements of nutrients, oxygen, and chlorophyll show no evidence of eutrophic conditions in any part of the lagoon. Tarawa Lagoon is characterized by relatively low levels of nutrients and moderate levels of plankton biomass. Nutrient concentrations are sometimes at least as high in the lagoon as in the surrounding ocean, suggesting a more variable environment than previously reported.

Chlorophyll and zooplankton biomass were variable throughout the study, but no seasonal pattern was noted. Chlorophyll, particulate matter, and zooplankton biomass were elevated in the lagoon; chlorophyll and particulate matter concentrations were highest in the eastern part of the lagoon.

Primary productivity was estimated at about 22 gC m^{-2} y^{-1}, and zooplankton production at about 8 gC m^{-2} y^{-1}. Assuming reasonable relationships between fishery yield and zooplankton production, the plankton in the lagoon supports a moderate portion of the fish and shellfish in the diet of Tarawa's human population, the rest of which must be supported by benthic or oceanic production.

Ctenophores (comb jellies) were abundant in the lagoon, particularly in the southern part. In spite of their high biomass, however, ctenophore predation removes only a small part of the zooplankton production.

Introduction

The purpose of this study was to examine water quality as it relates to ecosystem effects (public health aspects are dealt with by Danielson et al., this volume) and assess the condition of lower trophic levels (i.e., plankton) in the lagoon. This study expanded on the conclusions of a previous study, which was based on a single 2-week visit in the dry season (Kimmerer and Walsh 1981), by including a variety of additional parameters. We examined nutrient chemistry, salinity patterns, and dissolved oxygen to assess the state of the lagoon and the likely human influence. In addition, the abundance, biomass, and production of lower trophic levels were examined to measure the productivity of the lagoon and its potential fishery yield.

Most of the concern over water quality in Tarawa Lagoon stems from the hazard to public health from bacterial contamination. Concern has also been voiced that the input of human waste, together with the isolation of parts of the lagoon because of the construction of causeways, could result in eutrophication or other undesirable conditions. The study by Kimmerer and Walsh (1981) showed that most of the nutrient input to the lagoon was from the ocean, and that human waste was a minor source of nutrients. Productivity was argued to be relatively high in Tarawa Lagoon because of its location in the equatorial upwelling region, rather than because of human effects. Furthermore, causeways were considered to have had a minor influence on circulation in the lagoon, and therefore on the inputs of nutrients and other substances. Because the previous study was so limited, however, additional investigations were deemed necessary to fully resolve the importance of human inputs.

Methods

Data presented here are from three sets of samples: 1) transects comprising 10 stations around the lagoon sampled on eight dates from June 1992 to July 1993 (Plankton transects; Figure 1); 2) samples from Stations 1 and 8 collected on a more frequent basis (Time series stations); and 3) several transects across the southern half of the lagoon, sampled mainly to measure salinity. During each plankton transect, the two stations over the western reef (Stations 3 and 4) were sampled during a rising tide to obtain samples close to oceanic conditions. Not all of the methods described below were used in all sample sets.

At each station, a profile for temperature, salinity, and dissolved oxygen was taken with a Seabird Seacat conductivity-temperature-depth recorder (CTD). This instrument was set to take readings every 10-30 cm as it was dropped through the water. Data were downloaded to a computer at the end of every survey, then averaged into 1-m bins or for the entire water column. The CTD was calibrated at the factory before deployment to Tarawa.

Residence time of lagoon water was calculated using data on salinity distributions throughout the lagoon on seven dates (data from November 1992 were not used because the salinity gradient was too small). A lagoonwide mean of salinity was calculated by aggregating area and volume from each node of the circulation model (Chen et al., this volume) closest to each of the sample locations. Weighted mean salinity was calculated from vertically averaged data from each of these stations, weighted by volume. Mean surface temperature for each station was calculated similarly, weighted by area.

Residence time in the lagoon was calculated from a freshwater balance as discussed in Chen et al. (this volume), using net evaporation rates calculated from area-averaged lagoon surface temperature and daily meteorological conditions, and the proportion of fresh water from the salinity data. Values of residence time for each date were determined, along with a value for the entire period, using the following method. Daily meteorological data were used together with daily surface temperatures estimated from a sine-curve fit to the data (Introduction to the Study, Figure 4) to obtain daily values

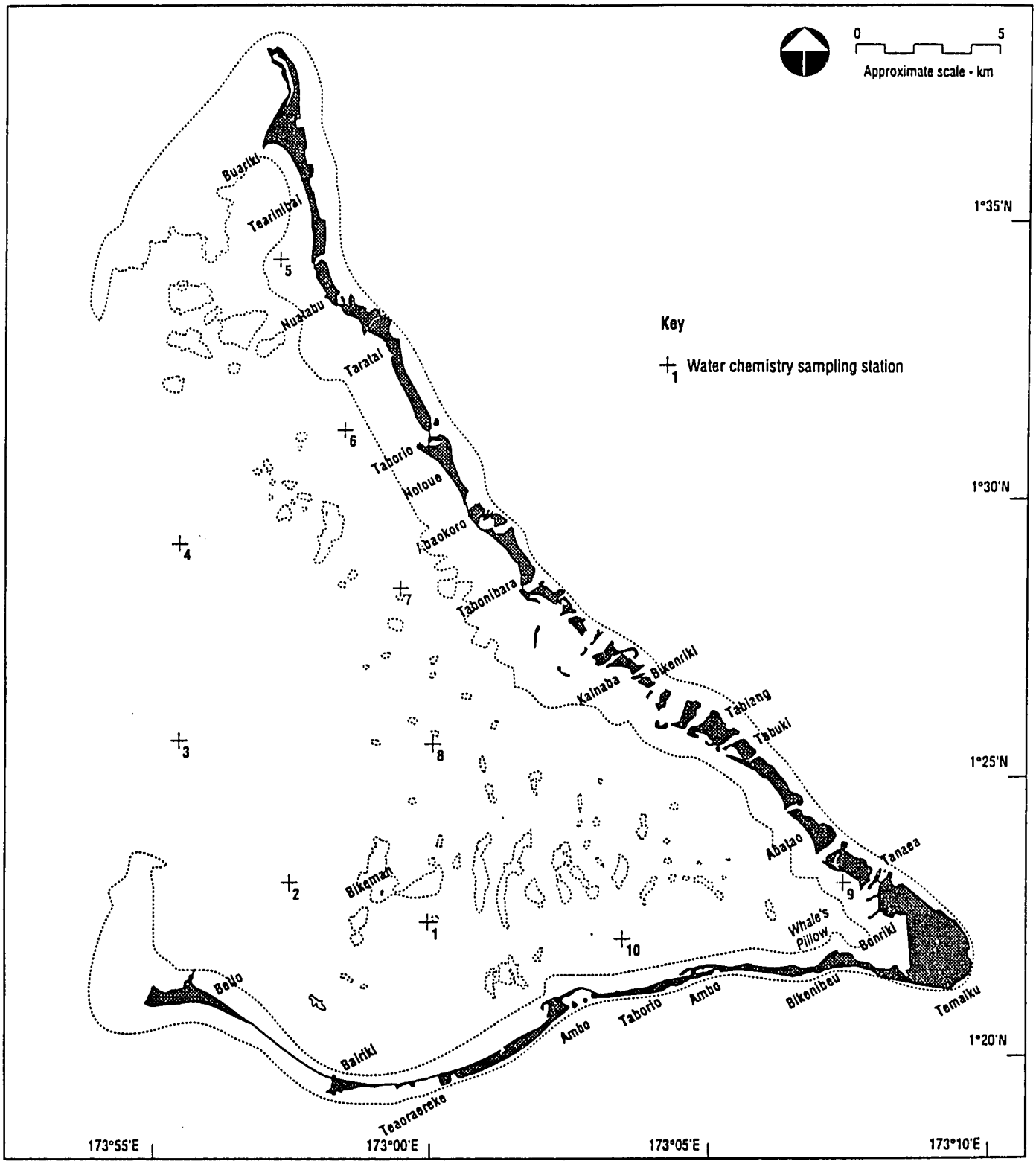


Figure 1 Map of Tarawa Lagoon showing location of villages, passes, and sampling stations used for water chemistry study in 1993. All locations are approximate. Station coordinates are given in Introduction to the Study (this volume).

of evaporation and rainfall. A non-steady-state version of the freshwater balance equation (Equation 4 in Chen et al., this volume) was used with assumed values of residence time, and the resulting proportion of fresh water was compared with proportions determined from mean salinity from days on which lagoon transects were run. To arrive at a best-fit value, the mean square error between model and data was minimized by iterations of the assumed residence time.

Transparency was estimated with a Secchi disk at every station, and on sunny days profiles of solar radiation were taken at 1-m intervals with a quantum photometer. Water samples for chlorophyll measurements were taken from just below the surface in brown, acid-rinsed 500-ml bottles. For most of the plankton transect samples, water for nutrient analyses was collected in acid-rinsed bottles, filtered on board through a glass-fiber syringe filter, and stored on ice for later analysis.

In the laboratory, samples for nutrients were stored frozen. Most samples were analyzed for phosphate and total phosphorus using the procedures of Strickland and Parsons (1972) on a laboratory colorimeter. In September 1993, we also took samples on a transect across the southern lagoon for analysis of all nutrients and total nitrogen and phosphorus by T. Walsh at the University of Hawaii using standard techniques on a Technicon AutoAnalyzer.

Samples for chlorophyll were size fractionated using a 10-μm-mesh nylon screen. A 200-ml subsample of the smaller size fraction and the entire contents of the screen were filtered onto 25-mm, glass-fiber filters, to which a few drops of a magnesium carbonate slurry were added, and stored frozen in the dark. Samples were transported on ice to California, where they were analyzed for chlorophyll with a Turner Model 111 or Turner Designs Model 10 fluorometer calibrated with pure chlorophyll (Strickland and Parsons 1972).

At plankton transect stations and time series stations, zooplankton samples were taken by vertical hauls with a ½-m diameter, 200-μm-mesh conical net equipped with a flow meter. Samples were preserved in 2-5% formaldehyde and later shipped to California for examination.

We twice attempted to determine primary productivity using the light and dark bottle method, but these attempts were unsuccessful because production was apparently too low to be determined by this relatively insensitive technique (using radioactive isotopes was not feasible in Tarawa). On 2-3 September 1993, the growth rate of phytoplankton chlorophyll was measured by the dilution technique (Landry et al. 1984). Surface water was filtered with a glass-fiber filter and stored overnight in the dark. At dawn the next day, water was collected with an acid-rinsed plastic bucket at Station 1 (Figure 1), run through a 100-μm-mesh screen to remove large herbivores, and dispensed into paired 4-L or 10-L Cubitainers after dilution to 5%, 10%, 25%, 50%, and 100% of initial concentration with the filtered water. The containers were moored at 2-3 m depth for incubation. Samples of ½ to 2 L were taken at 0, 6, 12, and 24 hr and filtered for chlorophyll concentration as described above. Growth and grazing rates were determined according to Landry et al. (1984).

The biomass of some zooplankton samples was determined by filtering the samples onto tared glass-fiber filters, drying them at 60° C for 2-3 days, weighing them, ashing them at 500° C for 2 hr, and weighing them again. Procedural errors in the laboratory resulted in useable samples from only June to September 1993, with an overlap of only five samples between the series of samples counted and the series analyzed for dry weight. The median ratio of biomass to total abundance for these samples was 1.5 μg ash-free weight per animal, or about 0.9 μg C based on ratios from Kaneohe Bay, Hawaii (Smith et al. 1981, Table 27). The latter figure was used to estimate carbon biomass of the remaining zooplankton samples from total counts.

Growth rates of common copepods were measured on five occasions, either by the method of Kimmerer and McKinnon (1987) or by incubation from egg to adult. Samples were collected by gentle net tows near Station 1. In the first method, samples were fractionated into two size classes, dispensed into Cubitainers containing surface water strained through a 35- or 52-μm-mesh net, and placed into containers to be preserved for initial counts. The containers were placed 2-3 m deep in the lagoon for incubation for 24 hr. In the second method, adult females of the most common species were pipetted from samples under a dissecting microscope and incubated overnight to produce nauplii, which were then used as inocula in Cubitainers as described above. At intervals, pairs of Cubitainers were sacrificed and the samples were preserved. In both methods, development rates were determined by microscopic counts of all life stages of the species of interest, and growth rates were calculated from literature values for weight per stage.

On several occasions, we estimated the abundance and biomass of ctenophores (*Bolinopsis* sp.) by triplicate tows with a 1-m^2 lift net hauled vertically from the bottom to the surface. The volume sampled was determined by the distance towed and the net efficiency, which was determined by flow meter to be 40%. Ctenophores were either counted or, if numerous, measured by volume with a graduated cylinder. Average volume per ctenophore was 2 ml, but ctenophores lost an average of 40% of their volume during collection because of abrasion in the net.

Individual ctenophores were captured during dives near Station 1 on 18 June and 4 September 1993. Ctenophores were gently placed in an insulated bucket of <35-μm, strained surface seawater for transport to the laboratory. In the laboratory, ctenophores were photographed to determine length, poured gently into a 200-μm-mesh cup, and poured into a 25-ml graduated cylinder for volume measurement. They were then placed on tared foils, dried for 48 hr at 60°C, weighed, and (June samples only) ashed and weighed again.

Nonlinear regression methods were used to relate volume to length, and linear regressions were used to relate dry weight to volume. The percentage of organic weight in the June samples averaged 22%, which is extremely high; this percentage may reflect loss of water in salts during ashing. Because the carbon content of *Bolinopsis vitrea* was 0.5% of the dry weight of ctenophores larger than 5 mm (Kremer et al. 1986), this value was used to estimate carbon biomass.

Results

Salinity, Oxygen, and Transparency

Temperature and salinity stratification was minimal. The largest differential recorded was 0.6° C and 1.2 practical salinity units (psu) (Figure 2). The greatest stratification was in the western stations in spring 1993; an east-west gradient in bottom salinity was slightly greater than the equivalent gradient in surface salinity, indicating that the surface water from shallow eastern stations was overlying deeper, more saline water to the west. Salinity increased from the ocean into the lagoon, except in November 1992.

Residence times from individual transects ranged from 2 to 12 days with a median of 5 days. The mean was 6 days, while the value determined by iteration was 5 days. This gave a reasonable fit of the data to a line predicting the proportion of fresh water in the lagoon (Figure 3).

Oxygen concentration was unstratified at most of the stations, including all the eastern stations. Oxygen was below 100% saturation most of the time (Figure 4), but the lowest values occurred in bottom samples on the western reef, where the only stratification occurred. Oxygen concentrations in the eastern part of the lagoon were generally high. Oxygen was slightly lower during March-June 1993 than during November 1992. The time series data showed no prominent trend in percent saturation of oxygen.

Nutrients

Most of the nutrient data from this study are for phosphate only (Table 1), but a variety of nutrients were analyzed from the single south lagoon transect in September 1993, and data were available from studies in 1978 (Kimmerer and Walsh 1981) and 1981 (Kimmerer unpublished).

In contrast to a previous report (Kimmerer and Walsh 1981), phosphate concentration did not show a strongly decreasing gradient into the lagoon, except in November 1992 and, to a lesser extent, September 1993 (Figures 5 and 6). In September 1993, dissolved inorganic nitrogen at deep lagoon stations decreased into the lagoon, while total dissolved nitrogen and phosphorous were roughly constant (Figure 6). Nutrient concentrations at six stations near the lagoon sand flats were generally higher than at nearby offshore stations (Figures 5-6).

A comparison between phosphate values determined in our laboratory and those determined at the University of Hawaii gave a relationship with a slope of 0.96 ($r = 0.56$, $N = 17$, slope not significantly different from 1; one outlier removed). This relatively poor relationship was partly a result of the low phosphate values in the lagoon (Table 1). Nitrate plus nitrite were also very low. Silicate was anomalous in that the concentration of this nutrient increased with distance into the lagoon (Figure 7).

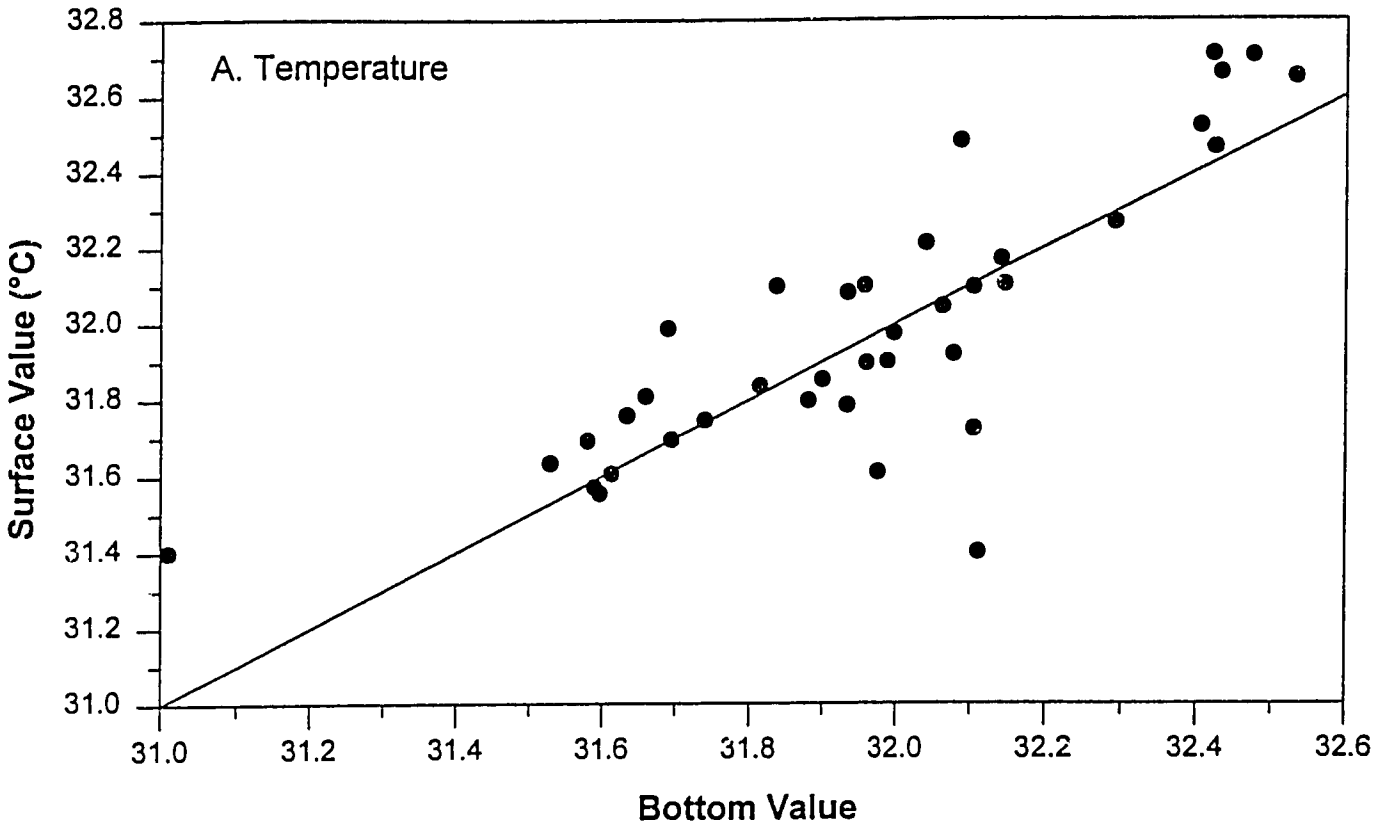
Table 1 Summary of nutrient concentration data; all units are $\mu g\text{-at}^{-1}$.

	All Samples 1993			September 1993			Data from December 1981			Means from 1978	
	Mean	SEM*	N	Mean	SEM*	N	Mean	SEM*	N	South	Central
Phosphate	0.16	0.1	72	0.07	0.02	18	0.26	0.03	25		
Dissolved organic Phosphorus (P)		0.82			0.25			0.31			
Total dissolved P	0.98	0.11	49	0.32	0.02	18	0.57	0.03	25		
Nitrate + Nitrite				0.10	0.05	18	0.72	0.16	25	0.03	0.4
Ammonium				0.49	0.13	18	0.51	0.04	25	0.36	0.34
Dissolved inorganic Nitrogen (N)				0.59	0.17	18	1.23	0.16	25	0.39	0.74
Dissolved organic N				10.19			7.79			5.6	3.8
Total dissolved N				10.77	0.52	18	9.02	0.64	25	5.99	4.54
Silicate				1.98	0.17	18	2.96	0.70	25		
Total particulate Carbon (C)							22.93	1.57	18		
Particulate inorganic C							1.39	0.44	5		
Total particulate N							2.01	0.26	18	2.9	1.8
Ratios of means:											
Inorganic N:P				7.9			4.7				
Organic N:P				41.0			24.9				
Particulate C:N							11.4				

Notes:

September 1993 data are from samples analyzed by the University of Hawaii. Data from 1981 were obtained from the southern lagoon from Kimmerer (unpublished) and 1978 data from the southern and central lagoon were obtained from Kimmerer and Walsh (1981); all nutrient concentrations, except those determined at the Tarawa laboratory, were determined in the same laboratory using the same techniques.

*SEM = standard errors of the mean.



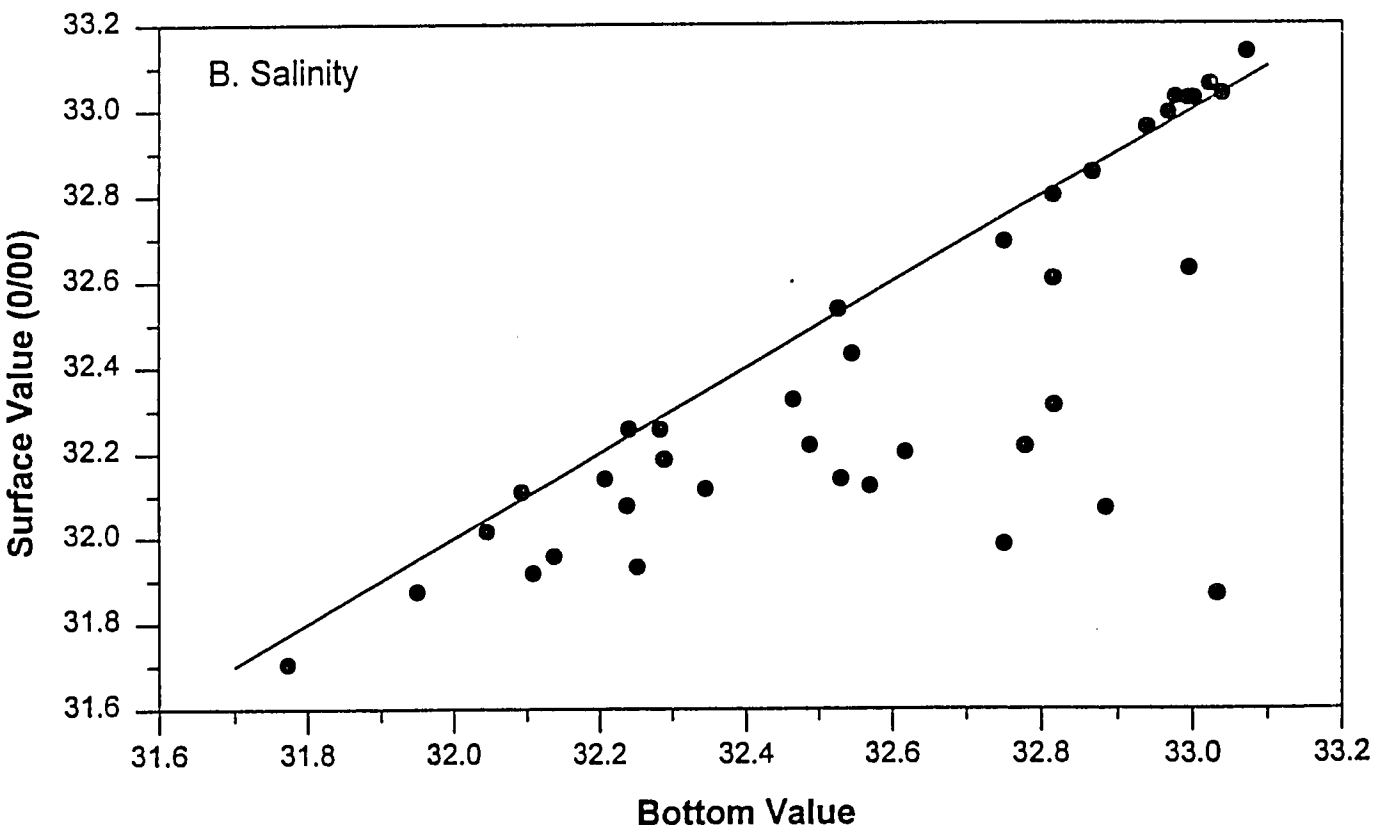


Figure 2 Surface versus bottom values for temperature and salinity from salinity transects, with a 1:1 line.

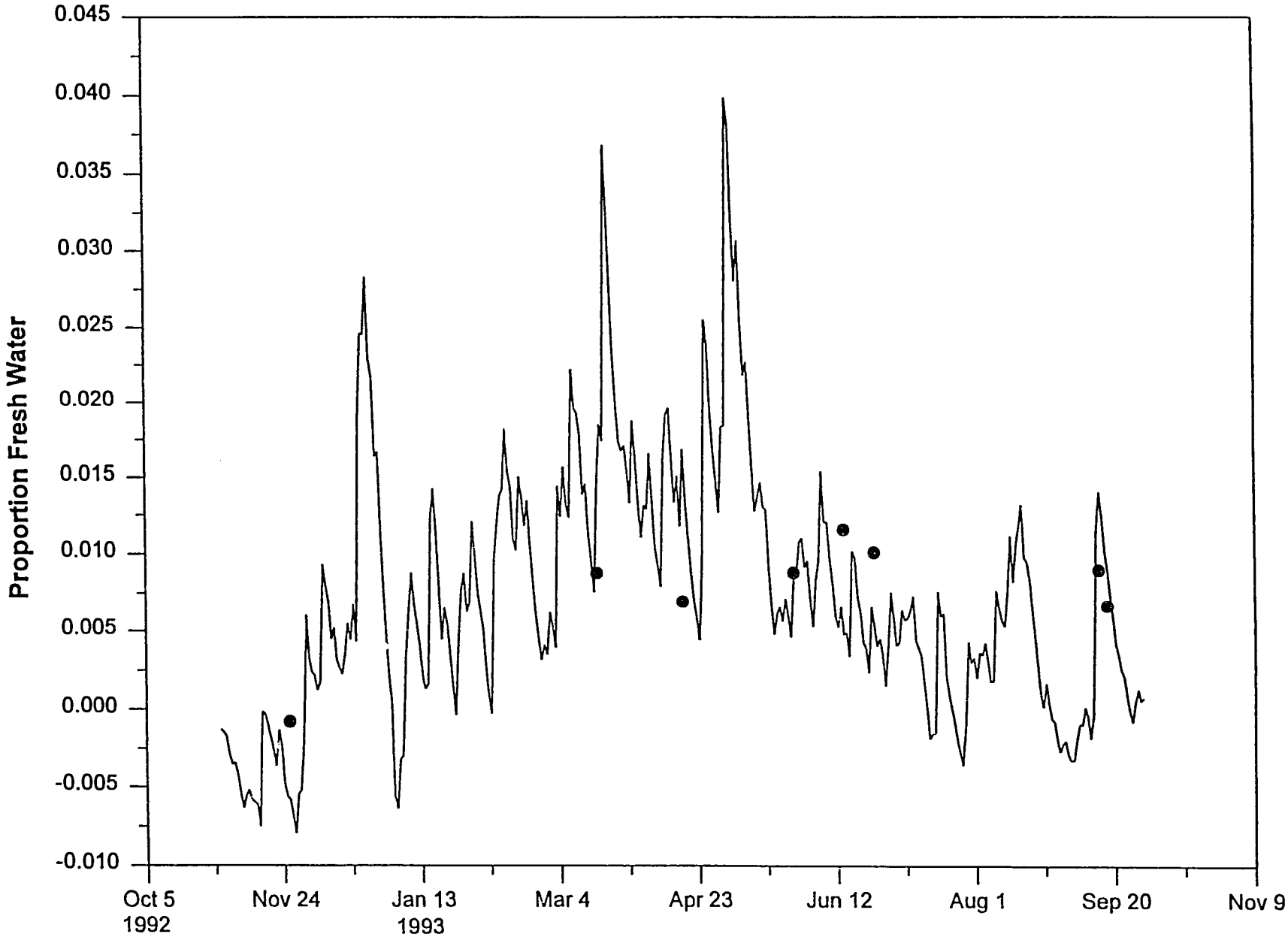


Figure 3 Proportion of fresh water in the lagoon determined by residence time model (line) and salinity data (symbols).

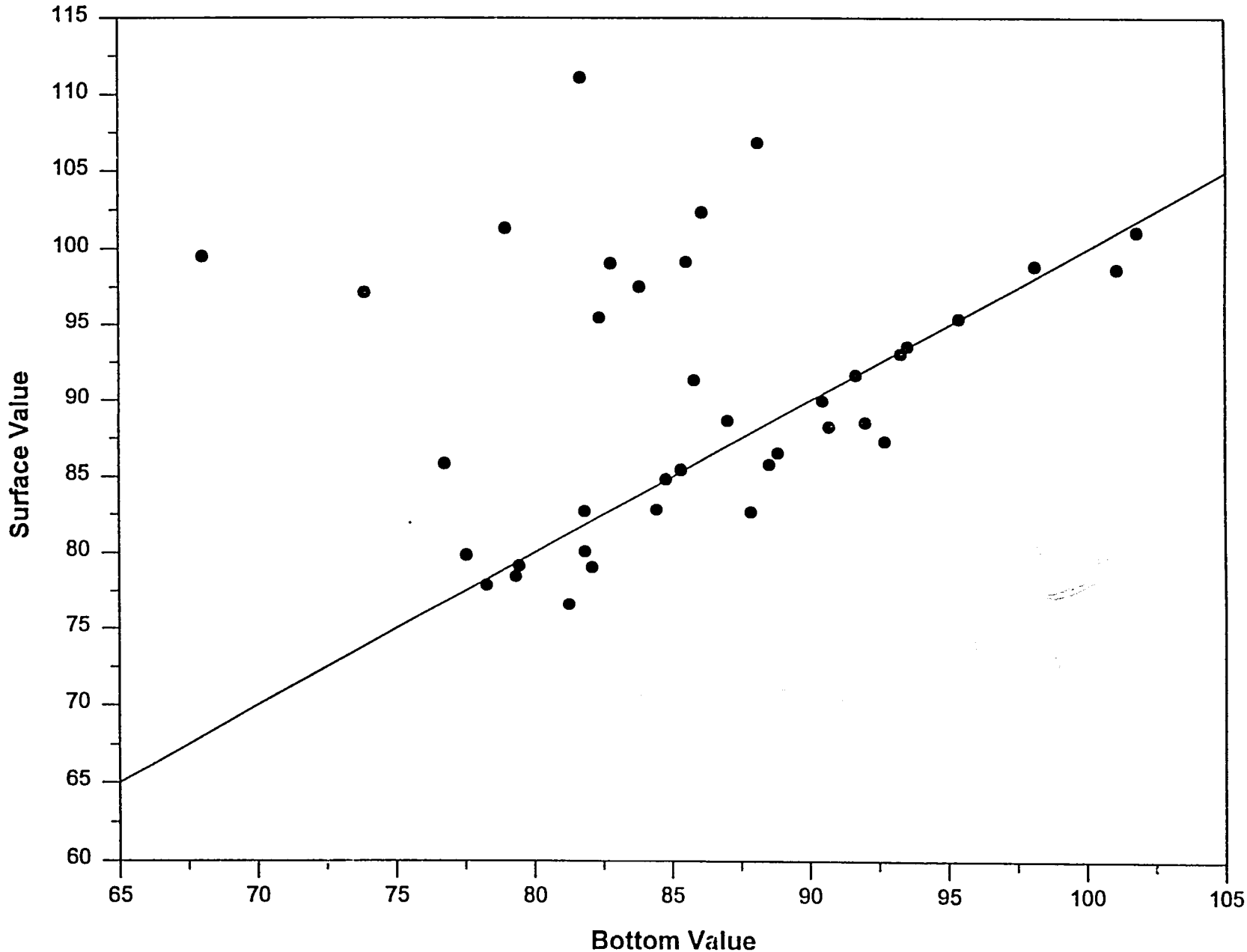


Figure 4 Oxygen percent saturation, surface versus bottom values from salinity transects.

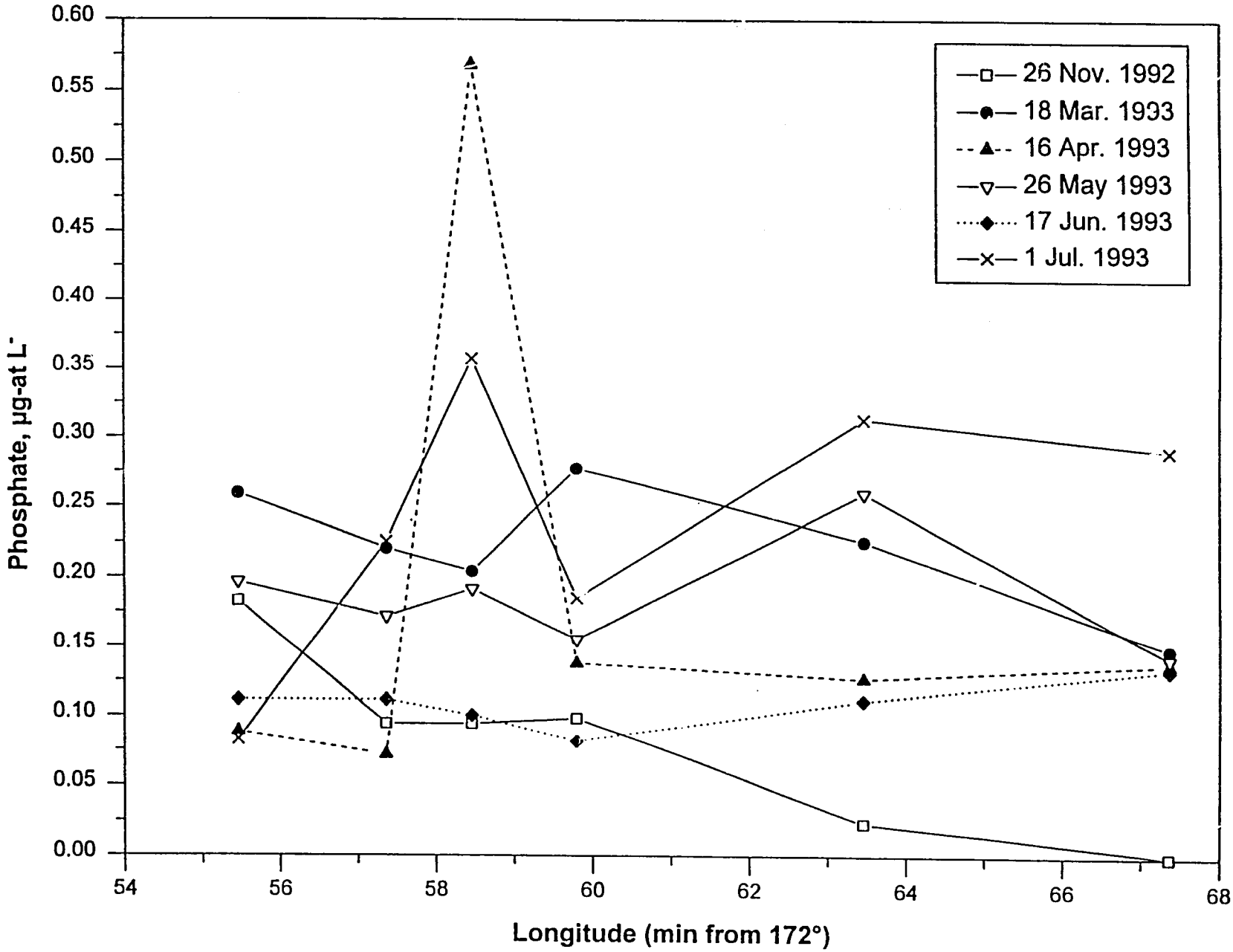


Figure 5 Phosphate concentration versus longitude as a surrogate for distance into lagoon on six dates in 1993. Data have been aggregated into longitude bins for graphing.

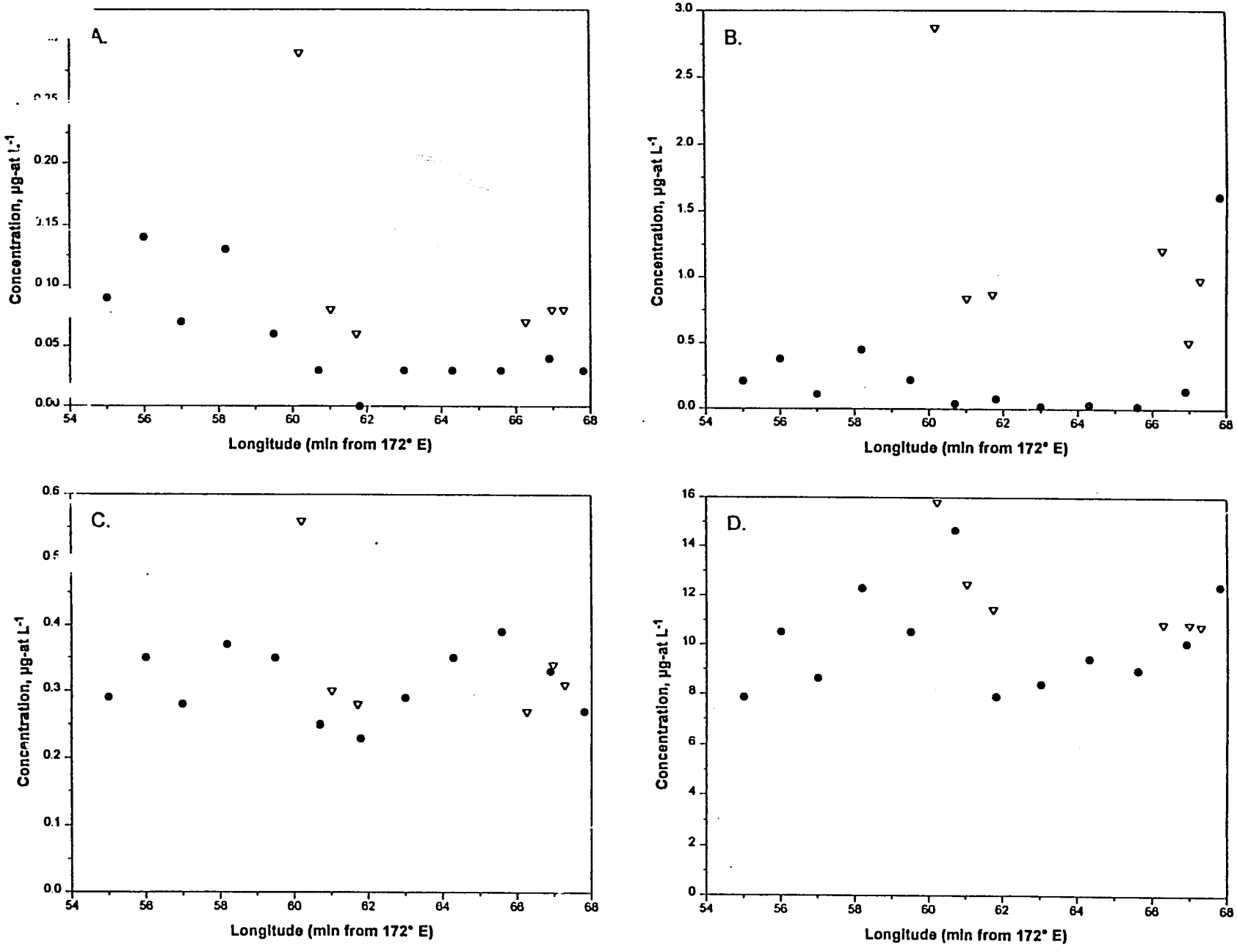


Figure 6 Concentrations of nutrients versus longitude for stations in the southern lagoon (circles) and on the southern reef flat (triangles) in September 1993: A) phosphate; B) dissolved inorganic nitrogen; C) total phosphorus; and D) total nitrogen.

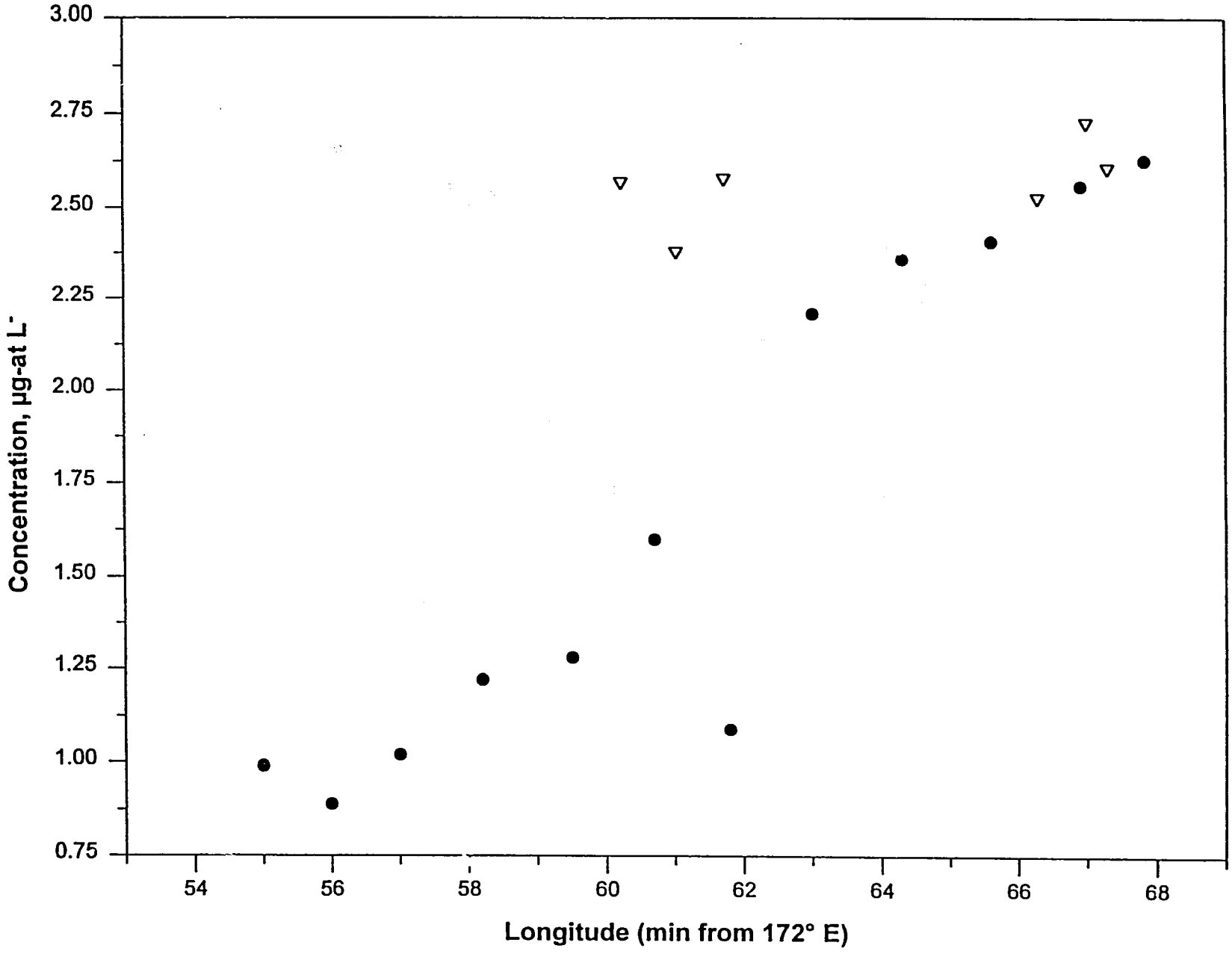


Figure 7 Silicate concentration versus longitude, September 1993; symbols as in Figure 6.

Ratios of dissolved inorganic nitrogen to phosphorous had a mean value of 11, significantly different from the Redfield ratio of 16 (Figure 8A). Ratios of total dissolved nitrogen to phosphorous, however, were about double the Redfield ratio (Figure 8B) and no relationship existed between dissolved organic nitrogen and phosphorus.

Light Extinction and Chlorophyll

The extinction coefficient as determined with a quantum photometer was related to Secchi disk depth:

$$k = 1.3 \pm 0.4 \text{ / Secchi}$$

where k is extinction (m^{-1}; mean $\pm$ SD, N = 8).

Extinction values determined from Secchi disk data and chlorophyll concentrations were higher in the southern and eastern portions of the lagoon and lower in the northern and western portions (Figure 9).

Mean chlorophyll concentration was 0.4 ± 0.3 $\mu g\ L^{-1}$ (SD; N = 70). Chlorophyll concentration increased with distance into the lagoon (Figure 9; analysis of covariance with date as covariate, $P<0.001$). No seasonal cycle was evident in the chlorophyll concentrations at Stations 1 and 8 (Figure 10). On average, 28% of the chlorophyll was in cells retained by a 10-μm-mesh strainer, with a higher proportion of large cells in samples from the eastern and southern stations.

The single dilution experiment gave a growth rate for phytoplankton chlorophyll of 0.24 d^{-1}.

Zooplankton

Qualitatively, Tarawa Lagoon zooplankton samples were notable for the quantity of gelatinous plankton. Many samples, particularly from the southeastern part of the lagoon, were filled with gelatinous material from disrupted ctenophores and larvacean houses. Furthermore, divers commonly observed ctenophores in abundances of many per cubic meter, and swarms of small medusae and chaetognaths were often seen during collection trips to Station 1.

Zooplankton abundance averaged 5,000 m^{-3} (geometric mean of all samples), and patterns of rank abundance agreed reasonably well between transects and time series stations (Table 2). The six species with the highest geometric means in all samples were the copepods *Calanopia minor*, *Acartia* sp., *Oithona oculata*, and *Oithona nana* (these species identifications are tentative); the larvacean *Oikopleura longicauda*; and an unidentified hydromedusa.

Table 2 Geometric means (number m^{-3}), geometric standard deviations, and rank order of abundance of zooplankton species and species groups identified in Tarawa Lagoon. Note that individual values do not add up to totals because of the use of geometric means. The geometric standard deviation is the antilog of the standard deviation of log-transformed values, and is multiplicative rather than additive.

	Station 1			Station 8			Transects		
Species	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank
Copepods									
Paracalanus sp. A	83	4.4	10	142	4.0	7	45	4.1	10
Paracalanus sp. B	6	2.8	15	10	3.9	22	17	3.3	15
Bestiolina sp.	83	3.6	9	303	3.4	3	54	5.5	9
Calanopia	392	4.2	1	1,163	5.2	1	223	5.3	1
Acartia sp. A	196	5.3	8	131	5.6	9	61	5.4	8
Acartia sp. B	0		18	9	4.2	26	14	3.7	18
Labidocera	1	1.3	26	9	5.9	24	7	3.2	26
Pseudodiaptomus	0		35	0		38	1	1.9	35
Clausocalanus	1	1.5	37	0		37	1	1.5	37
Calanus	0		38	0		41	1	1.6	38
Oithona oculata	52	5.4	3	147	8.0	6	154	8.1	3
Oithona nana	272	4.0	5	386	2.8	2	80	4.1	5
Oithona simplex	207	3.5	12	197	5.8	5	31	4.2	12
Oithona sp. A	3	1.9	21	13	4.1	19	9	2.7	21
Oithona plumifera	0	1.0	23	5	3.5	30	8	3.2	23
Corycaeus	0		29	3	2.4	32	4	2.2	29
Oncaea	1	1.3	22	7	3.4	27	9	2.8	22
Sappharina	0		36	1	1.5	35	1	1.4	36
Harpacaticoid	1	1.6	34	3	2.0	31	2	1.6	34
Macrosetella	0		40	0		40	0	1.2	40
Other Holoplankton									
Oikopleura	51	6.4	2	238	10.7	4	168	6.3	2
Sagitta spp.	22	3.9	16	18	4.7	16	17	3.7	16

Table 2 Geometric means, standard deviations, and rank order of abundance of zooplankton identified in Tarawa Lagoon (cont.).

	Station 1			Station 8			Transects		
Species	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank
Medusa A	43	6.5	4	124	12.4	10	99	6.2	4
Salp	5	2.7	32	5	2.3	28	3	2.1	32
Meroplankton									
Barnacle nauplius	1	1.4	39	0		39	1	1.3	39
Shrimp larva	9	3.0	20	18	4.2	15	12	3.0	20
Crab zoea	0		27	13	3.9	18	5	2.2	27
Polychaete larva	18	3.9	17	15	3.8	17	14	3.2	17
Gastropod veliger	10	3.6	19	11	3.6	21	12	3.2	19
Clam veliger	13	4.9	14	12	3.8	20	22	4.4	14
Snail larva	30	6.3	7	109	9.9	11	68	4.7	7
Brittle star larva	70	14.7	11	107	14.1	12	36	6.5	11
(Fish) egg	1	1.6	28	5	2.5	29	5	2.3	28
Fish larva	5	2.4	31	9	3.2	25	3	2.2	31
Total zooplankton	4,165	3.3		9,317	2.6		3,520	3.4	
Calanoid copepods	1,260	3.6		3,453	2.7		1,068	3.8	
Oithona spp.	748	3.2		1,206	3.7		570	4.2	
Total copepods	2,277	3.1		5,037	2.8		2,005	3.5	

Abundance patterns varied among lagoon stations between dates and among species of lagoon plankton (Figure 11). Abundance was highest for total plankton at Stations 6 and 8 in the northern deep lagoon, and lowest at Stations 3 and 4 on the western reef and Station 5 in the shallow northern lagoon. Most lagoon species were abundant at stations in the central lagoon, somewhat less abundant in the eastern corner of the lagoon (Stations 9 and 10), and least abundant at Stations 3 and 4. The major exception was the copepod *Oithona oculata*, which was most abundant at Stations 4, 5, and 6, and least abundant in the southern sector of the lagoon.

Data from the two time-series stations showed generally higher abundance in 1992 than in 1993, and rough correspondence in patterns between the two stations (Figure 12A). Zooplankton carbon biomass had median values of 5.3 and 7.4 mg C m^{-3} at time-series Stations 1 and 8, respectively, and varied irregularly with no clear seasonal pattern (Figure 12B). The median of all measured samples (N = 50) was 5.2 mg C m^{-3}.

Zooplankton growth was rapid, with complete development of copepods from egg to adult in less than 1 week for the copepod *Bestiolina similis*. Using literature values for weight of life stages of this species (Kimmerer 1983), growth rates were approximately 0.6 d^{-1} (Kimmerer in prep.).

Ctenophores had the following relationships of size and weight:

$$\text{Volume} = 0.0056 * L^{2.04},\ r^2 = 0.83 \qquad N = 17$$

$$\text{Dry weight} = 0.117 * L^{2.16},\ r^2 = 0.79 \qquad N = 17$$

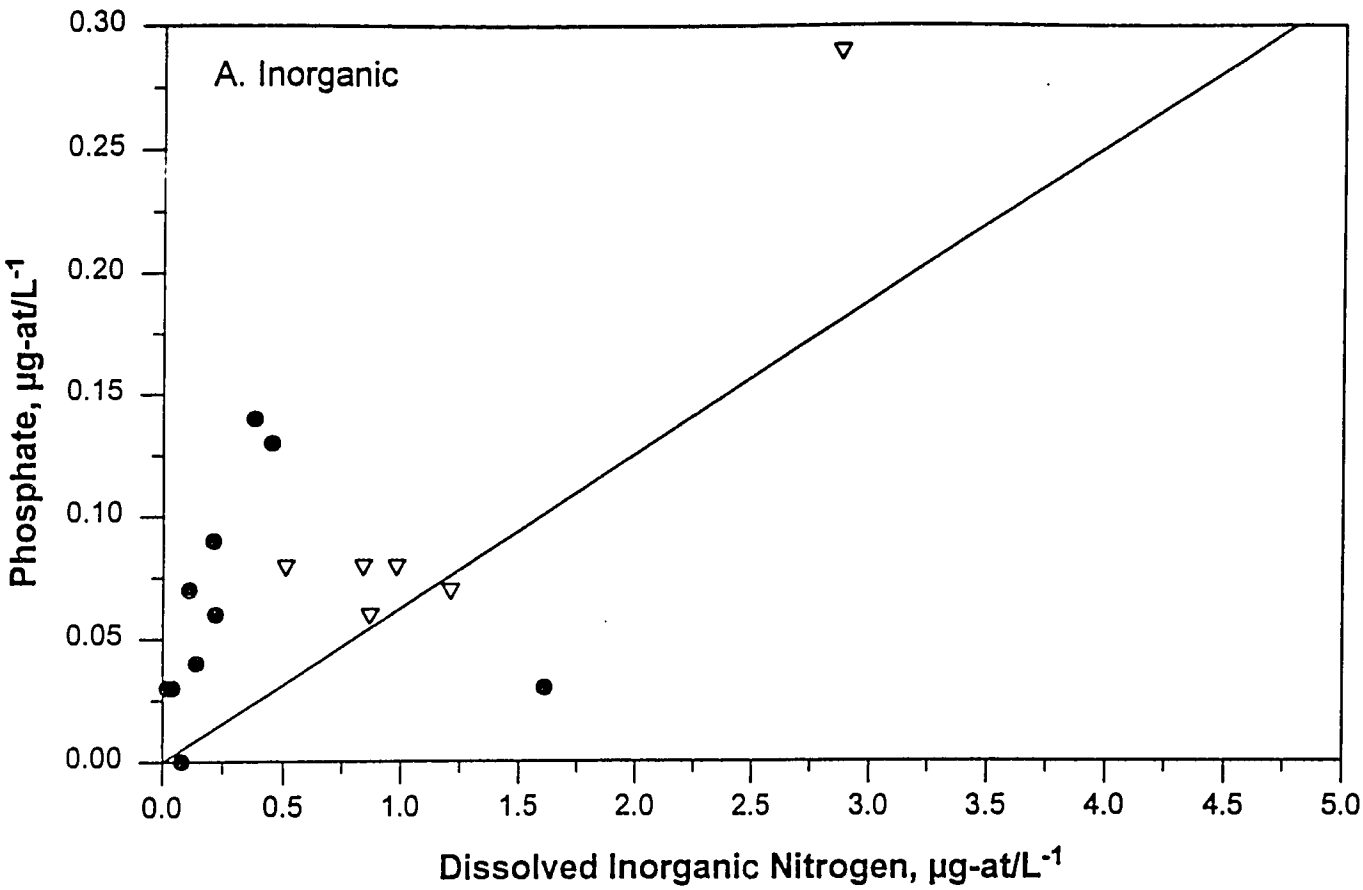
$$\text{Dry weight} = 32.1 * \text{Volume},\ r^2 = 0.98 \qquad N = 30$$

where length is in millimeters, volume is in milliliters, and dry weight is in milligrams.

Ctenophores were abundant on all sampling dates, but tended to be more abundant south of the line of reefs at 1°23'N than in the central and northern part of the lagoon. They were never collected at plankton Stations 3 or 4, over the western reef. Geometric mean abundance for all the lagoon stations was 2.8 m^{-3}, and geometric mean carbon biomass was 1.6 mg C m^{-3}. The highest abundances occurred in May and June 1993, with over 20 m^{-3} in the eastern part of the lagoon (Stations 9 and 10) and biomass in that region of 13 mg C m^{-3}.

Discussion

The median and mean residence times and the value obtained from the non-steady-state water balance model were close to each other (5, 6, and 5 days, respectively) The previous estimate of 11 days (Kimmerer and Walsh 1981) falls within the range of values obtained in this study. The value obtain-



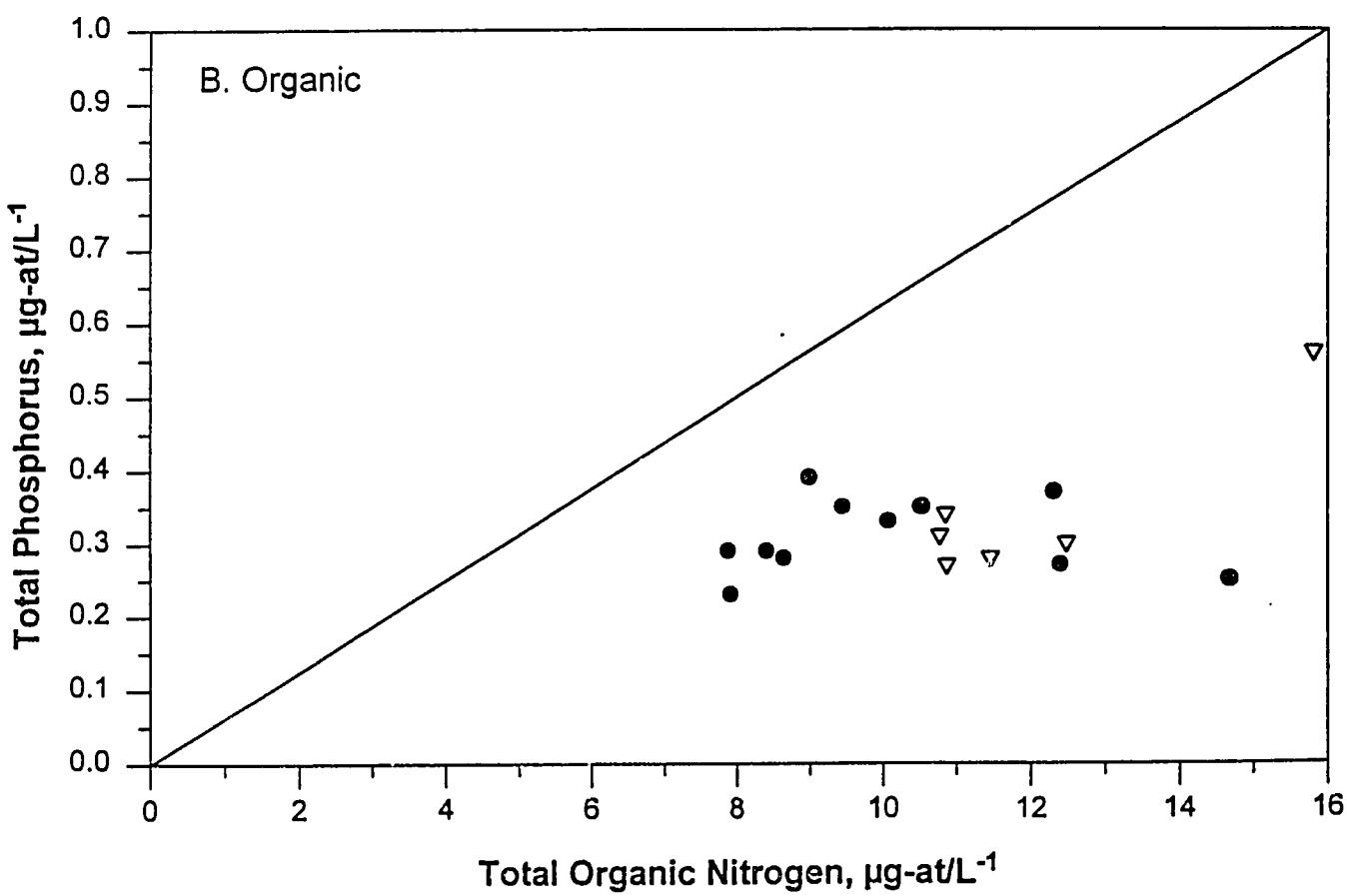


Figure 8 Dissolved inorganic and organic nitrogen and phosphorus in September 1993; symbols as in Figure 6. Line represents the Redfield N:P ratio of 16:1.

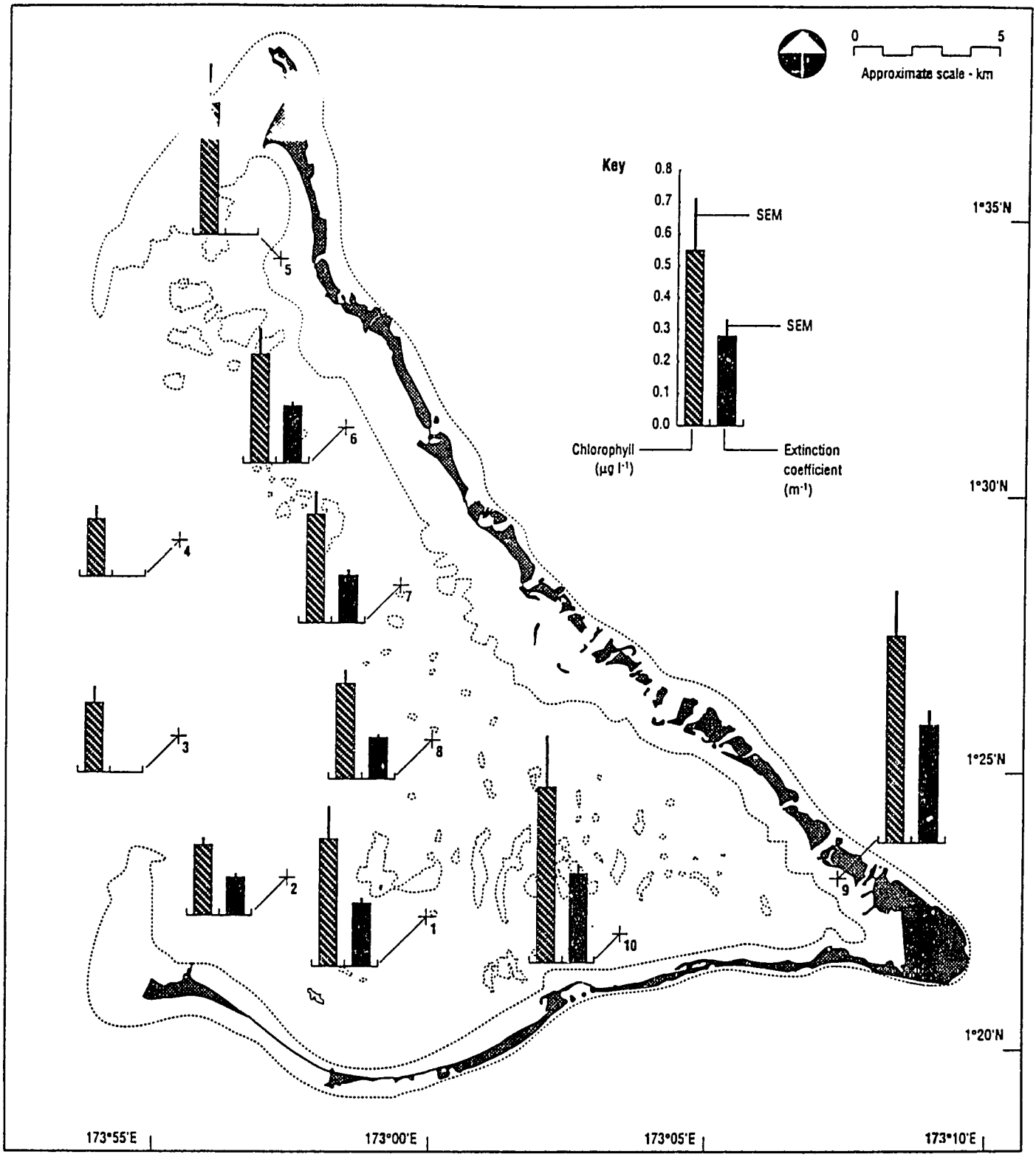


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Figure 9 Means and SEMs for chlorophyll and extinction on plankton transects. Extinction missing for stations 3 to 5 because usually Secchi depth > water depth.

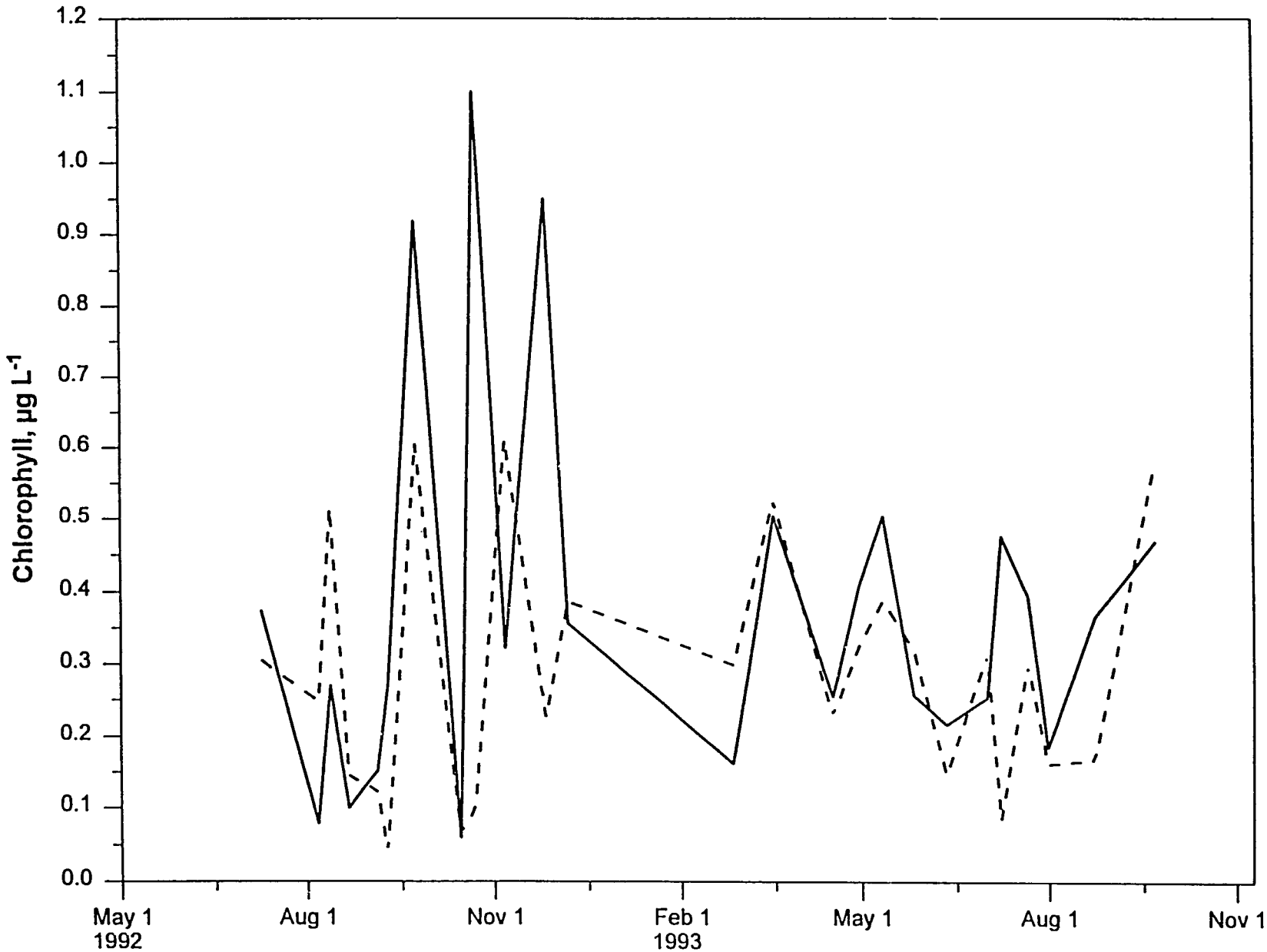

Figure 10 Chlorophyll concentrations at Stations 1 (solid line) and 8 (dashed line), 1992-1993.

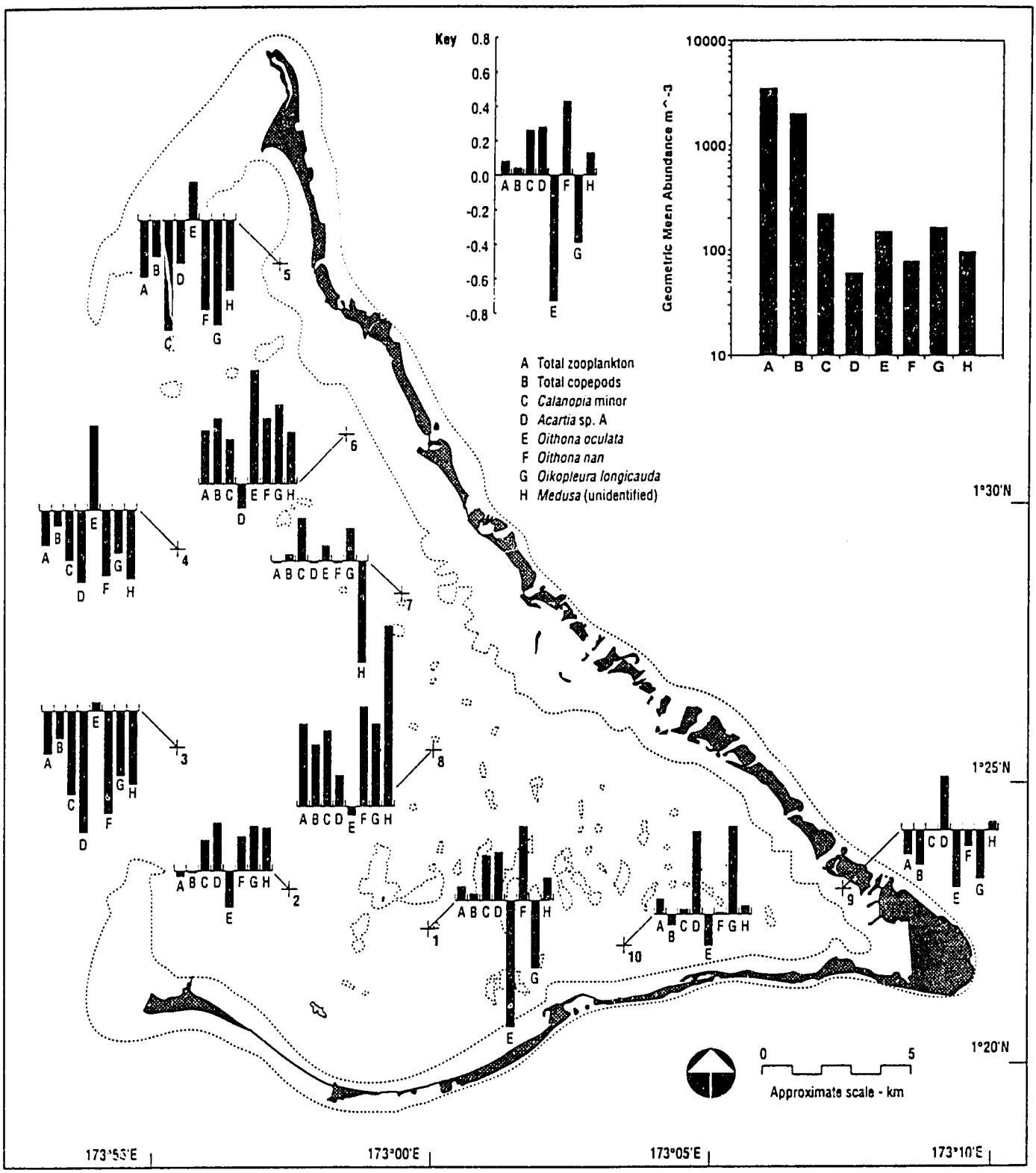

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Figure 11 Geometric mean abundance and deviations from the mean for each station for total zooplankton, total copepods and common species.

ed using the circulation model, calibrated to the current set of salinity data, was 9.5 days (Chen et al., this volume). No consideration was given to the spring-neap tidal cycle or the effects of wind, both of which affect circulation. Systematic errors in the estimate of evaporation rate also could alter these values; for example, evaporation over the lagoon reef flats would be higher than in the central lagoon, although the area of reef flats is small. Thus, the best estimate of residence time is approximately 1 week.

This short residence time has several implications for the ecology of the lagoon. The time available for plankton to convert nutrients into organic matter is fairly short, which may give a competitive advantage to benthic algae. In addition, only those plankton species with high enough population growth rates to offset losses to the ocean can survive in the lagoon. The fact that numerous species of zooplankton maintain populations within the lagoon suggests that their population growth rates are indeed high; alternatively, they may have behavioral adaptations to maintain themselves in the lagoon. The other implication of short residence time is that human inputs of nutrients are small compared to oceanic inputs, and human wastes are rapidly removed from the lagoon.

Relatively few data sets exist to allow a comparison of the water chemistry and lower trophic level biology of Tarawa with other tropical lagoons. The most complete such data set is from Kaneohe Bay, Hawaii, after cessation of sewage discharge into the bay (analyses were performed by the same laboratory; Smith et al. 1981). Values for nitrogen and phosphorus from Tarawa were similar to or slightly greater than those from Kaneohe Bay (Table 3). N:P ratios in Kaneohe Bay were 7 for inorganic nutrients and 30 for organic nutrients, similar to values for Tarawa Lagoon. Silicate concentrations were higher in Hawaii, presumably because of the influence of land drainage. Particulate organic matter was lower in Kaneohe Bay, with a C:N ratio of 7. This low ratio indicates that most of the particulate organic matter in Kaneohe Bay was plankton or detritus of recent planktonic origin. The relatively high organic C:N ratio in Tarawa Lagoon reflects the high detrital content of the water, as seen in the high proportion of gelatinous detritus in the zooplankton samples.

Table 3 Comparison of water chemistry data (μg-at l^{-1}) from Tarawa Lagoon (Table 1) and Kaneohe Bay, Hawaii (mean for central station, 1978-1979 postdiversion period, Smith et al. 1981).

	Tarawa Lagoon	Kaneohe Bay
Dissolved inorganic N	0.4 - 1.2	0.65
Dissolved organic N	5.6 - 10.2	5.7
Particulate N	2.0 - 2.9	1.8
Phosphate	0.07 - 0.26	0.1
Organic P	0.2 - 0.8	0.2
Silicate	2.0 - 3.0	9.0
Particulate organic C	21	13.0

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Total particulate matter, as indicated by light extinction coefficient, was highest for the two easternmost stations. This finding reflects the generally poorer circulation in this region, resulting in accumulation of fine particulate matter, and shoaling toward the east resulting in greater availability of sediments for resuspension (Weber and Woodhead 1972; Paulay, this volume). Much of the turbidity, however, is probably caused by particulate inorganic detritus. Despite the relatively poor light penetration, nutrient, chlorophyll, or oxygen measurements revealed no evidence of eutrophic conditions in any part of the lagoon.

Nutrient concentrations were at least as low in the lagoon as in the adjacent ocean, and chlorophyll concentrations never exceeded 2 $\mu g\ L^{-1}$. Oxygen concentrations were never below 65% saturation. At most stations, no stratification of oxygen concentration occurred (Figure 4). The exceptions, comprising about one-fourth of the samples, were mostly from Stations 2-4 near the western entrance, where oxygen concentration was near saturation at the surface and greatly reduced below the surface. This circumstance may have been caused by oxygen consumption by the reefs, although reefs should produce oxygen during the day. Alternatively, it could have been a result of reduced oxygen in ocean water, because these samples were taken during a flood tide. Eutrophication might be expected at inner lagoon Stations 9 and 10, where turbidity and chlorophyll concentrations are highest, circulation is least effective, and human population density is high adjacent to a small volume of lagoon water offshore. In contrast, however, we never observed stratified oxygen concentrations at these stations and the percent saturation ranged from 80% to 100%. Thus, as inferred from the data collected in 1978 (Kimmerer and Walsh 1981), the trophic status of the waters of Tarawa Lagoon is not significantly influenced by human activities.

Nutrient concentrations in the current study were similar to those measured in 1978 by Kimmerer and Walsh (1981) and in 1981 by Kimmerer (unpublished). Phosphate measurements made in the Tarawa laboratory were correlated with those measured at the University of Hawaii; the relatively poor correlation was probably because concentrations were near the limit of detection. Analyses in both previous studies were done by T. Walsh. A study by Naidu et al. (1992) reported higher nutrient concentrations in the lagoon than those reported by Kimmerer and Walsh (1981), and concluded that human influence had increased; however, the methods used were unsuitable for low-nutrient waters such as these. It is safe to conclude that nutrient concentrations have not changed in any meaningful way since 1978.

Phosphate was chosen as the predominant nutrient to measure in this study, even though it is generally understood that nitrogen is most likely to limit phytoplankton growth in this part of the ocean. This was a deliberate choice made for four reasons. First, dissolved fixed inorganic nitrogen (DIN) is present as three chemical species, one of which (ammonium) is difficult to measure accurately. Second, transformations among nitrogen species, most notably denitrification, can have tremendous effects on DIN that have little to do with uptake or release by plankton. Third, phosphate is easier to measure and therefore more suitable for the conditions of this study. Fourth, and most important, because DIN is removed very rapidly from the water column (by a combination of uptake and denitrification), concentrations away from the source are practically zero, and therefore uninformative (see figures in Kimmerer and Walsh 1981).

The relatively low inorganic N:P ratio (Table 1) is probably due to denitrification and rapid uptake of inorganic nitrogen by plants; the high organic N:P ratio is probably due to the more rapid recycling of organic phosphorus than nitrogen. Particulate organic C:N ratios obtained in December 1981 averaged 11, well above typical values of around 6.6 for living plankton, again reflecting a detrital component.

The increase of silicate with distance into the lagoon is somewhat anomalous, because plankton concentrations are higher in the lagoon than in the ocean. The only likely source of silica is plankton; thus, this increase may be due to remineralization of siliceous plankton entering the lagoon from the ocean. This gradient was observed in September 1993, when phosphate was depressed in the lagoon, suggesting net uptake of that nutrient. The silica gradient cannot be explained unless there is a progressive loss of siliceous phytoplankton within the lagoon; we have no data on this parameter.

Phytoplankton biomass (chlorophyll concentration) increased with distance into the lagoon. In addition, the proportion of large cells was higher at inner lagoon stations than at western stations. The larger size fraction of phytoplankton is considered more suitable as food for most zooplankton (i.e., copepods) than are smaller cells. Thus, food concentrations for zooplankton were higher in the inner lagoon.

The single growth-rate measurement was insufficient to determine primary productivity. Data from studies of similar environments, however, can be used to estimate what this value should be. Central Kaneohe Bay, Hawaii, has a mean depth of 10 m, a mean light extinction coefficient of 0.23 m^{-1}, and mean chlorophyll concentration of 0.6 $\mu g\ L^{-1}$ after of sewage discharge into the bay was terminated (Smith et al. 1981). Light penetration to the bottom was about 10%, similar to the mean for all stations within Tarawa Lagoon (Stations 1, 2, and 5-10). Nutrient concentrations were similar. Thus, conditions for growth were roughly similar. Phytoplankton growth rate in central Kaneohe Bay, determined from primary production and chlorophyll, was estimated at about 0.74 d^{-1} The temperature in Tarawa Lagoon is about 5°C higher, so the growth rate should be correspondingly greater.

Our single estimate of growth rate was 0.24 d-1, but that may be low. The growth rate method may be biased against rapidly-growing species that do not maintain their growth rate for the duration of the experiment. That is, the species that accumulate biomass in the containers may be slower-growing species than the bulk of the biomass in the lagoon. The measurements in Kaneohe Bay were made using the carbon-14 method which is very sensitive and can be applied over a short incubation.

An approximate value for phytoplankton growth rate may be on the order of 0.8 d^{-1}. Assuming a carbon to chlorophyll ratio of 50 (Smith et al. 1981) and using the mean chlorophyll of 0.4 $\mu g\ L^{-1}$, the daily production rate would have been approximately 16 mg C $m^{-3}\ d^{-1}$, about half that in Kaneohe Bay (Smith et al. 1981). At a mean lagoon depth of 6 m, this figure translates to about 35 gC $m^{-2}\ y^{-1}$.

Zooplankton abundance did not show a strong pattern within the lagoon, except that abundance of total zooplankton and most lagoon species was less over the western reef and in the far northern lagoon, and somewhat less in the eastern lagoon, than in the central lagoon. The reduced abundance over the western reef was probably a result of the lagoon water mixing with ocean water, which contains few of the species abundant in the lagoon. Reduced abundance in the north may have been related to the large number of reefs in the area, which, as entire systems, can consume large quantities of zooplankton. This theory is supported by the high abundance of *Oithona oculata* in the western and northern regions; this species is often associated with reefs.

Zooplankton biomass was about 6 mg C m^{-3} in Tarawa Lagoon, a low value compared to that in Kaneohe Bay, where zooplankton biomass larger than 335 μm was 8 mg C m^{-3} (Smith et al. 1981, Table 25). The growth rate of approximately 0.6 d^{-1} was close to values obtained from a regression of growth of a variety of copepods against temperature, assuming that food is not limiting (Huntley and Lopez 1992). If this growth rate is representative of all the zooplankton in Tarawa Lagoon, the secondary production rate would be 3.6 mg C m^{-3}, and integrated production would be 8 gC m^{-2} y^{-1}. Thus, mesozooplankton secondary production is about 22% of total primary production. These estimates are extremely crude, however.

Because we did not measure the feeding rate of ctenophores, we estimated their predatory impact from literature values. Carbon-specific respiration rates of freshly caught *Bolinopsis vitrea* from the Bahamas were about 8% d^{-1} (Kremer et al. 1986). Growth efficiencies of ctenophores are low (<10%), and digestive efficiencies were about 70% at food concentrations below 1 x 10^5 m^{-3} (Reeve and Walter 1978). Thus, ingestion rate should be approximately 13% d^{-1}, or 0.2-0.3 mg C m^{-3} d^{-1}. This finding represents roughly 5% of the extant zooplankton biomass per day. The predatory impacts of other abundant gelatinous plankton are unknown. However, this low average rate of removal suggests that, except when ctenophores are unusually abundant, zooplankton growth is sufficient to overcome ctenophore predation.

The potential for fishery yield based on lagoon plankton can be estimated very roughly as follows. If humans harvest mainly piscivores, then the harvest targets fish two trophic levels above the zooplankton. If the ecological efficiency of each level is about 10%, then the potential yield is about 1% of zooplankton production, or about 80 mg C m^{-2} y^{-1}. With the total area of deep lagoon being about 4 x 10^8 m^2, this figure translates to 32 tonnes C y^{-1} or about 800 tonnes y^{-1} live weight, which is equivalent to a per capita harvest of about 30 kg y^{-1}. This number would increase, of course, if planktivores are the primary food source for humans, and indeed some of the common food fish are consumers of plankton (e.g., *Gerres* sp.). In either case, fishery yield based on planktonic production could contribute substantially to the diet of Tarawa residents.

However, most of the common food fish in the diets of Tarawa residents are benthic feeders (e.g., bonefish and emperors) (Beets, this volume). These fish feed on benthic filter- or deposit-feeders which in turn are probably dependent ultimately on phytoplankton. Making a similar calculation to that above (2 trophic levels at 10% efficiency), the potential fishery yield should be on the order of 140 kg y^{-1}, about enough for sustenance.

Thus we can conclude, on the basis of extremely rough calculations, that lagoon production is adequate to supply fish to the entire human population of Tarawa. Later chapters (Beets, this volume, Johannes this volume) discuss why this potential is not being realized.

Microbiological Contamination of Water and Shellfish in Tarawa Lagoon, Kiribati: Remediation Strategies for Contaminated Shellfish

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Microbiological Contamination of Water and Shellfish in Tarawa Lagoon, Kiribati: Remediation Strategies for Contaminated Shellfish

By

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Abstract

Previous studies have shown that overcrowding and waste disposal practices have led to high levels of fecal contamination of nearshore lagoon waters and shellfish in South Tarawa. The present study was conducted to further examine the extent of fecal pollution and its impact on shellfish. In addition, two methods for the remediation of fecal contamination of shellfish were investigated. Median fecal coliform (FC) values in water samples taken from eight of nine (88%) transects exceeded current U.S. standards for water used to grow shellfish (43 most probable number [MPN] FC/100 ml). Samples from four of the nine transects (44%) exceeded human bathing water standards (200 MPN FC/100 ml). All shellfish collected within 25 m of shore exceeded the currently accepted standard for shellfish meat (240 MPN FC/100 g meat), whereas shellfish collected farther out on the reef flats (>1,000 m) contained no measurable FC. In addition to human activity, a sanitary survey of the shoreline revealed large numbers of swine being raised within 6 m of the water's edge in some areas. Two methods of remediating FC in shellfish were tested: depuration in saltwater and cooking. FC was depurated from a commonly consumed shellfish, *Anadara* sp. (*te bun*), within 3 days by holding in clean seawater. FC concentrations were reduced by almost 1,000-fold following 10 min of cooking.

Introduction

The concentrations of fecal coliforms have steadily increased within Tarawa Lagoon, Kiribati (Johannes et al. 1979; Naidu et al. 1992; Kelley 1993). Most recently, Kelley (1993) reported that nearshore fecal coliform concentrations exceeded typical health standards in several areas within the lagoon. Despite increased efforts by the Kiribati government to improve toileting, a relatively limited number of usable flush toilets are available, and many residents continue to use the lagoon, ocean reef, or jungle brush as their toilet.

The purpose of this study was to sample the southern portion of the lagoon to evaluate the microbiological water quality of the water and common shellfish. In addition, two methods for the remediation of FC contamination in shellfish were investigated.

Methods

Sixty-eight water samples were collected in seven areas of South Tarawa Lagoon (Figure 1), including near shore (1-m-deep water at the beginning of the outgoing tide), offshore in the lagoon, along the grass shelf (< 1,000 m from shore), and in deeper water (> 1,000 m from shore). Two nearshore locations were chosen for time series analyses for FC concentration over a 12-hr period, corresponding to the semidiurnal tidal cycle. All water samples were collected in sterile glass sample jars and transported on ice to the laboratory within 2 hr. The cockle *Anadara* sp. was collected either nearshore on the sandy bottom (<25 m from shore), on a grassy shelf (>25 to < 1,000 m) or in deeper waters (> 1,000 m). The harvested shellfish were placed on ice and transported to the laboratory within 2 hr.

Microbiological analyses for fecal coliform in water and shellfish samples were carried out using the Multiple Tube Fermentation Test described by the American Public Health Association (APHA) (1970).

A 30-L aquarium was used for the depuration study. Sand, collected from an area of the lagoon shown to be devoid of FC, was placed into the aquarium, and clean seawater from the ocean side of the atoll was added. Both lagoon and ocean waters were tested for the presence of FC. *Anadara* sp. harvested from areas known to have high FC concentrations were placed in the tank and allowed to burrow into the sand. Twenty animals were harvested at 0, 3, 6, 9, 24, 48, and 72 hr in triplicate and analyzed for FC, as described above. This experiment was conducted three times (replicates S-1, S-2, and S-3).

One-hundred-fifty *Anadara* sp. were collected from an area known to be contaminated with FC. All shells were thoroughly scrubbed with clean tap water. All but 20 of the *Anadara* sp. were placed in a large pot containing 1 L of water. The first 20 clams were processed as the time zero control. Steam rising from the water surface was used as the signal to begin timing. At 5-, 10-, 15-, and 20-min intervals, 30 cockles were removed and placed on ice to minimize further cooking. FC evaluation of the shellfish meat was carried out as described in APHA (1970).

A walking sanitary survey was conducted along the shore where the nearshore samples were taken. General observations regarding beach activities were noted and an attempt was made to identify nonpoint sources of FC.

Results

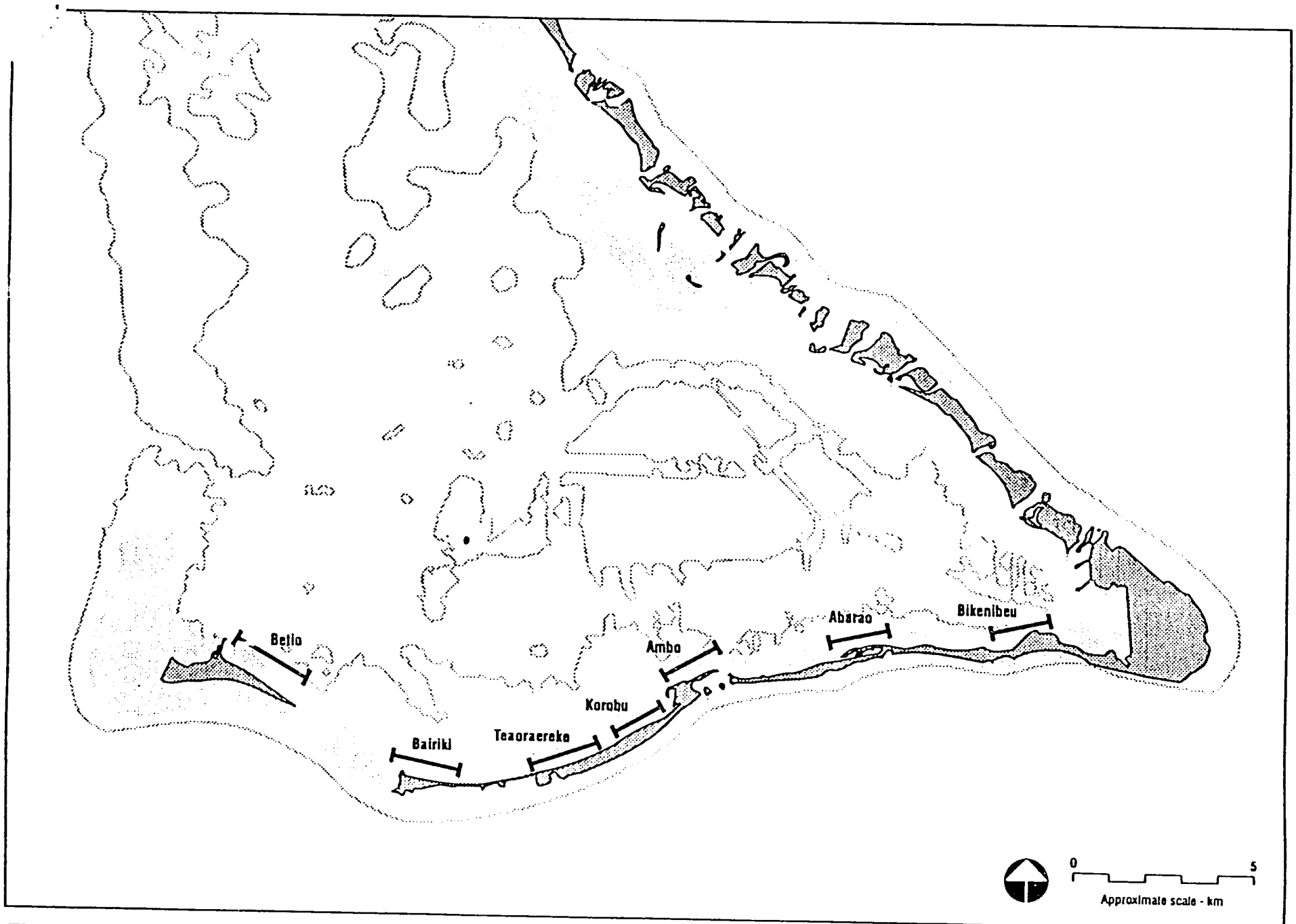

Figure 1 Schematic representation of site locations for microbiological studies, Tarawa Lagoon, Kiribati.

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standards (200 MPN FC/100 ml). The most continuously high levels of FC concentration were along the nearshore transect at Korobu; the lowest median values were at the nearshore Teaoraereke and Ambo transects. Variability between sites within transects was greatest at Betio and Bairiki. The highest concentrations of FC measured during the survey were on these transects (13,000 MPN FC/100 ml at Betio and 50,000 MPN FC/100 at Bairiki). The water above the seagrass bed also failed to meet standards for growing shellfish. The deep water lagoon samples were all below detection for FC.

Table 1 Results of South Tarawa Lagoon water testing.

Location	Date	Fecal Coliform (Median MPN/100 ml)	Range FC (Median MPN/100 ml)
Teaoraereke	26 July 1993	105	<20 - 1,700
Bikenibeu	24 Aug 1993	555	<50 - 5,000
Seagrass shelf	21 Sep 1993	110	80 - 110
Korobu	26 Oct 1993	2,250	130 - 7,000
Bairiki	10 Nov 1993	671	40 - 50,000
Betio	6 Dec 1993	225	<20 - 13,000
Abarao	5 Jan 1994	140	<20 - 1,700
Ambo	5 Jan 1994	40	<20 - 1,700
Deep water (lagoon)	various dates	<20	<20

The results of the tidal/time series samples are presented in Figure 2. At the Teaoraereke transect, the levels of FC closely followed the flow of the tide; however, at Korobu the FC levels remained high throughout the tidal cycle. This may indicate low tidal current velocities at this location on this particular occasion or greater use of the area. Rainfall was high on both dates (39 and 30 mm, respectively), but available data do not show the timing of rainfall. Presumably, rainfall would increase contamination and variability.

Shellfish Analyses

The results of the analyses for FC in shellfish are presented in Table 2. It is apparent that shellfish harvested in deeper waters (>1,000 m from shore) are not directly affected by the FC concentrations found near shore. FC concentrations of shellfish harvested from the seagrass area (<1,000 m from shore), however, exceeded the maximum allowable concentration for shellfish meat (230 MPN FC/100 g). Shellfish collected nearshore exceeded the standard by 20 fold.

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Table 2 Results of South Tarawa Lagoon shellfish testing, 7 September 1993.

Location	Fecal Coliform (Median MPN/100 ml)
Offshore No. 1	<20
Offshore No. 2	<20
Offshore No. 3	<20
Seagrass shelf No. 1	671
Seagrass shelf No. 2	671
Near shore	5,000

The results of the depuration experiment are presented in Figure 3. The first two studies (S-1 and S-2) revealed that this method of depuration was ineffective for the first 24 hr. A third study (S-3), however, showed a significant decline in the number of FC after 48 hr and, by 72 hr. FC were nondetectable.

The results of the cooking study are presented in Figure 4. Cooking the shellfish for more than 5 min but less than 10 min reduced FC levels well below the accepted FC standard.

Sanitary Survey

The results of the sanitary survey are presented in Table 3. Residents collect shellfish and swim all along the south lagoon, as well as toileting there. FC levels appear to correlate with population density. No conditions were observed along the Korobu transect, however, that could account for the higher median value found there. Although a few houses and housing projects have flush toilets in Betio and Bairiki, most of the population in these areas continues to use the lagoon as a toilet.

Table 3 Sanitary survey of shoreline along sample transects.

Location	Animal Husbandry	Toileting	Shellfishing	Swimming	Crowding[1]	Exceeded FC Bathing Standard (200 MPN/100 ml)
Bikenibeu	+++	Yes	Yes	Yes	4	Yes
Abarao	+	Yes	Yes	Yes	1	No
Ambo	+	Yes	Yes	Yes	1	No
Korobu	+	Yes	Yes	Yes	3	Yes
Teaoraereke	++	Yes	Yes	Yes	3	No
Bairiki	++	Yes/No	Yes	Yes	3	Yes

Betio	++	Yes/No	Yes	Yes	5	Yes

[1]Crowding was judged relative to Betio on a scale of 1-5 (minimum to maximum)

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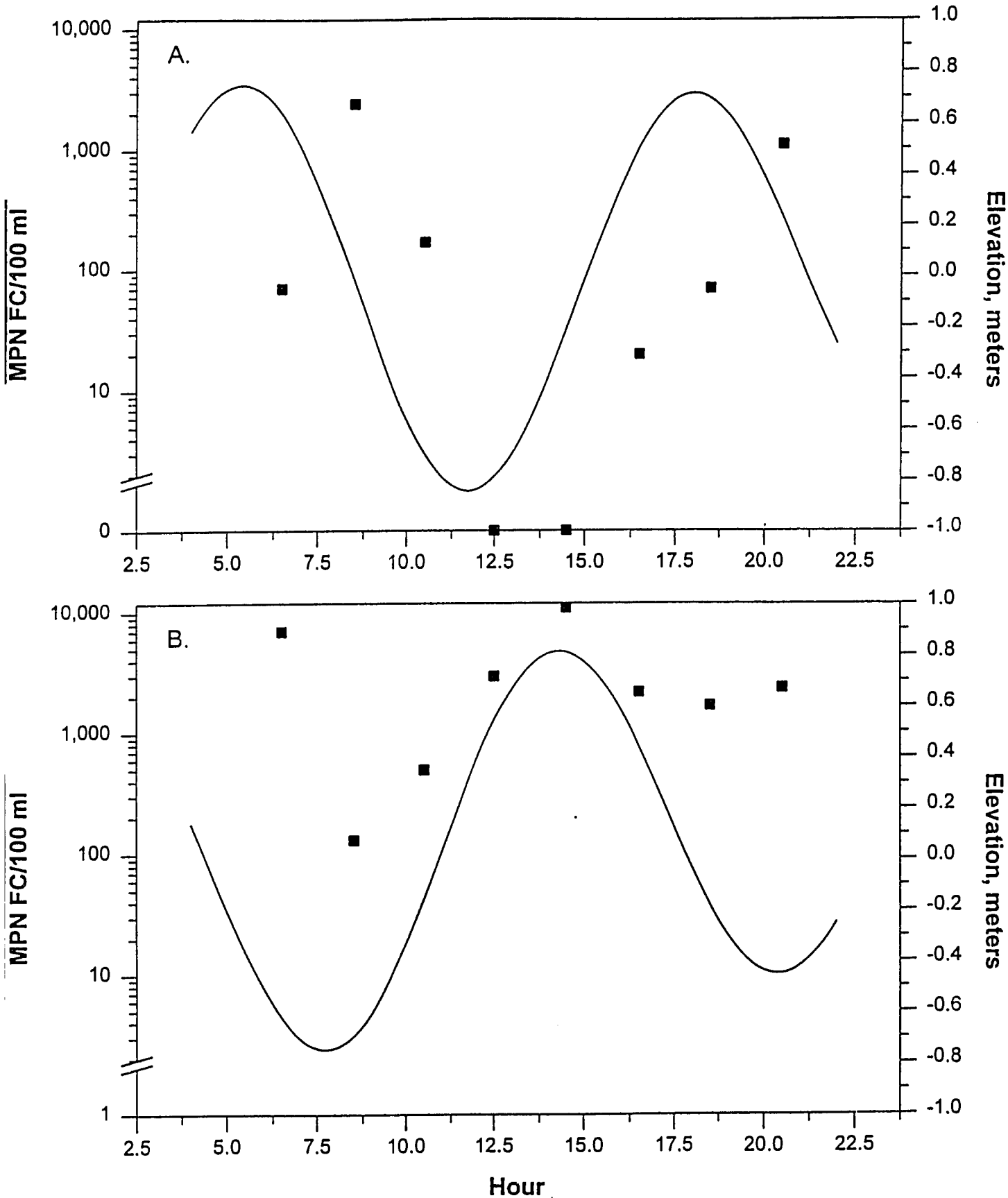

Figure 2 Relationship between tidal flow and fecal coliform concentrations at A) Teaoraereke (4 August 1993) and B) Korobu (26 October 1993) in Tarawa Lagoon, Kiribati.

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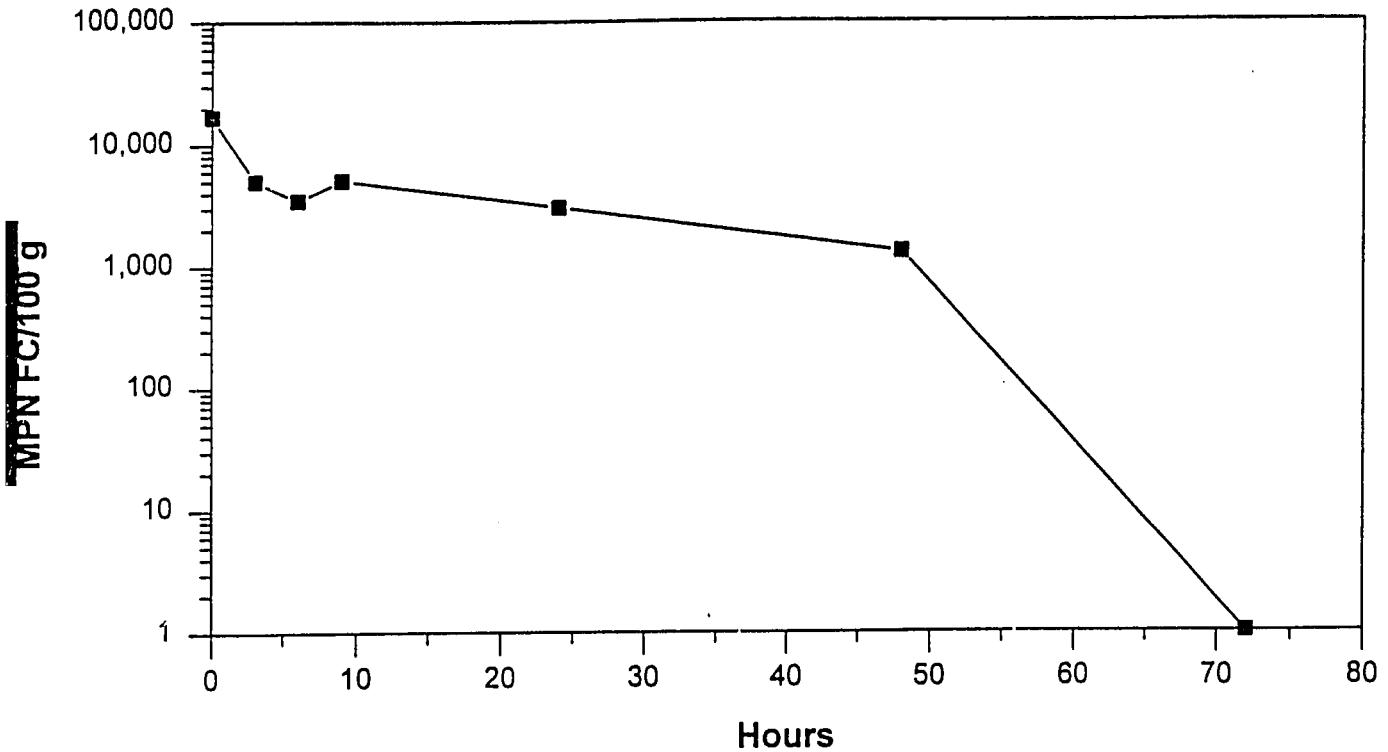

Figure 3 Results of depuration experiments on *Anadara* sp. from Tarawa Lagoon contaminated with fecal coliform.

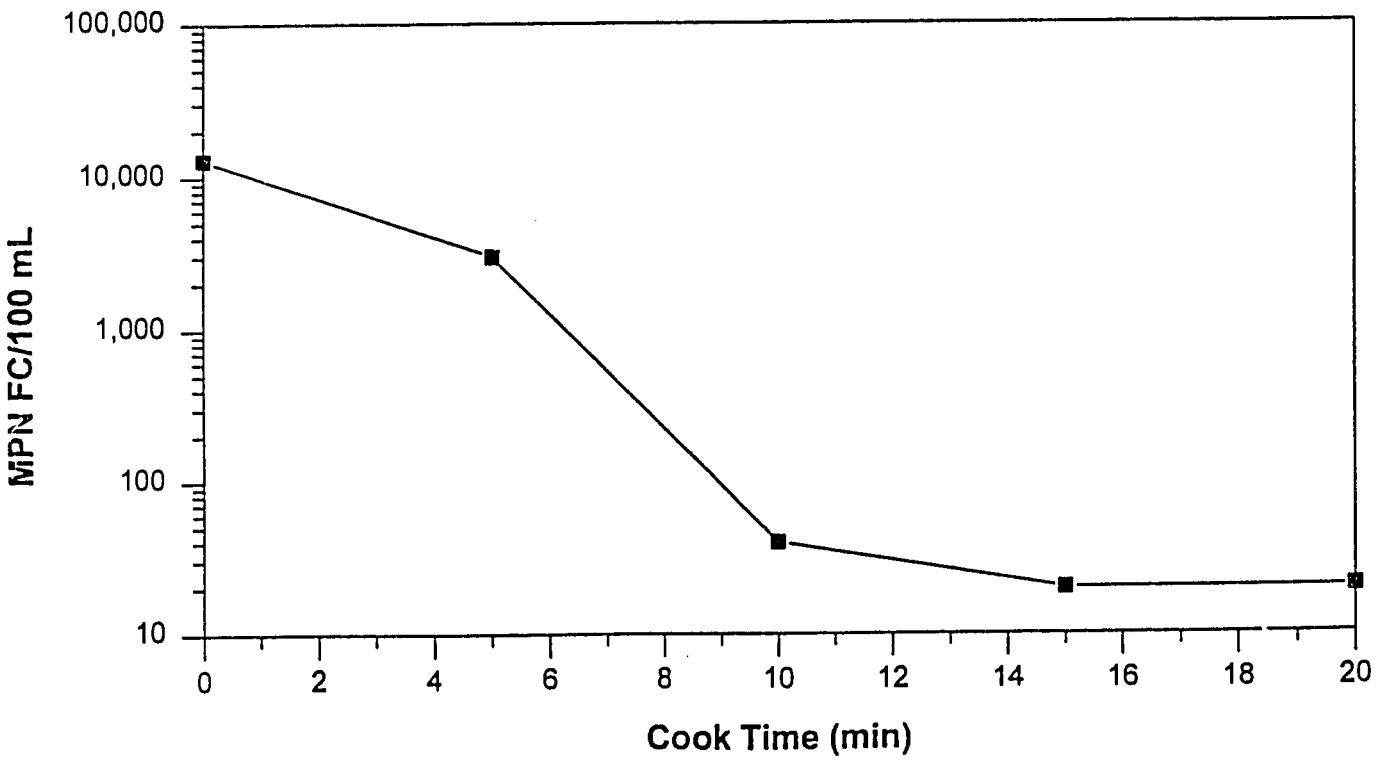

Figure 4 Results of cooking experiment on *Anadara* sp. from Tarawa Lagoon contaminated with fecal coliform.

Areas with no detectable FC concentrations were those with the least activity. In some cases, sample sites were along causeways where it was not practical for people to erect housing, so overall activity in these areas was very low.

Swine were found in many areas along the shore of the lagoon. FC concentrations appear to be an adequate measure of the impacts of crowding and animal husbandry. Swine may have a significant impact on FC levels in some areas. At Bikenibeu, swine holding pens line the shoreline for about a kilometer.

Discussion

Previous studies in Tarawa Lagoon documented the occurrence of high concentrations of fecal coliforms along the southern portion of the lagoon (Johannes et al. 1979; Naidu et al. 1992; Kelley 1993). Our study included transect sampling along the southern lagoon in an attempt to further define the extent of fecal pollution.

According to Kelley (1993), Bikenibeu is by far the most heavily polluted area along the shore. This survey found that the concentrations of FC in waters off Bikenibeu are similar to those previously reported. FC concentrations at Betio and Bairiki, however, are not significantly greater. Betio does have some flush toilet facilities; however, with the high population density (>5,000 persons/km^2), many people continue to use the lagoon as a toilet. The situation at Bairiki is similar; there is a mix of housing, some with and some without flush toilets.

FC concentrations dropped dramatically in offshore samples. The phenomenon of coliform die-off in tropical marine waters has been documented by Fujioka et al. (1981) and Fujioka and Narihawa (1982). These studies demonstrated that sunlight can reduce coliform concentrations by a factor of 100 within 2 hr of exposure. Sunlight probably plays a major role in the reduction of coliforms introduced into the shallow portions of the lagoon. Kelley (1993) reported a die-off rate of 0.11 h^{-1}, equivalent to a die-off of 50% in 6 hr or half a tidal cycle. This low rate is still sufficient to reduce FC concentrations below detection limits in deep lagoon waters, according to model studies (Chen et al., this volume).

The highest median value observed, at Korobu, could not be explained by the sanitary survey. Crowding and toileting were not found to be significantly different at Korobu than at any other site. The areas along causeways, however, may be used for toileting because of the privacy afforded by vegetation and the lack of settlements in the immediate areas.

Rainfall was not factored into our study or that of Kelley (1993), and rainfall data were available only through October 1993. In light of the number of swine residing along the shore (especially at Bikenibeu), rainfall effects could be highly significant. According to the guidelines of the National Shellfish Sanitation Program (1992), shellfish growing areas should be evaluated to determine fecal coliform loading following rainfalls. In addition, shellfish regulating programs should set harvesting

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An increasing body of evidence (Rivera et al. 1988; Fujioka et al. 1988; Hardina and Fujioka 1991) has demonstrated that the coliform organism used as a standard indicator of the presence of human sewage contamination may not be suitable for use in tropical waters. These studies show that the presence of coliform (including fecal coliform) is so ubiquitous that it is useless as an indicator. Our study found that FC levels did correlate with activity along the shore, with FC concentrations below the detection limit in several uninhabited areas. What has not been addressed is the impact of swine on the lagoon. Even if people are using the lagoon as a toilet, the large amount of swine waste washed into the lagoon following rainfalls must overwhelm the contribution by humans in some areas.

Clearly, shellfish harvested in the seagrass beds on the lagoon flats and the nearshore areas are unfit for human consumption. This is in agreement with Kelley (1993), who found that contamination of shellfish drops further out onto the seagrass bed. Again, rainfall effects were not addressed in either study.

Although the shellfish are contaminated, our study showed that clearing FC from the meat is a simple process. A greater than 10,000-fold depuration of FC in shellfish was observed by simply placing the shellfish in a tank of recirculating seawater for 72 hours. Caution must be used when interpreting this finding. Enteric viruses have been detected in water and shellfish tissue that have met FC standards (Gerba et al. 1979; Rose and Sobsey 1993). Sobsey et al. (1991) have demonstrated that enteric viruses (specifically hepatitis A virus) do not depurate from clams at the same rates as bacteria and that depuration may not be an adequate remedial method for the removal of this virus. Conversely, Shuval et al. (1971) and Fujioka et al. (1980) have demonstrated undefined antiviral properties in tropical ocean waters. Whether these properties are in the waters of Tarawa has not been determined.

Recently, the U.S. National Academy of Sciences, Institute of Medicine (Ahmed 1991) reviewed the factors affecting seafood safety. One of the conclusions from the review was "thorough cooking of seafood products would virtually eliminate all microbial and parasitic pathogens." Our results confirm this observation and show that cooking shellfish appears to be the safest and most convenient method for reducing microbiological organisms in shellfish.

Coral Reefs and Coral Communities of Tarawa

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Coral Reefs and Coral Communities of Tarawa

By

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Abstract

Tarawa Lagoon provides an unusual setting for coral reefs because it lies in the equatorial upwelling, a region of high productivity. The triangular lagoon is largely enclosed from the east and south, but the western side is linked with the ocean through a wide, submerged barrier reef. The dense human population of Tarawa has affected the lagoon through intense fishing pressure and through the construction of causeways that have closed all the small passages (*hoas*) between islands in the southern part of the atoll, and some on the eastern side. The impacts of these factors are apparent on the reefs. Coral cover and diversity increase from west to east and north to south as a consequence of the one-sided opening of the atoll. Algae are abundant and the reefs are dominated by fragmenting corals in much of the central lagoon, probably as a result of high productivity. Many of the reefs in the northern and western part of the lagoon appear healthy but Acropora mortality has occurred along the barrier reef and little live coral remains in the southeastern lagoon. Radiocarbon dating revealed that this mortality occurred within the last few hundred years, possibly this century. If this dieback is recent, then the urbanization of Tarawa may have been responsible for the reef kill. As a consequence of this mortality, much of the reef habitat and associated communities on the shoals of the southern lagoon have been lost.

Introduction

Tarawa lies in the nutrient-rich waters of the equatorial upwelling zone, which contributes to the great productivity of the atoll and surrounding ocean (Kimmerer and Walsh 1981; Kimmerer, this volume). The geomorphology of Tarawa (Figure 1) is characterized by an eastern and southern reef rim capped almost entirely by islets and a western rim submerged to several meters below the surface, creating a one-sided connection between the atoll lagoon and the surrounding ocean. This limited connection with the ocean has been further exacerbated by the closure of all the reef flat passages that once connected the lagoon with the open ocean between the islets of the southern reef rim. These connections have been obliterated by causeways constructed over the past 50 years to facilitate transportation along the long (approximately 30 km), narrow (50-500 m wide) metropolitan area of South Tarawa. Fewer causeways have been built along the eastern series of reef islets known as North Tarawa, and consequently some water still flows through the shallow passages there (Chen et al., this volume).

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The shape of the atoll, combined with subsequent closure of passages, has created a lagoon with marked northwest to southeast gradients in water quality, including inorganic nutrients, salinity, and turbidity; plankton productivity, composition, and biomass; and sediment composition (Weber and Woodhead 1972; Kimmerer and Walsh 1981; Kimmerer, this volume). The distribution of benthic habitats and the community structure of both soft and hard (reef) bottom habitats follows these gradients.

The purpose of this study was to document the nature and variation of shallow water reef communities throughout Tarawa Lagoon to 1) assess the influence of the unusual setting of Tarawa on the composition of coral and associated reef communities, 2) assess the current state of these reefs, and 3) evaluate potential human impact on lagoonal reefs. A similar analysis of soft bottom communities is presented by Paulay in this volume.

Methods and Materials

Description of Study Site

Although the general physiography of Tarawa is comparable to that of other atolls, the major habitat types differ in several respects. Many of these differences may be attributed to the location of the atoll in an upwelling region and to its lopsided shape. Four major habitat types can be differentiated within the lagoon: 1) a rim of sand flats, 2) a submerged barrier reef, 3) a central lagoon bottom, and 4) patch reefs and shoals that rise toward the surface (Figure 1).

1) **Sand flats.** Intertidal to shallow subtidal sand flats front the lagoonal sides of islets as well as shallow passages along the southern and eastern lagoon margin. These unusually wide (to approximately 2.5 km) sand flats are dominated by soft sediments and are essentially devoid of living reefs or corals; their physiography and biota are discussed in Paulay (this volume).

2) **Submerged barrier reef.** A barrier reef reaching to within approximately 0-8 m of the surface extends nearly continuously from near the northern tip (Naa and Buariki) of the atoll to its southwestern corner (Betio), interrupted only by the single wide shipping channel about 10 km north of Betio. As this reef reaches northward, it gradually becomes more shallow, so that a long stretch at its northern tip reaches the intertidal zone. The reef is several hundred meters wide and has considerable topographic variation through its oceanward to lagoonward sides, with a typical relief of 1-5 m. Short channels and pockets of coarse sand are interspersed among reef promontories of various heights. Because of its dissected form and gentle slope, the reef front of this barrier reef differs from the reef front of typical atolls, including the southern and eastern sides of Tarawa, which tend to have a much more even, less dissected topography.

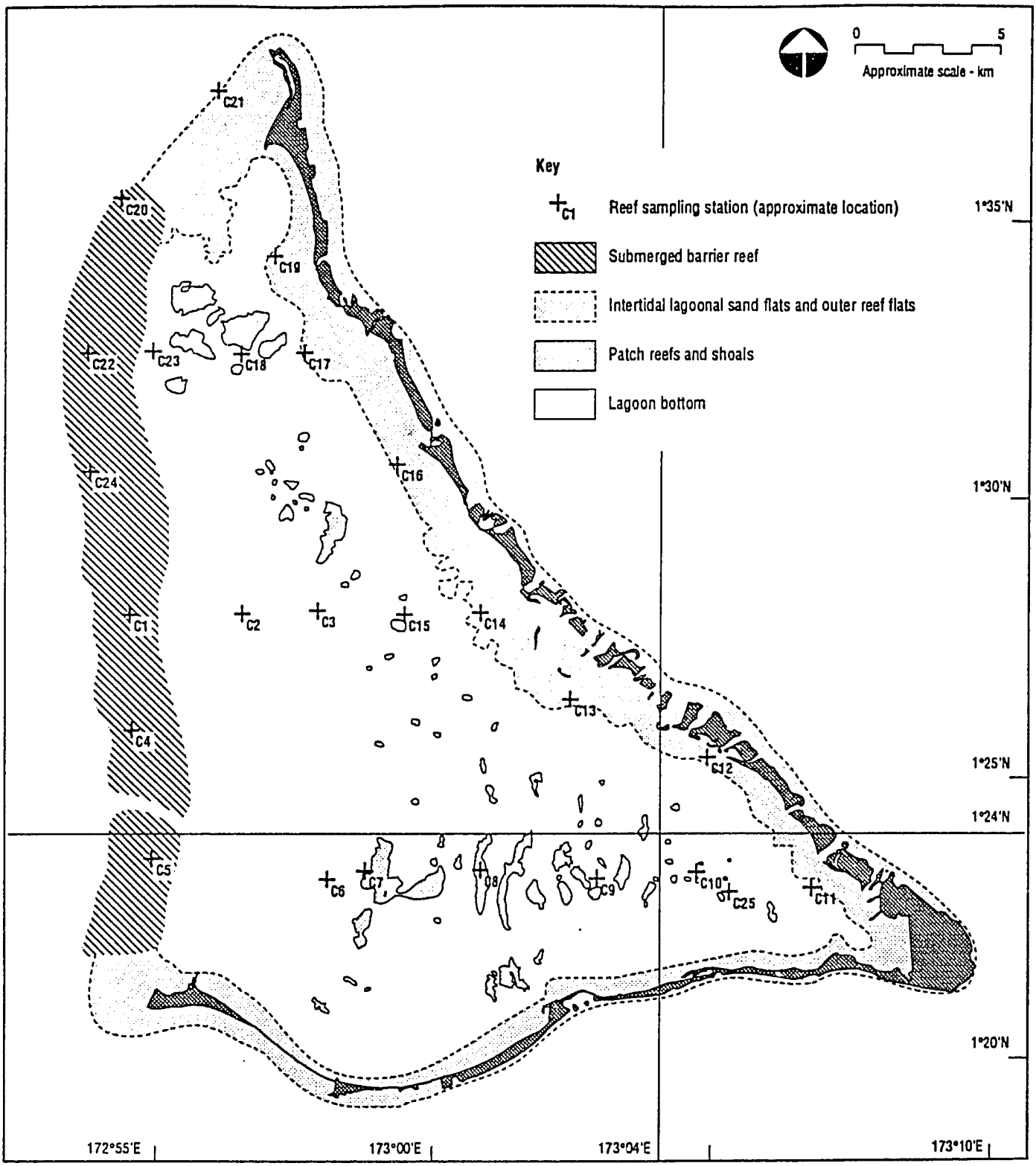

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Figure 1 Map of Tarawa Lagoon showing location of reef sampling stations (C1–C24) and four main habitats (barrier reef, sand flats, patch reefs and shoals, and lagoon bottom). Not all minor shoals/patch reefs have been charted, so these habitats are underrepresented. Coral mortality is greatest south of 1°24'N and east of 173°4'E.

3) **Lagoon bottom.** The lagoon bottom slopes gently from marginal sand flats and the barrier reef toward the relatively flat, wide lagoon floor. Patch reefs and shoals rising from the lagoon bottom, as well as narrow fringing reefs locally flanking the sand flats, can harbor rich coral communities. The lagoonal slope and plain, however, are largely devoid of corals. Only occasional colonies of primarily *Pocillopora damicornis* and *Porites* species were seen. The biota and environments of the lagoonal soft bottoms are described in more detail in Paulay (this volume).

4) **Patch reefs and shoals.** Numerous patch reefs and shoals rise from the lagoon bottom. Patch reefs and shoals are distinguished by the prevalence of reef matrices and coral communities on the former, and soft sediments on the latter, although they clearly intergrade. As discussed below, patch reefs are the prevalent form in the northern lagoon, while shoals, which can attain a much greater areal extent, characterize the inner, southeastern lagoon. The southern lagoon is markedly dominated by large shoals, with a striking series of very large shoals, many elongated in a north-to-south direction, extending about 2-7 km from the southern atoll margin (Figure 1). These shoals partly divide the atoll lagoon into a larger northern and smaller southern section (Kimmerer and Walsh 1981).

   Patch reefs and shoals may extend vertically anywhere from just above the lagoonal plain to just reaching and even extending above the surface. Several shoals in the southern lagoon extend well into the intertidal zone. One of these shoals, Bikeman Island, was high enough to harbor lush vegetation until it suddenly disintegrated through erosion in the past decade (Chen et al., this volume). The structure and communities of shoals and patch reefs are discussed in detail below.

Methods

To evaluate the distribution of major bottom cover and the abundance and diversity of corals, quantitative surveys were run at 24 stations and numerous additional sites were examined qualitatively. The 24 quantitative stations were situated along five transects: three crossing the lagoon east to west, one along the submerged western barrier reef, and one along the scattered fringing reefs and nearshore patch reefs bordering the sand flats of North Tarawa (Figure 1). All stations were situated on fringing reefs, barrier reefs, patch reefs, or shoals, because the coral cover of the lagoon bottom between these promontories or the nearshore sand flats was insignificant. We attempted to place stations evenly along the five major transects; however, the sparsity of the patch reefs and fringing reefs in some areas necessitated some adjustment of station positions. Although we chose shallow (0-5 m deep at low tide) sites for most stations, only deeper reefs (to a maximum of 11 m deep) were available at a few sites. All site locations were determined by a global positioning system (GPS) with no corrections (Introduction to the Study, this volume).

Bottom cover (e.g., live coral, macroalgae, reef pavement, rubble, and sand) was measured using a point-quadrat method, with paired, 0.25-m^2 stringed quadrats, with 16 line intercepts, placed at

5-m intervals along a 30-m transect line (seven pairs). Coral cover, identified to genus, was also measured by the line-intercept method under the same 30-m transects. Coral diversity was semiquantitatively enumerated in a 10-min, timed search, in which all coral species encountered were recorded, with portions of unidentified species collected for subsequent identification.

Although few coral species were found alive and coral cover was low in the southeastern lagoon, the skeletal remains of numerous additional species indicated more thriving reefs at some time in the past. To investigate this loss of diversity, dead and living coral species were enumerated at several stations in this area. Samples of several species known only from dead colonies within the southeastern lagoon were collected at Stations C10, C11, C24, and C25 (Figure 1) and radiocarbon dated by Beta Analytic, Inc. (Miami, Florida).

Results

Coral cover in the lagoon shows a general decrease from northwest to southeast (Table 1; Figure 2). Quadrat and line-intercept measures of coral cover were within 5% coral cover at all but two stations (C18 and C24) (Figure 3). Although coral cover was consistently moderately high in the northern stations (20-40%) and always low in the southern lagoon (0-3%), it fluctuated considerably among patch reefs through the middle of the lagoon (5-50%) (Figures 2 and 3). Much of the variation in the central lagoon is the result of variation in reef type. Central lagoonal patch reefs vary greatly in their minimum depth, size, shape, and relative abundance of soft and hard substrata. This variation is readily apparent in the various cross-lagoon transects (Figure 3).

In contrast, coral cover decreased rather uniformly from north to south along the physiographically less variable barrier reef. Coral cover also decreased north to south along the fringing reefs bordering the eastern sand flats (Figure 3). Coral cover was lowest on the shoals in the southeastern portion of the lagoon.

Montipora, Acropora, Porites, Heliopora, and *Pocillopora* were the dominant coral genera at the 24 stations surveyed (Figure 4). The relative abundance of different genera, however, varied regionally among stations. Patch reefs in the middle and northern lagoon are strikingly dominated by a diversity of *Montipora* and *Acropora* species, while most reefs in the southern lagoon (stations C6-C12) lack these genera and consequently have a low coral cover dominated by *Porites* spp. and *Pocillopora damicornis*. In contrast, the western barrier reef hosts a much more heterogeneous coral assemblage, dominated by *Porites, Heliopora*, and a variety of faviid and other genera, with small amounts of *Acropora, Montipora* and *Pocillopora*. (Figure 5).

The pattern of generic richness, as measured by 10-min-long, timed searches, is similar to coral cover, increasing from south to north and from east to west (Table 2, Figure 6). Generic diversity is clearly highest on the western reef, moderately high throughout the central lagoonal patch reefs, and lowest

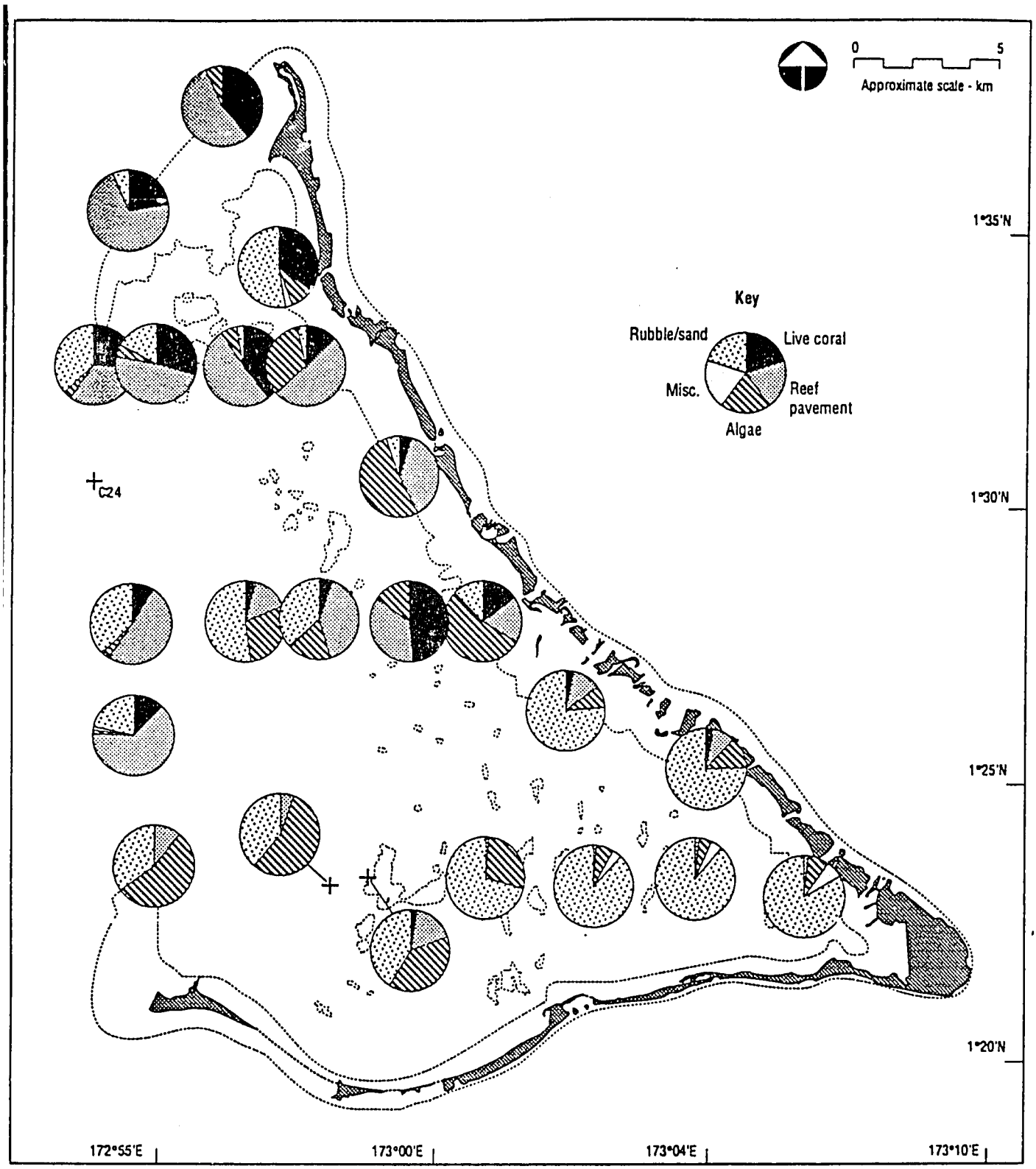

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Figure 2 Map of Tarawa Lagoon showing the proportion of bottom cover types at 24 reef stations (based on quadrat data, see methods). Miscellaneous category includes mostly sedentary invertebrates other than hard corals. Algal cover is red and brown algae, except at Station 5, where it is entirely Halimeda. No Halimeda was found at other stations.

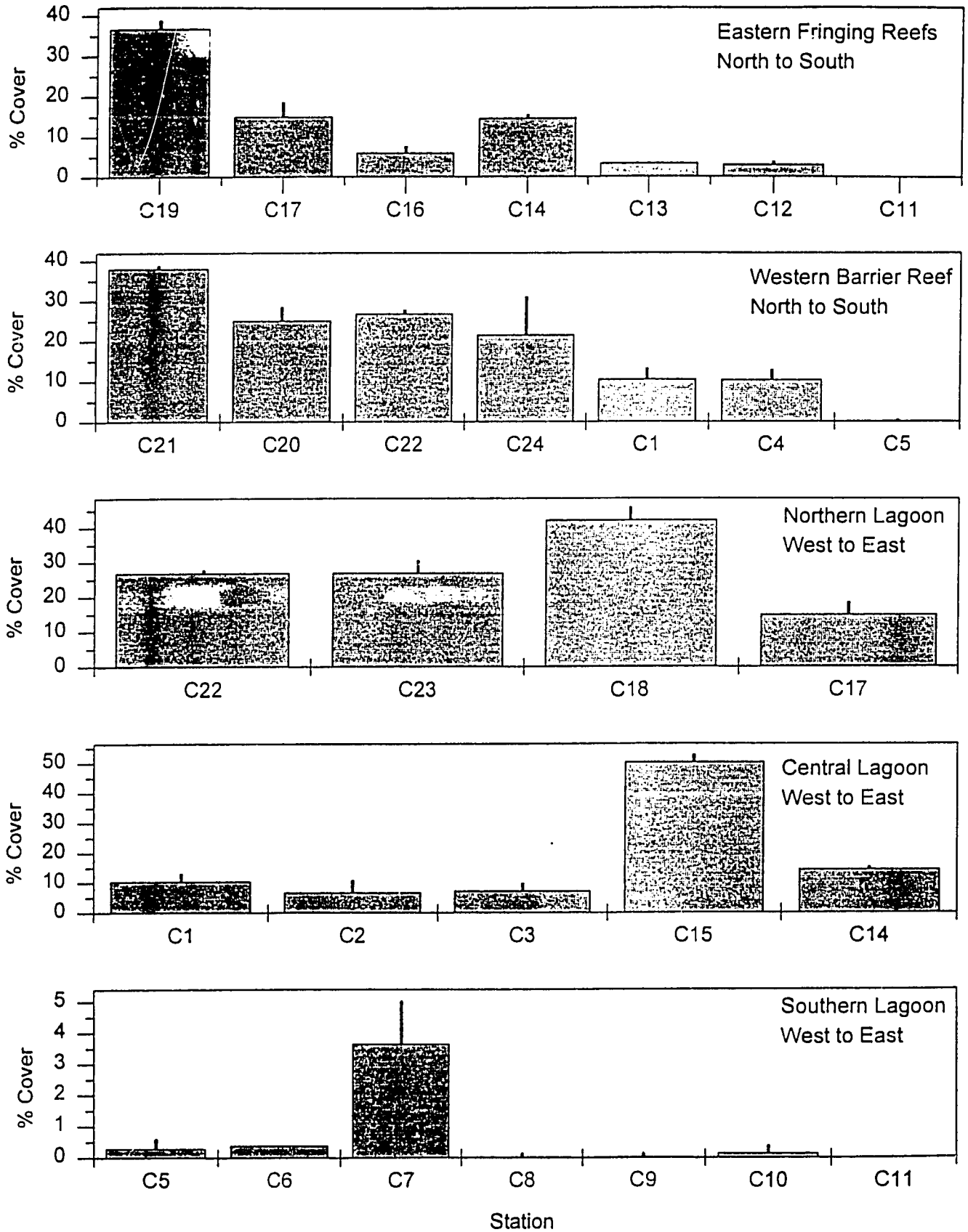

Figure 3 Comparison of percentage of coral cover at 24 quantitative stations on five transects in Tarawa Lagoon. Coral cover is mean +/- 1 SD of quadrat and transect measures of cover combined.

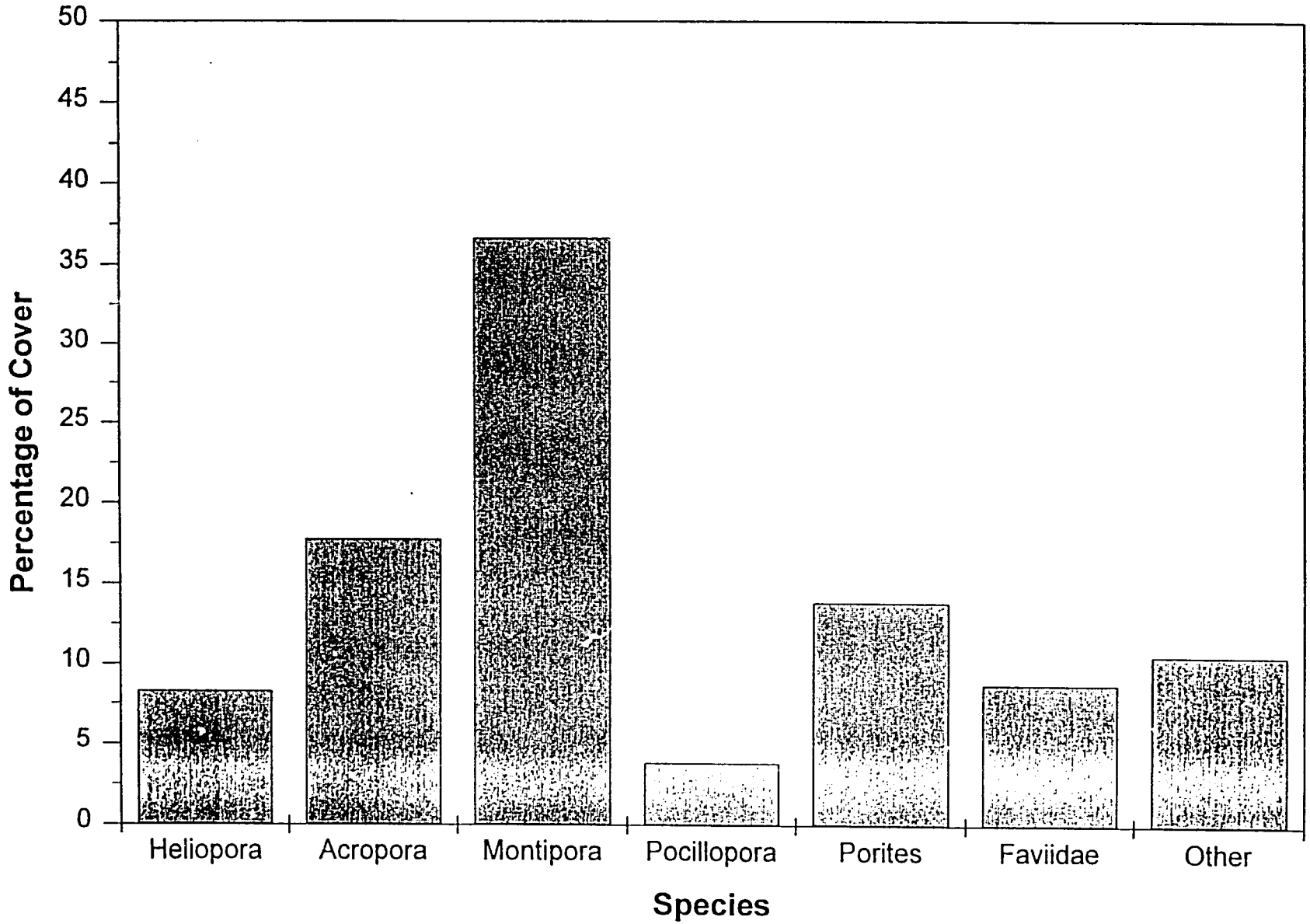

Figure 4 Percentage of hard coral cover by major taxa, based on line-intercept transect data (Table 1), summed for all 24 quantitative stations.

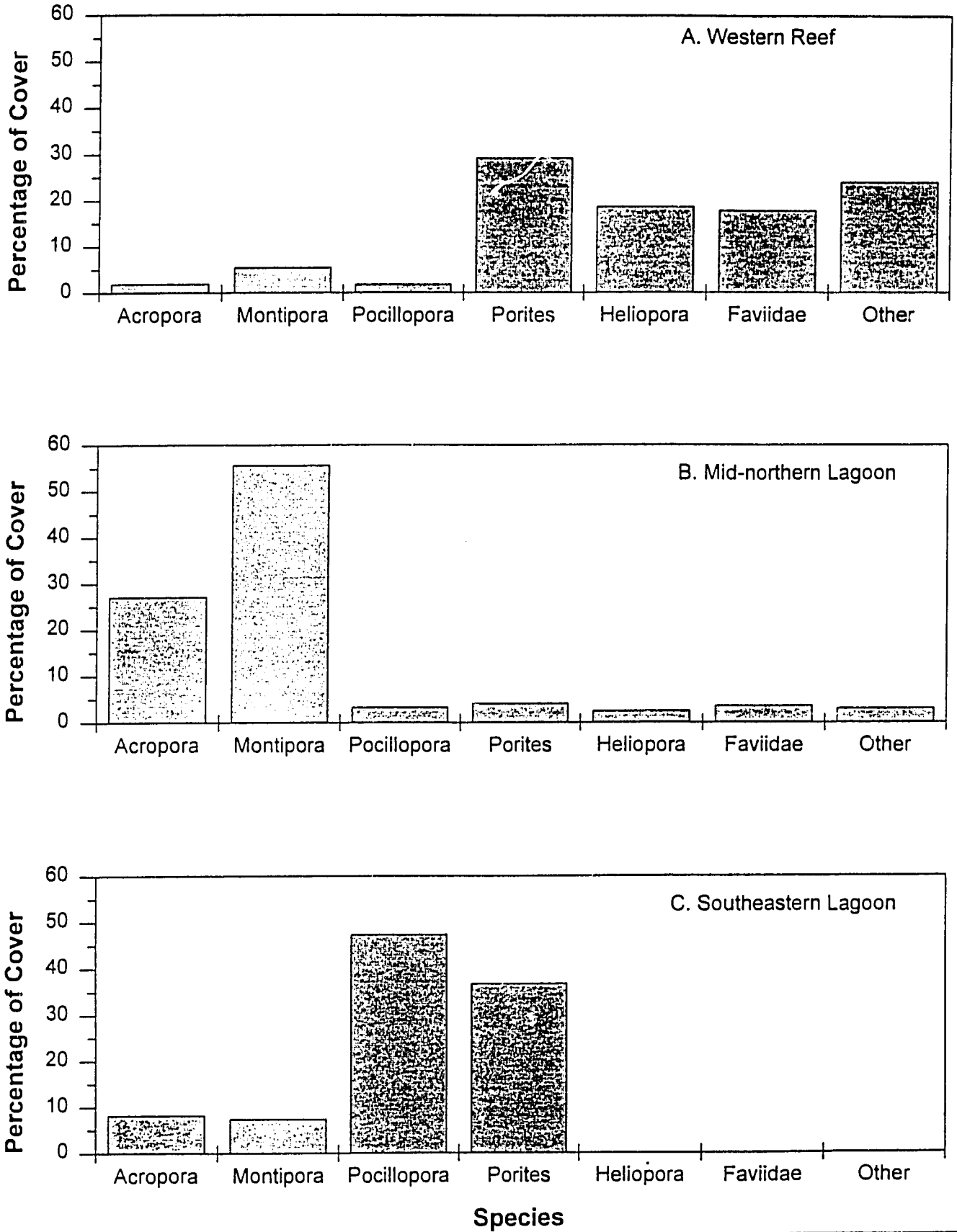

Figure 5 Percentage of hard coral cover by major taxa, based on line-intercept transect data (Table 1), summed for three distinct lagoonal areas: A) western reef, all stations (C1, 4, 5, 20, 21, 22, 24) along the western barrier reef; B) midnorthern lagoon, all patch reef stations (C2, 3, 14-19, 23) in midlagoon and northern lagoon; and C) southeastern lagoon, all patch reef and shoal stations (C6-12) in the southeastern lagoon.

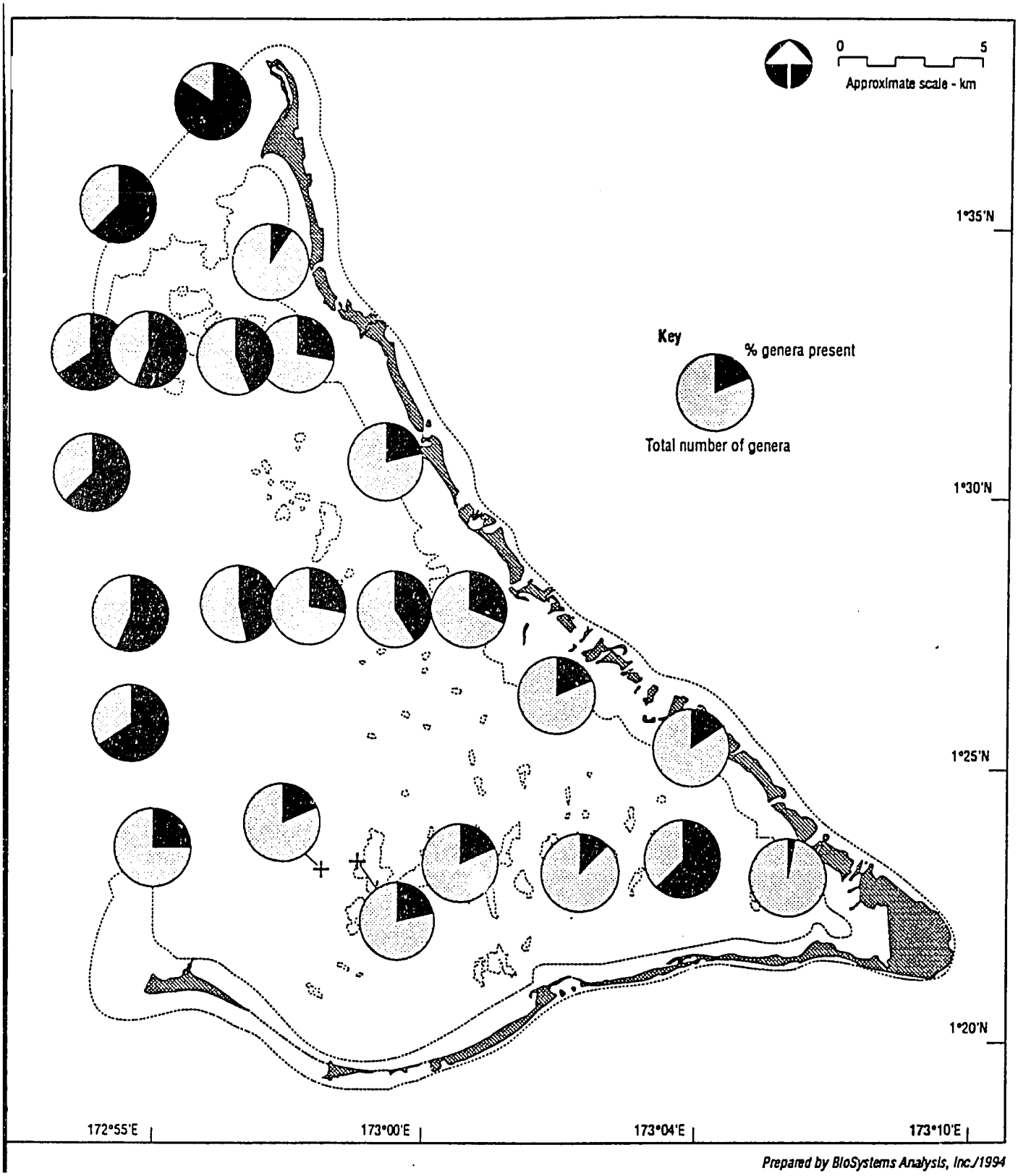

Figure 6 Generic richness of hard corals per station. Comparison of number of genera encountered during 10-minute, timed search at station to the total number of genera encountered during all such searches at the 24 stations.

Table 1 Percentage of coral cover by genus for each station; Tarawa Lagoon, Kiribati.

Order	Station Number																							
Genus	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24
Scleractinia																								
Acanthastrea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Acropora	0.0	3.6	1.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.4	1.4	2.1	0.0	1.1	9.9	35.7	2.6	0.0	0.0	4.5	0.0
Alveopora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Astreopora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Coscinaraea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.1	0.0	0.0	0.0	1.0	0.1	0.0	0.1	0.0
Cyphastrea	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.5	1.5	0.0	0.3	0.0	0.5	0.9	0.5
Echinopora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.3
Favia spp.	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2	4.5	1.0	1.9	0.3
Favia stelligera	0.6	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.5
Favites	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.8	0.0	0.3	0.1
Fungia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.5	0.7
Goniastrea	0.0	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.4	0.0	0.1	0.5	1.2	0.8	0.1
Herpolitha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Hydnophora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Leptastrea	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.3	0.7	0.9	0.1	1.7
Merulina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Montastrea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Montipora (branching)	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Montipora (encrusting)	1.9	4.3	6.7	1.7	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	11.0	45.6	15.6	31.7	0.0	1.1	0.0	1.4	0.1	5.2	0.0
Mycedium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.1
Pavona	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.3	0.0	0.1
Platygyra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.1	0.5	0.0	0.0
Pocillopora	0.1	0.0	0.1	0.2	0.1	0.0	3.3	0.1	0.0	0.3	0.0	0.0	0.0	2.2	2.6	1.1	0.1	0.1	0.1	1.1	0.3	0.6	1.2	0.0
Porites rus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0
Porites, branching	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.4
Porites, massive	3.7	1.8	1.1	2.3	0.0	0.3	0.0	0.0	0.1	0.0	0.0	2.5	0.8	0.9	0.4	0.0	0.2	0.7	0.3	9.9	7.9	3.6	0.6	5.6
Psammocora	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.9	0.0	0.4
Seriatopora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	2.5	0.0
Stylocoeniella	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stylophora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.2	0.0
Turbinaria	2.7	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	5.3	0.1	1.3
Milleporina																								
Millepora	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0
Coenothecalia																								
Heliopora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.3	0.0	7.0	3.2	11.8	4.9	2.0
Total cover of hard corals	12.5	9.7	9.2	8.7	0.1	0.4	4.6	0.1	0.1	0.3	0.0	2.5	3.4	17.0	52.0	7.1	17.5	44.9	38.2	27.6	37.6	27.6	24.9	15.0

Table 1 Percentage of coral cover by genus for each station; Tarawa Lagoon, Kiribati (cont.).

Order	Station Number																							
Genus	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24
Alcyonacea																								
Sarcophyton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.3
Sinularia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Zoanthidea																								
Palythoa	0.2	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2
Corallimorpharia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0
Total cover of all sessile fauna	12.7	9.7	9.2	9.2	0.1	0.4	4.6	0.1	0.1	0.3	0.0	2.5	3.4	17.0	0.0	7.1	17.5	44.9	38.2	27.6	40.0	29.1	24.9	0.0
Sand channels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.3	24.3	0.0
Transect length (m)	30.0	30.0	30.0	30.0	60.0	30.0	30.0	90.0	90.0	90.0	90.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0

Table 2 Reef coral genera recorded in 10-minute diversity searches, by station number, Tarawa Lagoon.

Genus	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Millepora				X						X	X										X		X	X
Heliopora				X	X		X		X				X	X			X	X		X	X		X	X
Stylocoeniella	X	X		X																				X
Pocillopora	X		X	X	X		X	X	X	X	X	X		X	X	X	X			X	X	X	X	X
Seriatopora																				X	X	X	X	
Stylophora														X						X	X	X	X	
Acropora	X	X	X	X			X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Montipora	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Astreopora	X	X	X	X			X	X		X		X	X	X				X		X	X	X		X
Porites	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Fungia	X	X		X	X			X		X	X			X	X	X		X		X	X	X	X	X
Herpolitha																					X			
Halomitra					X	X															X			
Psammocora	X	X		X	X	X		X				X	X		X					X	X	X	X	X
Coscinaraea														X	X	X	X	X		X	X	X	X	
Pavona	X			X	X													X		X	X	X	X	X
Acanthastrea		X																						
Lobophyllia	X																				X			X
Symphyllia					X																			
Mycedium																					X	X		X
Merulina	X	X													X						X	X	X	
Hydnophora				X																X	X	X		
Favia	X	X	X	X											X			X		X	X	X	X	X
Favites	X	X		X		X									X			X		X	X	X		
Goniastrea	X	X	X	X											X	X	X	X		X	X	X	X	X
Platygyra	X	X	X	X						X					X		X	X		X	X	X	X	X
Oulophyllia				X																				X
Plesiastrea						X																		
Cyphastrea	X	X	X	X			X							X	X		X	X		X	X	X	X	X
Echinopora				X														X			X			
Leptastrea	X	X		X	X	X														X	X	X	X	X
Turbinaria	X			X																X	X	X		X
Total	18	15	9	21	8	6	7	6	4	2	1	5	6	10	13	7	9	14	3	20	27	21	18	20

An "X" indicates that the genus was recorded at a station in a 10-min search. Additional genera located at each station after the 10-min search are not recorded. An underlined "X" indicates that genera were not recorded at a station alive during or after the search, but were found as dead skeletons.

along the southern lagoon shoals and the fringing reefs bordering the eastern sand flats. Generic richness decreases dramatically west to east along the southern transect; in the southeastern corner, only a single genus, *Porites*, was found alive.

Generic richness shows less variability than coral cover through the central lagoon. The great variation in coral cover in the central lagoon appears to be the result of the dominance of a few genera (especially *Montipora*, but also *Acropora*) (Figure 5). Several stations, especially in areas of the inner lagoon, have low coral diversity combined with high coral cover, the result of rich stands of one or a few species. The generic richness of most of the submerged barrier is fairly uniform, with 18-21 genera. Thus, about two-thirds of the genera encountered throughout the quantitative survey were found within 10 min on a typical barrier reef station.

In contrast to the low diversity of corals now found in the inner southeastern lagoon, dead skeletons of several coral genera indicate that species richness was greater in the past. Only *Pocillopora damicornis, Porites* spp., and a single *Montipora* were found alive south of 1°24'N and east of 173°04'E. This area was surveyed quantitatively at stations C10 and C11, and qualitatively at several other sites, including other shoals and fringing reefs. In contrast, we encountered dead skeletons of *Millepora, Acropora, Montipora, Astreopora, Fungia, Stylophora, Goniastrea, Platygyra, Favia,* and *Cyphastrea* on the surface of shoals in this same area, attesting to a much richer coral community in the past (Table 3). Considering both dead and living colonies, these shoals appear to have been dominated by *Acropora*.

Table 3 Identification of live and dead coral species found in the southeastern elbow of Tarawa Lagoon, by station number.

Genus	C10	C25	C11
Porites	L	L	L
Pocillopora	L	L	D
Montipora	D	L	
Acropora	D	D	D
Favia		D	
Goniastrea		D	
Millepora	D	D	D
Cyphastrea		D	
Fungia	D	D	D
Stylophora		D	
Astreopora	D	D	
Platygyra	D		

L = live specimens seen.
D = dead colonies only.
Station coordinates are C10: 1°23.263'; 173°04.718'E; C11: 1°22.996'N; 173°06.749'E; C25: 1°22.995'N; 173°05.266'E.

Radiocarbon dating of eight colonies of coral species that are no longer extant revealed ages ranging from 440-750 A.D. to 1520-1840 A.D. (Table 4). Because the collections are from a time-averaged death assemblage, the youngest dates are most indicative of the date for the demise of these reefs. Furthermore, these calibrated ages may be older than actual ages, because the ages were corrected for reservoir effect from known-aged coral samples from Enewetak Atoll, which is not in an upwelling area. Because Tarawa is in the equatorial upwelling region, it is bathed in older waters, and coral samples should include a larger reservoir effect. Samples to measure this effect, and thus correct these ages, are currently being sought.

Table 4 Results of radiocarbon dating of eight coral samples collected from dead colonies in southeastern Tarawa Lagoon.

Sample	Species	Station	$^{13}C/^{12}C$	Adj. Age (BP)	Cal. Age (AD)
Beta-72240	*Acropora* sp.	C25	+0.5	1950 ± 60	440 - 750
Beta-72241	*Stylophora mordax*	C25	+0.4	850 ± 60	1460 - 1740
Beta-72242	*Millepora dichotoma*	C10	+1.9	1330 ± 60	1050 - 1340
Beta-72243	*Stylophora mordax*	C25	-0.9	1030 ± 60	1330 - 1600
Beta-72244	*Acropora* sp.	C11	-0.6	910 ± 60	1430 - 1690
Beta-72245	*Fungia fungites*	C10	+2.2	780 ± 60	1520 - 1840
Beta-72246	*Platygyra daedalea*	C10	-0.4	1460 ± 70	950 - 1270
Beta-72247	*Cyphastrea serailia*	C25	+0.7	1440 ± 60	950 - 1280

Station locations are as in Table 3. $^{13}C/^{12}C$ is in parts per thousand. Adj. Age is conventional radiocarbon age ± 1 sigma, reported as RCYBP (radiocarbon years before 1950 A.D.). Cal. Age is calibrated age within 2 sigma (95% probability) = best actual age estimate, including correction for reservoir effect derived from Enewetak Atoll (Marshall Islands) samples. Dating by Beta Analytic, Inc., Miami, Florida, USA.

The abundance of sand and rubble as surface cover on lagoon patch reefs and shoals increases greatly from northwest to southeast (Figure 2). The lack of suitable substrate for coral attachment may be partly responsible for the low coral cover in the southeastern corner of the lagoon. Most of the southern lagoon is dominated by shoals or mounds covered by soft sediment and limited rubble. In contrast, the patch reefs of the northern lagoon have much less soft sediment.

The absence of hard bottom is not in itself sufficient to limit coral growth, evidenced by the dense, multispecies thickets of arborescent *Acropora* growing over large areas of sandy bottom in the northern lagoon (e.g., Station C19, with 35% live coral cover of mostly free-standing *Acropora* thicket over sand) (Figure 2). All the southern shoals are littered with dead *Acropora* sticks, indicating that similar thickets probably occurred there in the past. Moreover, in several of the southern sand shoals, an extensively bioeroded reef framework or branching-coral jumble lies just a few centimeters under the sand surface, suggesting that the substrate of the southern shoals evolved recently from typical patch reefs through reef death and burial.

Fleshy benthic algae are not important as cover on the submerged barrier reef (0-7%), but often dominate the cover on patch reefs in the central lagoon (5-54%) (Figure 2). These algae are also uncommon in the southeastern lagoon (5-13% for southeasternmost stations C9-12), an area dominated by soft bottoms with little opportunity for algal attachment. The southernmost station (C5) on the western reef is an exception, with 54% covered with algae. Algal cover here, however, is dominated only by *Halimeda*, a genus that was insignificant at all other stations surveyed.

Discussion

This section reviews the influence of the nature and historical evolution of the marine environment of Tarawa on the composition of the atoll's lagoonal reefs. Important variables to consider include the asymmetrical form of the atoll, the location of the atoll in the equatorial upwelling zone, and potential natural and anthropogenic disturbances.

Effect of Geomorphology

The diversity and abundance of corals and other benthic organisms in Tarawa Lagoon follow major north-to-south and west-to-east gradients. These gradients are related to the shape of the atoll and to the physical, chemical, and biological gradients that are derived from the one-sided connection between the lagoon and the open ocean. Because most water exchange with the surrounding ocean is through the western submerged barrier reef (Chen et al., this volume), oceanic conditions dominate toward the west in the lagoon, and restricted lagoonal conditions prevail toward the east. The lagoon at the southeastern "elbow" of the atoll is the most distant and, therefore, the most restricted from this oceanic interchange. For example, marked gradients have been documented in nitrate, phosphate, sediment grain size (decreasing west to east), phytoplankton biomass, and turbidity (increasing west to east) (Weber and Woodhead 1972; Kimmerer and Walsh 1981).

Most reef corals in the central Pacific Ocean occur in oceanic rather than lagoonal conditions (Maragos 1974; Chevalier 1979; Paulay 1988); thus, the increase of both coral diversity and abundance in the lagoon toward the northwest is not surprising. A clear zonation of coral species is seen across the lagoon (Figure 5). Numerous genera (e.g., *Stylocoeniella, Pavona, Mycedium, Hydnophora*, and *Oulophyllia*) appear to be limited to the more or less oceanic conditions along or near the western reef. Others, notably several species of *Montipora* and *Acropora*, thrive in the central lagoon, but no longer survive in the most restricted southeastern elbow area. Two species of *Porites* and *Pocillopora damicornis* reach the silt-laden, low-transparency, plankton-rich waters of the southeastern lagoon.

Marked gradients in water quality, sediment composition, coral diversity, and coral zonation are characteristic of semienclosed atoll lagoons in which most oceanic interchange is restricted to a limited part of the atoll perimeter. Few atolls, however, have the unusual shape of Tarawa. In most

atolls, such gradients are set, not from an entire submerged side, but from one or a few narrow but deep passes. In the Tuamotu atolls, which have only one or two passes, several coral genera are restricted to, and the greatest species richness of corals occurs, near the pass entrances (Chevalier 1979). At Canton Atoll (Phoenix Islands, Kiribati), both coral cover and species richness decrease in a highly significant, linear manner, moving away from the single deep passage (Jokiel and Maragos 1978). This pattern appears to also be present at Fanning Atoll (Line Islands, Kiribati), although this information has not been quantified (Maragos 1974). Coral communities are restricted to the vicinity of the single pass that enters Aldabra Atoll (Seychelles) (Taylor 1978).

Effect of Upwelling

Although live coral cover was less than 50% at all stations sampled, reefs appeared to be healthy in most places. The moderate coral cover, even along the western reef, probably reflects the limitations on reef development imposed by high productivity (Birkeland 1988) and adverse conditions in lagoonal backwaters (Neumann and Macintyre 1985). The decrease in coral cover along the barrier reef from north to south (Figure 3) may reflect the same limitations and conditions. As the lagoon widens toward the south, turbidity, sediment load, and phytoplankton content increases (Kimmerer and Walsh 1981; Weber and Woodhead 1972; Kimmerer, this volume), and, thus, conditions become less suitable for corals. High productivity can restrict coral reefs through competition as benthic algae smother adult corals or prevent settlement of coral recruits (Birkeland 1977, 1988). High productivity also increases the abundance of suspension feeders, many of which are reef bioeroders (e.g., lithophagine, gastrochaenid bivalves, clionid sponges, and pyrgomative barnacles) (Highsmith 1980). All these processes may be operating on Tarawa.

One of the most striking features of the midlagoon patch reefs is the great abundance and biomass of red and brown macroalgae. Algae are frequently more abundant as bottom cover than are corals on these reefs, and are clearly shading and smothering neighboring coral colonies. This abundance of fleshy algae is not unexpected for reefs in the central Pacific upwelling region. Birkeland (1988) observed that shallow tropical ecosystems change from coral to algal dominated communities as productivity increases.

The dominance of encrusting *Montipora* species on many lagoonal patch reefs (Figure 5B) may be a consequence of the abundance of benthic algae on these reefs that interferes with coral recruitment. All reefs where more than 40% of the live coral cover is *Montipora* have over 15% algal cover. Most of these species of *Montipora* are encrusting forms, with highly fragmented and irregularly shaped colonies. The success of these species relative to other corals may be the result of their prolific recruitment through large clonal fragments rather than sexually produced, minute propagules. Asexual fragmentation also is probably an important, if not predominant, mode of recruitment for several of the *Acropora* species that form large stands of one or a few species in the central lagoon. *Acropora* and *Montipora* together constitute 82.9% of the coral cover of the central lagoon (Figure 5B). *Montipora* and *Acropora* also are abundant in the midlagoonal to inner lagoonal reefs at Canton

(Jokiel and Maragos 1978) and Fanning atolls (Roy and Smith 1971; Maragos 1974), both of which have restricted circulation and are located in the equatorial upwelling region.

The paucity of algae along the western reef cannot be explained by lower nutrient levels because they are at least as high as, or higher than, in the central lagoon (Kimmerer and Walsh 1981; Kimmerer, this volume). A possible explanation is increased herbivory; fish, particularly herbivores, are more abundant along the western reef than in the inner lagoon (Beets, this volume).

Finally, the moderate planktonic productivity of the lagoon (Kimmerer, this volume) is almost certainly responsible for the intensity of bioerosion observed in the lagoon. Although we did not quantify bioerosion rates, the abundance of bioeroders increases dramatically from the western barrier reef to the eastern inner lagoon, as does phytoplankton biomass. The increase in phytoplankton biomass is itself probably a result of the increased residence time of inner lagoonal waters, which allows phytoplankton biomass to accumulate longer (Kimmerer and Walsh 1981; Kimmerer, this volume). Inner lagoonal reefs are riddled with a variety of boring and nestling bivalves (numerous *Lithophaga* spp., gastrochaenids, *Botula fusca, Irus macrophyllus,* several *Barbatia* spp., *Isognomon, Pinctada,* and *Malleus regula*), clionid sponges, and polychaetes. Highsmith (1980) has shown that on an oceanwide scale, bioerosion increases with increased productivity.

Disturbance

Although most reefs in the lagoon appeared healthy, two areas showed evidence of coral mortality: the western barrier reefs and nearby patch reefs and the southeastern elbow of the lagoon. A striking aspect of much of the submerged barrier reef and several adjacent lagoonal patch reefs was the paucity of *Acropora* (Table 1, Figure 5A). Large, intact, but dead *Acropora* skeletons were moderately common at several western sites where living *Acropora* were rare. This pattern suggests selective recent mortality of *Acropora*, possibly as a result of *Acanthaster* predation, or coral bleaching, a process that can preferentially affect *Acropora* (personal observation).

The mortality of reef corals in the southeastern lagoon was even more striking. Of the 12 coral genera evident from skeletal remains, only two or three were found alive. Moreover, coral skeletons, especially of *Acropora* spp., were abundant, attesting to a time in the past when these reefs were much more developed and different species dominated the reefs. Further evidence can be seen in the dense jumbles of branching corals and massive reef framework that lies under a few centimeters of sand in these southern shoals. The surviving species, *Pocillopora damicornis* and *Porites* spp., are renowned for their hardiness (Paulay 1988).

The observed coral mortality could be the result of deteriorating conditions resulting from the enclosure of the inner lagoon. The elbow became more isolated approximately 5,000-6,000 years ago when reefs reached the ocean surface along the southeastern rim of Tarawa (Marshall and

Jacobson 1985). Isolation increased with subsequent island buildup and, in this century, with the construction of causeways that closed shallow passages. Although Chen et al. (this volume) found that the effect of causeways on lagoon circulation was minor, causeways have been linked with reef mortality in Palmyra Atoll (Dawson 1959).

The radiometric ages of locally extinct coral skeletons suggest that these reefs were more diverse until at least a few hundred years ago. Therefore, the observed mortality was not a consequence of the mid-Holocene closure of the lagoon mentioned above. The possibility that the corals have died as a result of increasing human activity during this century cannot be eliminated. If the local reservoir effect on carbon-14 is as important as suspected, the age of these corals may be considerably more recent.

Although the coral died no more than a few hundred years ago, the area is now dominated by shoals rather than patch reefs. Within this time, the relatively diverse reefs of the southeastern lagoon were reduced to sand and rubble by the intense bioerosion that prevails in the inner lagoon. The rapid destruction of these reefs and their conversion to soft bottom-dominated shoals is attested to by the reef framework or reef rubble lying just under these shoals. Furthermore, these buried coral skeletons are completely riddled with holes made by borers, particularly *Botula* and *Lithophaga*.

The death of diverse reefs in the area has probably had major repercussions on species associated with the reef. Numerous reef-associated bivalves, such as *Tridacna maxima, Hippopus hippopus, Chama lazarus, Chama pacifica*, and oyster species appear to have been extirpated in the area, although they are represented by subfossil specimens. The demise of some of the larger species could also be the result of direct human predation. Several of the smaller species (e.g., *Chama pacifica* and oysters) lived cemented to *Acropora* branches, so these species died with their "hosts." Finally, the paucity of fish life on these shoals is striking. The few remaining reef fish (e.g., lutjanid and lethrinid juveniles) are always tightly associated with the remaining live *Porites* heads. Therefore, the death of the reef also must have had a considerable impact on fish populations in the area.

Benthic Ecology and Biota of Tarawa I agoon: Influence of Equatorial Upwelling, Circulation, and Human Predation

By

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Abstract

The benthic biota of Tarawa Lagoon is influenced by the unusual combination of environmental and human-related factors that characterize the lagoon. Oceanic waters, enriched by equatorial upwelling, exchange with lagoon waters across the submerged western reef. As a result of high productivity from upwelling waters, population densities of heterotrophic mollusks and irregular echinoids are unusually high for an "open" atoll. The dense human population on the atoll relies largely on marine resources for its protein needs. Lagoonal sand flats harbor dense and diverse mollusk (especially bivalve) communities, particularly in seagrass beds. These communities support an intense subsistence fishery in which approximately 1,000 tonnes of shellfish are collected annually in South Tarawa. Much of the biomass of the two preferred species, the bivalve *Anadara* sp. (*te bun*) and the gastropod *Strombus luhuanus* (*te nouo*), is taken. Both the seagrass and shellfish beds appear to have expanded considerably in the last 50 years. In addition, off central and eastern South Tarawa, dense mollusk and echinoid communities from 2 to 8 m deep support a limited but intense commercial fishery that removes approximately 1,000 tonnes of *Anadara* per year, representing much of the available biomass. In contrast to these shallower mollusk-rich habitats, most of the deep lagoon floor is dominated by irregular echinoids averaging 40-70 m^{-2} for the three largest species in the inner lagoon. All aspects of the benthos follow a marked west-to-east and north-to-south zonation, reflecting the one-sided exchange of oceanic waters.

Introduction

Although atolls are the dominant reef and island type in the central Pacific, the marine biotas of only a few atolls have been studied thoroughly. Limited studies show that while fore-reef environments tend to be similar among atolls, lagoon environments and biotas show great diversity, even among nearby atolls (e.g., Salvat 1967; Chevalier 1976, 1979). Much of this variation results from the diversity of present (and historically evolving) geomorphologies of atolls, and the resulting variation in oceanographic and ecologic conditions. The degree of water exchange between ocean and lagoon is an important influence because it affects other environmental parameters, such as sediment grain

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size, sediment production rates, reef growth and erosion rates, and lagoon depth. Variation in productivity, both in the surrounding ocean and in lagoon waters, also can lead to substantial differences among reefs (e.g., Highsmith 1980). The impact of humans, rapidly accelerated by growing populations, improved technologies, and the resulting increased utilization of limited resources, also exerts strong influences on reef communities in many areas of the tropics (Wilkinson et al. 1993).

Tarawa Atoll, the metropolitan center of the Republic of Kiribati, offers an unusual combination of environmental factors, many of which appear to have significantly affected its marine ecology and biota. The nutrient-rich waters of the equatorial upwelling area support high planktonic productivity and biomass (Kimmerer and Walsh 1981; Kimmerer, this volume), which in turn enhance benthic productivity and biomass (see below).

Because of Tarawa's unusual triangular form, with islets closing off much of the eastern and southern sides, most of the exchange between lagoon waters and the surrounding ocean occurs across the submerged western barrier reef (Figure 1) (Chen et al., this volume). This limited exchange creates marked west-to-east and north-to-south gradients in nutrients, phytoplankton, sediment composition, coral diversity and abundance, and bioerosion across the atoll lagoon (Kimmerer and Walsh 1981; Kimmerer, this volume; Paulay and Kerr, this volume).

Previous work on the benthic marine biota of Tarawa and neighboring atolls is limited. Zann and Bolton (1985) described the ecology of *Heliopora* and quantitatively described the reefs around Betio. Before the Betio-Bairiki causeway was constructed, Zann (1982) described the marine ecology of the Betio area and provided a checklist of reef corals. Bolton (1982a) described the epifauna and infauna of the intertidal lagoonal sand flats fronting the islets of South Tarawa; unfortunately, many of her identifications were erroneous. Numerous other shorter technical reports describe aspects of shellfish, giant clams, bêche-de-mer, pearl oysters, and fish (Gillett et al. 1991).

Randall (1955) reviewed the fishes of the Tungaru Archipelago (former Gilbert Islands), and Banner and Randall (1952) described the marine biology of Onotoa Atoll, south of Tarawa. Among the island groups surrounding Tungaru, the marine biota of the Marshall Atolls to the north have been extensively studied (e.g., Devaney et al. 1987), and the marine biota of Nauru to the west and Tuvalu to the south are poorly known. Canton Atoll (Phoenix Islands) and Fanning Atoll (Line Islands) (both now part of Kiribati) to the east have been the subjects of University of Hawaii multidisciplinary studies summarized in issues of Atoll Research Bulletin (1978 [No. 221]) and Pacific Science (1971 [25:2] and 1974 [28:3]), respectively. These atolls have special relevance to Tarawa because they also lie in waters influenced by equatorial upwelling.

The major benthic habitats of Tarawa Lagoon can be divided into four major types: 1) an intertidal to shallow subtidal sand flat that fronts the islets and passages of the southern and eastern sides of the atoll, 2) the lagoon slope and floor that cover much of the lagoon interior, 3) the patch reefs and shoals that rise from the lagoon bottom, and 4) a submerged barrier reef that forms the western atoll

rim (Figure 1). The major soft bottom habitat types are reviewed in detail below, and the impact of human gathering pressures on invertebrate populations of the atoll is discussed. Paulay and Kerr (this volume) review the reef habitats.

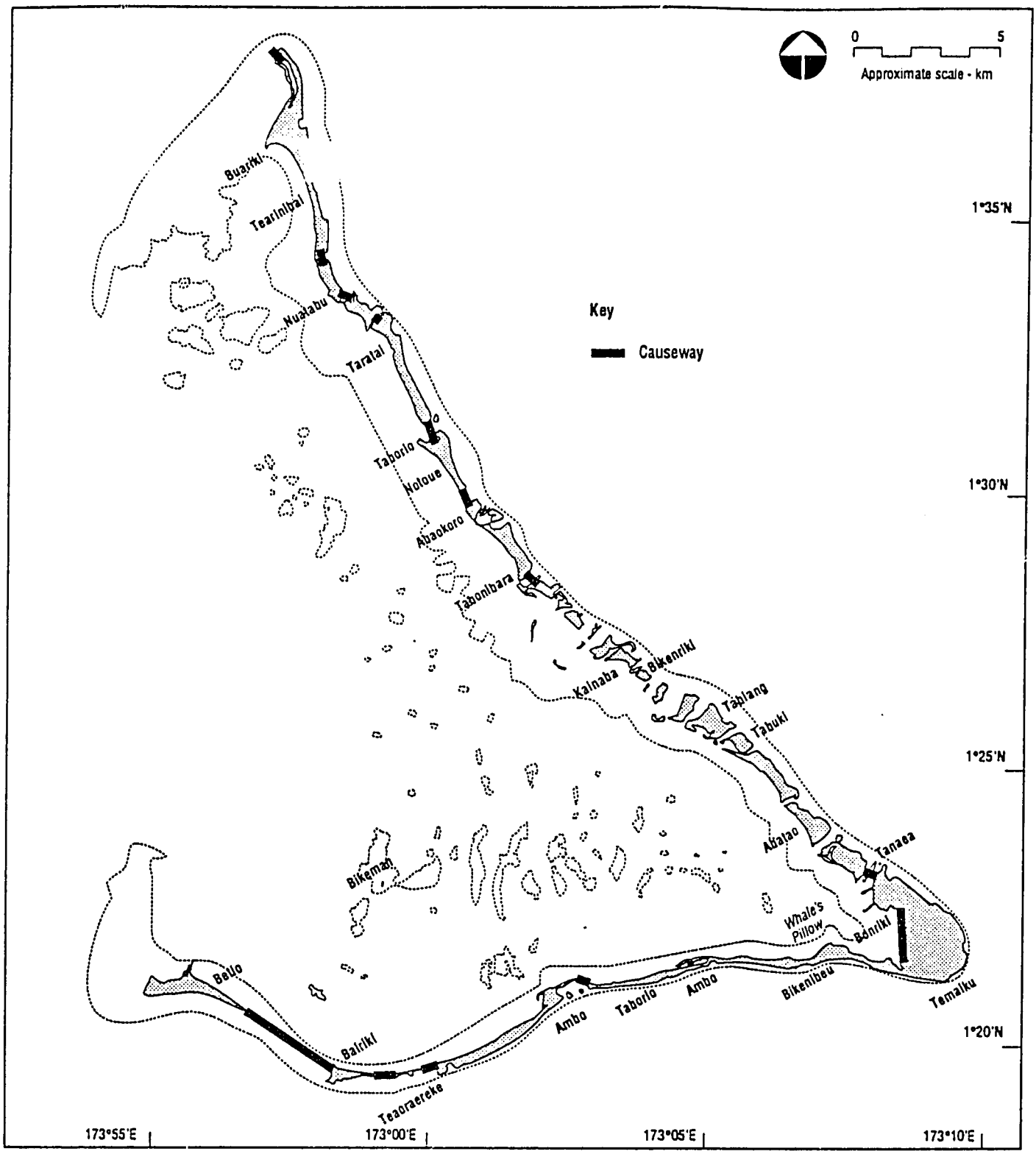


Figure 1 Map of Tarawa Lagoon showing location of villages and causeways.

Methods

Sand Flats

Sand flats were studied through quantitative surveys, qualitative examination of the fauna, and mapping of seagrass beds from aerial photographs. Because the primary purpose of our surveys was to evaluate the shellfish resources of this habitat in South Tarawa, our quantitative surveys focused on mollusks.

Fifteen transects with nine stations each were set perpendicular to shore at regular intervals along the length of South Tarawa (Figure 1; coordinates for all sampling stations are given in Introduction to the Study, this volume). Stations 1-3 were on the beach slope: Station 1 was halfway between the upper strandline and the lower end of the slope (where the slope meets the sand flat plane), Station 3 was at the lower end of the slope, and Station 2 was halfway between Stations 1 and 3. Stations 4-6 were spaced equidistantly along the sand flat between Station 3 and the landward end of the seagrass bed. Stations 7-9 were in the seagrass bed, if present. Station 7 was set 5 m lagoonward from the landward margin of the bed, Station 8 was in the middle of the bed, and Station 9 was 5 m shoreward from the lagoonward margin of the seagrass bed. At locations lacking seagrass beds, Stations 4-9 were evenly spaced along the sand flat, from one-sixth lagoonward of Station 3 to the edge of the sand flat.

Two 0.5- by 0.5-m quadrats were haphazardly placed within 5 m of each station. The sediment at each quadrat was excavated to 20 cm deep or until bedrock was reached; the depth of the excavation was noted. Sediment was passed through a 2-mm mesh screen, and all live mollusks and echinoids were collected. Mollusks were picked at the station; numerous smaller (< 1 cm) mollusks, therefore, were probably overlooked. All specimens were identified to species in the laboratory, and their maximum shell length was measured.

At many quadrats, including most of those at Stations 1-3, no shellfish were recorded by the technicians. These quadrats may represent areas devoid of shellfish (e.g., due to hard bottom), or samples may have been collected but never analyzed. Most of the missing data are from samples at Stations 1-3 (where the fauna is poor) and at three of the 15 transects (Teaoraereke, Dainippon causeway, and Temakin-Betio). These stations and transects are not considered further. Because most of the stations and transects that lack data are in areas (i.e., beach slope and western sand flat) characterized by gravelly sediments or hard substrata, the lack of data probably reflects a lack of shellfish, rather than lost collections. The few (5% of the total, $N = 144$) quadrats with missing data at Stations 4-9 in the other 12 transects are therefore assumed to not contain shellfish; an error in this assumption would increase shellfish abundance slightly.

The percentage of sand flat covered with zoanthids was evaluated by the point-quadrat method at the same sites, under 16 intersection points set in a 0.25-m^2 stringed quadrat. Zoanthid cover was consistently evaluated under only seven of the transects (Abarao, Eita east, Eita west, Ambo, Antenon, Nanikai, and Takoronga).

The extent of seagrass beds was evaluated from site visits throughout North and South Tarawa and from aerial photographs (1943 photographs housed at Bishop Museum; 1984 photographs housed at Survey Department, Tarawa) for South Tarawa. Most aerial photographs of North Tarawa did not include the seagrass zone.

Lagoon Slope

The gently sloping lagoon bottom bordering the seagrass beds in South Tarawa supports dense *Anadara* populations. These populations form the basis of an intense canoe-based diving fishery (see below). The lagoon slope (defined as the area within 1 km of the lagoonward edge of the seagrass beds) was surveyed to evaluate the geographic spread of these beds and to identify the macrobiota associated with them.

Two surveys were run through the South Tarawa lagoon slope; the first was set evenly across the whole lagoon slope, the second focused on the major *Anadara* bed. In the first survey, nine evenly spaced transects, oriented north to south, were run on the lagoon slope from Nanikai to Bikenibeu (Figure 1). On each transect, paired 0.25-m^2 quadrats were haphazardly placed on the bottom at five stations located by the global positioning system (GPS): 0.05′ (minute of latitude = 90 m), 0.15′, 0.25′, 0.35′, and 0.55′ north of the lagoonward end of the seagrass beds. Depth and GPS location were recorded for each station. Within each quadrat, divers searched for large (1-2 cm or more) mollusks and echinoids, visually and by hand, to a sediment depth of approximately 10 cm. This method is faster and just as effective as sieving for large (2-7 cm) mollusks and echinoids. Collected specimens were identified and measured in the laboratory.

The second survey focused on the *Anadara* bed offshore of Taborio-Bangantebure. A series of spot dives were conducted from east to west across this bed to establish its length, followed by four south-to-north passes to establish its width. Finally, the population density of larger mollusks and echinoids was surveyed at 10 randomly selected stations within the bed, with four replicate 0.25-m^2 quadrats, as described for the first survey.

Lagoon Floor

The lagoon floor was surveyed at 14 stations along three east-west transects across the lagoon (Figure 14, discussed below under Lagoon Floor in Results and Discussion section). At each transect, two divers swam for 5 min and recorded or collected obviously larger macrofauna. Two 0.25-m^2 quadrats were then haphazardly placed for quantitative enumeration of smaller fauna. Within each quadrat, larger epibenthic species (mostly irregular echinoids) were collected, and bottom sediments were excavated to a depth of approximately 10 cm, carefully shoveled into a large bag, and sieved on board through a 2-mm-mesh screen.

Mollusks and echinoids were the dominant fauna retained by the 2-mm-mesh screen, although small polychaetes were visibly abundant on the bottom. Species were identified, and shell and test lengths were measured for all mollusks and echinoids.

Gatherer Surveys

Shellfish are an important part of Tarawa residents' diet, and the productive lagoon provides abundant stocks that are easily accessible, even to people with no fishing equipment. A landings survey was conducted to evaluate the type and intensity of gathering pressure on shellfish.

Surveys were implemented to count the number of people collecting shellfish and to measure the weight and species composition of their catches. Both types of surveys were implemented for gatherers on the South Tarawa sand flats and for divers on the offshore Taborio-Bangantebure *Anadara* bed. Qualitative observations and brief interviews with gatherers were conducted whenever possible.

To estimate the number of people gathering on the sand flats, gatherers from the western tip of Betio to the tip of the Bonriki World War II landing spot were counted from vantage points that allowed observations throughout the entire sand flat. These counts were probably greater than 90% accurate; six such counts were made.

Gatherers were intercepted at 13 locations along the shore of South Tarawa as they arrived onshore from collecting trips to the sand flats. The number of gatherers who contributed to each catch, the time spent gathering, the habitat (nearshore sand flat, mid-sand flat, seagrass bed, or deep lagoon) where they gathered, and the time of arrival were recorded. Each catch was weighed as a whole, and the weight and number of individuals of each species were determined from either the whole catch or a subsample. The maximum shell length of a random subsample of 20 (or the number available, whichever was greater) shells of each species in each catch was measured with calipers. Because not all samples were processed with equal thoroughness, not all this information is available for all catches. Where the number of individuals of a single species was determined, but not the

species' summed weight, the latter was calculated from the average weight per shell for the species, as determined from other samples.

The number of gatherers working the Taborio-Bangantebure *Anadara* bed was counted from a boat on six occasions by skirting all vessels seen in the area and counting the divers associated with each vessel. The harvest of divers working the Taborio-Bangantebure *Anadara* bed was largely determined by interviewing divers onsite. This method was more effective than landing surveys because, with only a few canoes working the area, their catches would have been difficult to intercept onshore. In addition, the standard rice bags that divers use to hold shellfish allow a fairly accurate assessment of catch size.

Data throughout this discussion are given as mean ± 1 SD, unless otherwise noted.

Results and Discussion

Sand Flats

Physiography and Habitats

The extensive intertidal to shallow subtidal sand flats in Tarawa Lagoon range from approximately 300 m to 2.5 km wide and harbor dense infaunal invertebrate communities (see below) (Bolton 1982a). The sand flats fronting the lagoonal sides of islets in South Tarawa differ from those in North Tarawa. The South Tarawa flats are considerably narrower, have more extensive marginal seagrass beds, and have poorer fringing reef development off their lagoonal margin. Aspects of the biota in the two areas also probably differs. Because our surveys focused almost entirely on South Tarawa, comparisons of the biota with that of North Tarawa are limited.

Sand flats are dominated by poorly sorted, coarse sands with abundant gravel made of shells and coral fragments (Weber and Woodhead 1972; Richmond 1990). The lagoonal sand flats in South Tarawa can be demarcated into three regions: 1) a relatively steep beach slope, 2) the wide, gently sloping expanse that constitutes most of the sand flat, and 3) the lagoonal end of the sand flats, which in large areas of South Tarawa support beds of the seagrass *Thallassia hemprichii* (see below). Some nearshore areas of sand flats (especially in the southeastern elbow and along sections of North Tarawa) support stands of shrub-sized mangroves (*Rhizophora mucronata*), with extensive fiddler crab populations.

The gentle slope of the sand flats abruptly gives way to the steeper lagoonal slope at approximately 0.5-1 m below lowest low water, at the lagoonward edge of the seagrass bed, if present. Although no living corals were seen on the sand flats, in South Tarawa the lagoonal slope adjacent to the sand flats supports scattered colonies or clumps of colonies of primarily *Porites* spp. and *Pocillopora*

damicornis. Fringing or patch reefs that are often dominated by *Acropora*, and are more developed, often contiguous, and generally more diverse, occur on the lagoonal slope in North Tarawa.

Biota

The South Tarawa sand flats host a dense and diverse assemblage of mollusks. Twenty-six mollusk and five echinoderm species were noted in the quantitative surveys. Bivalves dominated the fauna both in species richness (20 bivalves versus six gastropods) and numerically (93% of mollusk individuals encountered).

The mean density of 10 species exceeded 1 m^{-2}, averaged over the sand flat (Stations 4-9) (Figure 2). The most abundant species encountered were three small (<2 cm) bivalves: *Codakia bella*, *Wallucina* sp., and *Timoclea marica*, of which *C. bella* and *T. marica* are harvested in small quantities. The three most important species for local consumption, *Gafrarium pectinatum* (*te koumara*), *Anadara* sp. (*te bun*), and *Strombus luhuanus* (*te nouo*), were also among the 10 most abundant species.

The population densities of several species (e.g., *C. bella, G. pectinatum,* and *Anadara* sp.) increase lagoonward across the sand flat and are highest in the marginal seagrass beds. Other species (e.g., *Wallucina* sp. and *T. marica*) show less clear trends or are most dense at mid-sand flat (Figure 3). In contrast, a few species (e.g., *Atactodea striata* and *Asaphis violascens*) are restricted to the higher reaches of the sand flat and to the beach slope. The overall abundance of mollusks shows relatively little variation across the sand flat, with an insignificant increase lagoonward (Figure 4).

The increasing abundance of many mollusks lagoonward could be natural, or it could be the result of greater human predation in the higher intertidal zone, which is exposed more frequently than the lower intertidal zone. For abundant and lightly harvested species such as *C. bella* (Figure 3), the former explanation is more likely, particularly because lucinid bivalves have been shown to prefer seagrass habitats (Jackson 1970). In contrast, for economically important shellfish such as *Anadara*, human predation may be important in determining zonation. Rough calculations (see below) indicate that a large portion of the standing crop is taken by humans, supporting the above hypothesis.

Economically Important Shellfish Species

***Anadara* sp. (*te bun*).** The shallow-burrowing arcid bivalve, *Anadara* sp. (an unidentified member of the *Anadara antiquata* [Linné 1758] species complex; incorrectly identified as *Anadara maculosa* [Reeve 1844] in several technical reports from Tarawa), is the most important shellfish harvested in South Tarawa (see below). *Anadara* was found to be most common between Abarao and Banraeaba and rare west of Nanikai (Figure 5). This distribution corresponds closely to the distribution of seagrass beds along South Tarawa (see below). *Anadara* sp. was found almost exclusively at Stations 7-9 (i.e., in the seagrass bed area). The population density of this shellfish increased steadily lagoonward within the seagrass beds from 0.75 ± 1.6 m^{-2} (Station 7) to 3.5 ± 5.0 m^{-2} (Station 8) and 8.3 ± 9.3 m^{-2} (Station 9). These population density values are based

only on transects between Bikenibeu and Banraeaba (i.e., the region where *Anadara* sp. was encountered). Therefore, values are larger than those plotted across the entire sand flat depicted in Figure 3. Overall, *Anadara* abundance averaged 4.2 $\pm$ 6.8 m^{-2} throughout the seagrass bed in this region. Yamaguchi et al. (no date) found comparable densities (means of 0.9-7 m^{-2} at four sites) in 1991. Assuming that the seagrass area along South Tarawa is approximately 10 km long and 150 m wide and the mean *Anadara* density is 4 m^{-2}, the population size is approximately 6 $\pm$ 10 x 10^6. Because the population extends lagoonward on the shallow lagoon slope, the total number accessible by wading is considerably larger (see Lagoon Slope section below).

***Strombus luhuanus* (*te nouo*).** The epibenthic conch *Strombus luhuanus* is the second most important shellfish harvested in South Tarawa and dominates catches in many areas of the coastline (see below). The distribution of *S. luhuanus* was highly variable among the transects and stations surveyed (Figures 3 and 6). This conch was largely restricted to Stations 6 through 9, with an average population density of 1.4 $\pm$ 5.9 m^{-2}. Given a habitat width of approximately 250 m, a 20-km-long sand flat in South Tarawa would support a population of approximately 7 $\pm$ 30 x 10^6. These densities are considerably below those (means of 4.0-30.5 m^{-2} at four sites) that Yamaguchi et al. (no date) encountered in 1991, and are low given the tremendous gathering pressure on this species (see below). The high variability of the data as well as qualitative observations indicate that distribution of *S. luhuanus* is patchy on the sand flat, perhaps as a result of the high mobility of this species. The above figures (based on 34 specimens) may considerably underestimate the actual population density of this species.

***Gafrarium pectinatum* (*te koumara*).** The venerid clam *Gafrarium pectinatum*, although numerically more abundant than the other two species, is collected less frequently because of its burrowing habit and smaller size. Nevertheless, *G. pectinatum* is an important local bycatch and can dominate catches in South Tarawa (see below). The distribution of *G. pectinatum* varied greatly among transects, with the Temaiku and Banraeaba transects traversing particularly dense beds (Figure 7). The Temaiku bed, extending across the large sand flat at the elbow, is well known and the focus of much gathering activity. *G. pectinatum* was found at all stations lagoonward of the beach slope, and its overall abundance increased offshore (Figure 3). Except for the Temaiku population, which is centered in the middle of the unusual Temaiku sand flat, this species was strikingly more abundant in the seagrass zone than at mid-sand flat (Figure 3). The mean abundance of *G. pectinatum* across all quadrats is 6.6 $\pm$ 19 m^{-2}; therefore, if the South Tarawa sand flat is approximately 500 m wide and 20 km long, the projected population would be 6.5 $\pm$ 19 x 10^7 individuals. Yamaguchi et al. (no date) found comparable densities (means of 0-19.1 m^{-2} at four sites) in 1991.

Other Organisms. In addition to supporting a rich molluscan community, the sand flats harbor a diversity of other invertebrates; however, these species were not studied quantitatively. Bolton (1982a) provides abundance data on a variety of other groups, especially polychaetes and crustaceans; however, many of her identifications appear to be erroneous. A few conspicuous organisms or species that dominate other habitats on the atoll are discussed below.

Holothurians and irregular echinoids were the only echinoderms encountered during the surveys. Only a single specimen each of three larger irregular echinoids, *Maretia planulata*, *Laganum depressum*, and *Metalia sternalis*, were encountered in the quantitative surveys. These species may be more common locally near the lagoonward end of the sand flat, and they dominate deeper lagoon waters (see below). Three holothurian species, *Holothuria atra*, *Bohadschia vitiensis*, and *Holothuria pardalis*, were noted on the sand flat. *H. atra* was fairly common (mean population density of 0.35 m^{-2}). *B. vitiensis* is common at the lagoonward margin of the sand flat at low intertidal to shallow subtidal depths where it partially burrows in the sand bottom. Bolton (1982a) recorded eight species of holothurians from the sand flat, four at densities of up to several hundred per square meter; however, reconciling her data with the present findings is difficult.

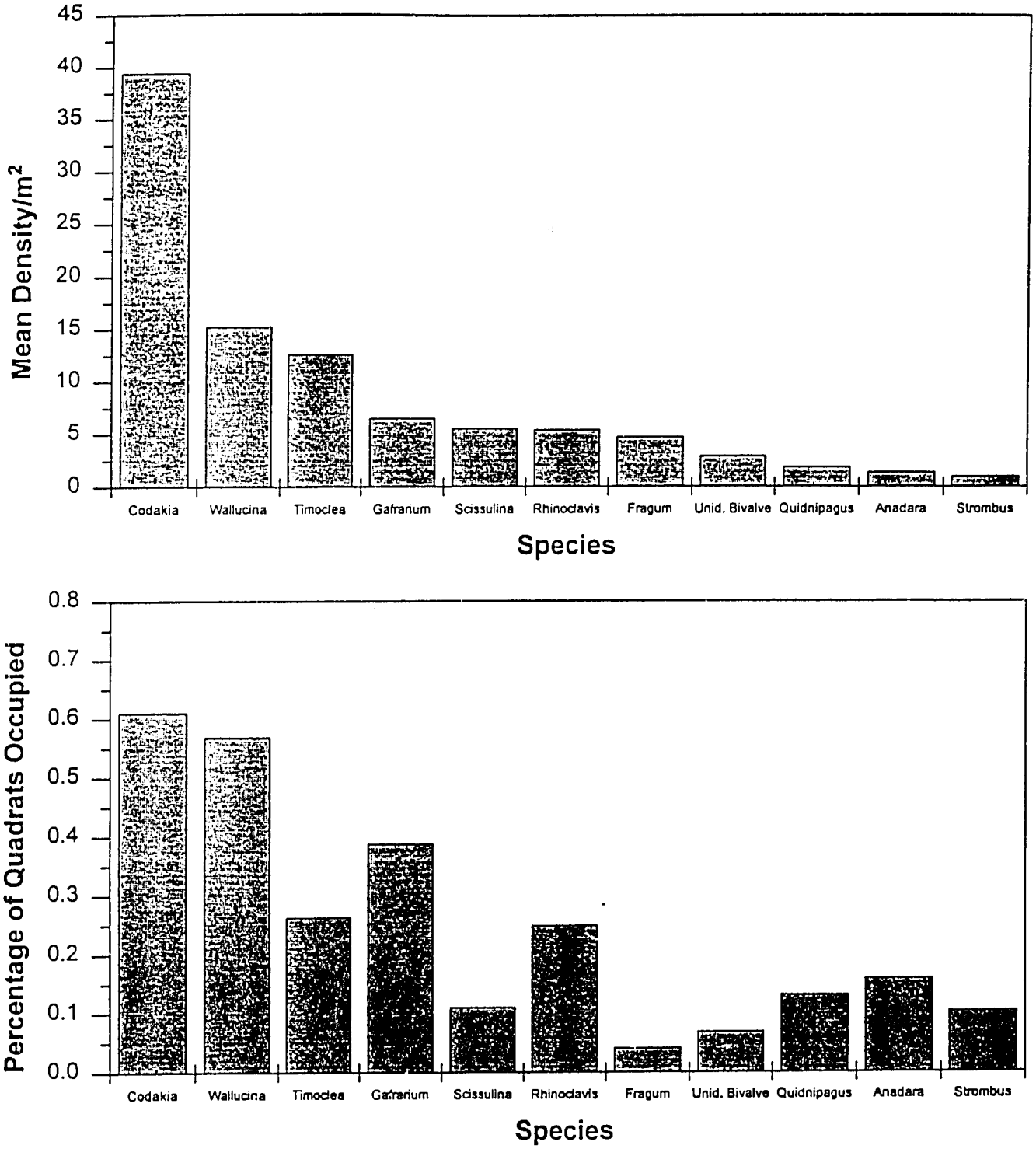


Figure 2 (Top) Mean population density of mollusks on South Tarawa sand flat, over all transects and sand flat Stations 4-9 (N = 144 quadrats); species are as follows: *Codakia bella, Wallucina* sp., *Timoclea marica, Gafrarium pectinatum, Scissulina dispar, Rhinoclavis asper, Fragum* sp., unidentified bivalves, *Quidnipagus palatam, Anadara* sp., *Strombus luhuanus*; and (Bottom) Percentage of quadrats in which species were found.

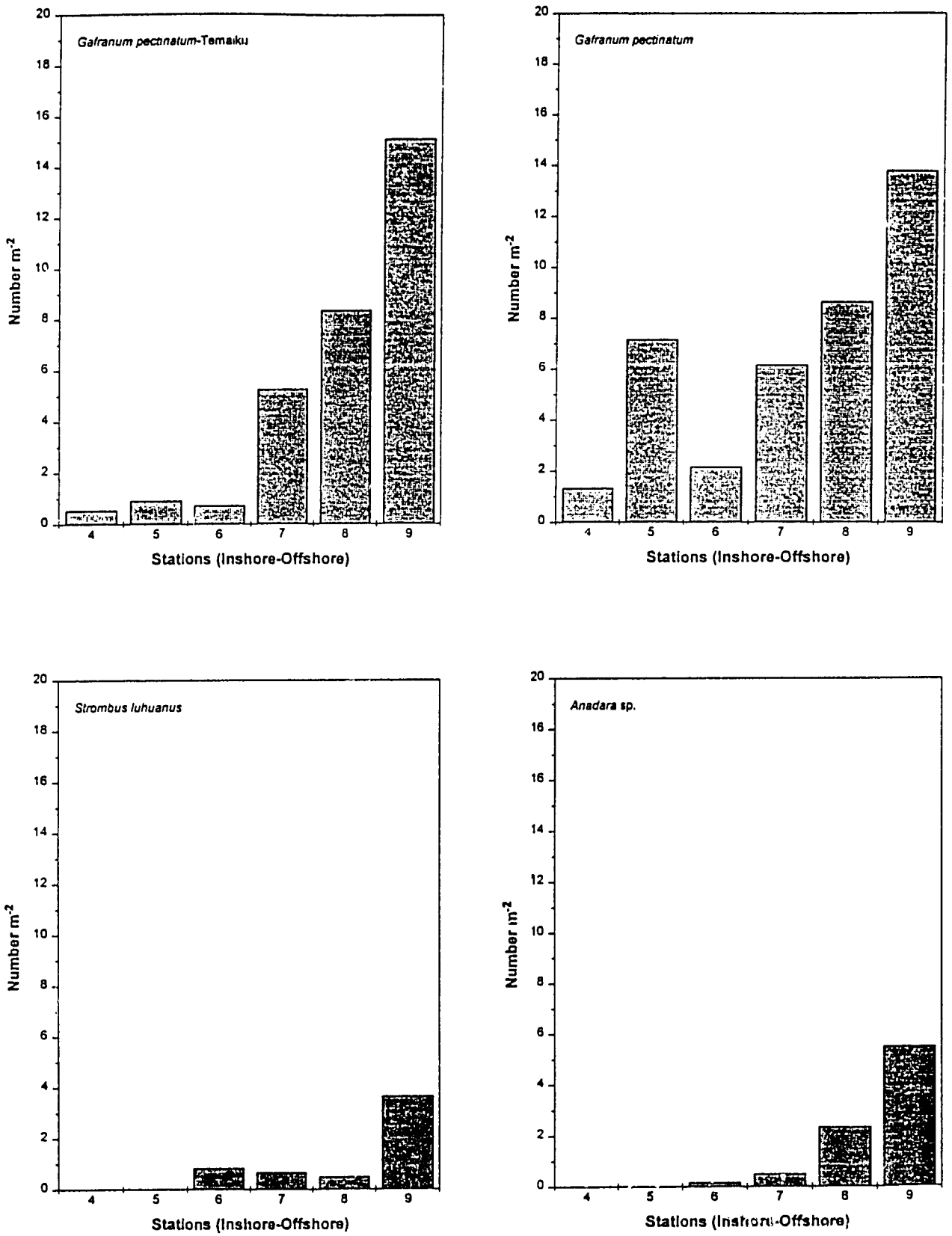
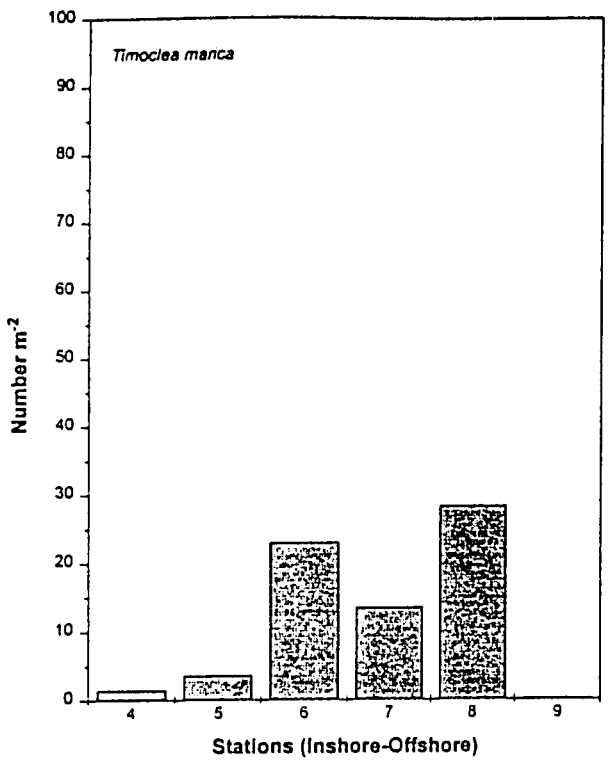
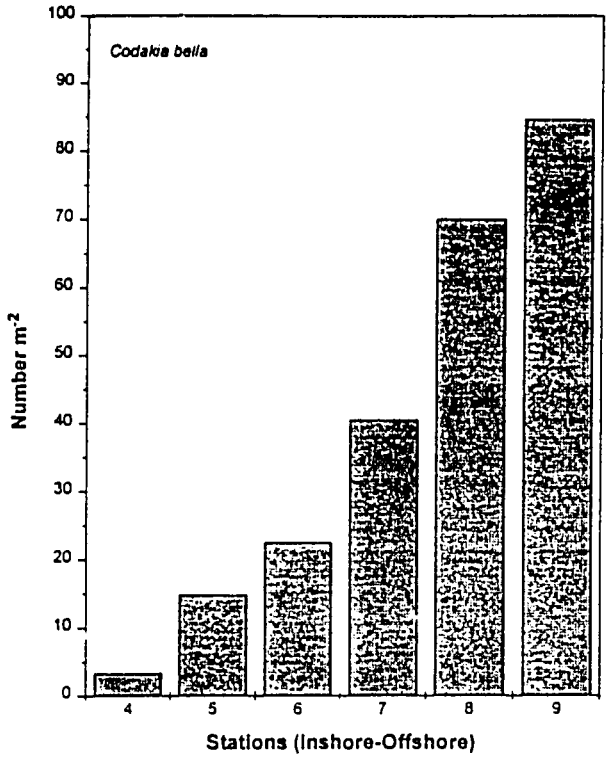


Figure 3 Mean population density of *Gafrarium pectinatum*, *Strombus luhuanus*, *Anadara* sp., *Timoclea marica*, *Codakia bella*, and *Wallucina* sp. across South Tarawa sand flat (per Stations 4-9, mid sand flat through seagrass bed and outer sand flat), for all transects.





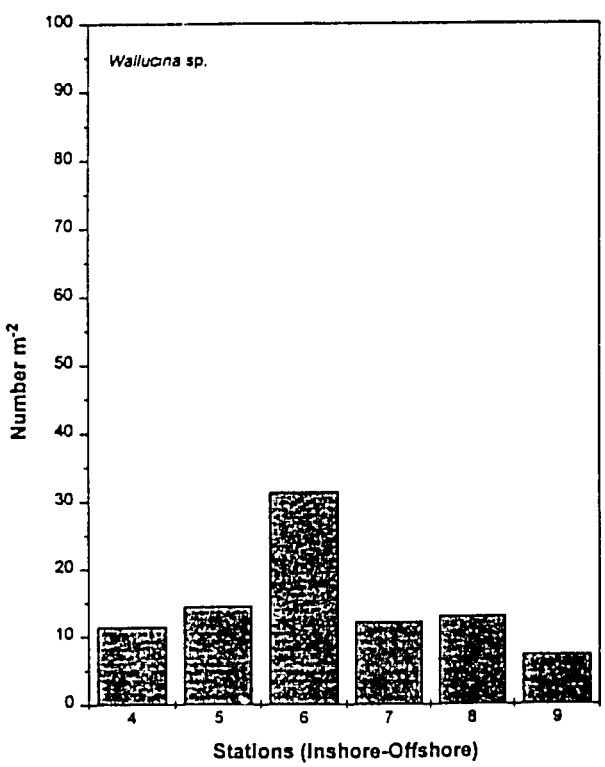


Figure 3 Mean population density of *Gafrarium pectinatum*, *Strombus luhuanus*, *Anadara* sp., *Timoclea marica*, *Codakia bella*, and *Wallucina* sp. across South Tarawa sand flat (per Stations 4-9, mid sand flat through seagrass bed and outer sand flat), for all transects (cont.).

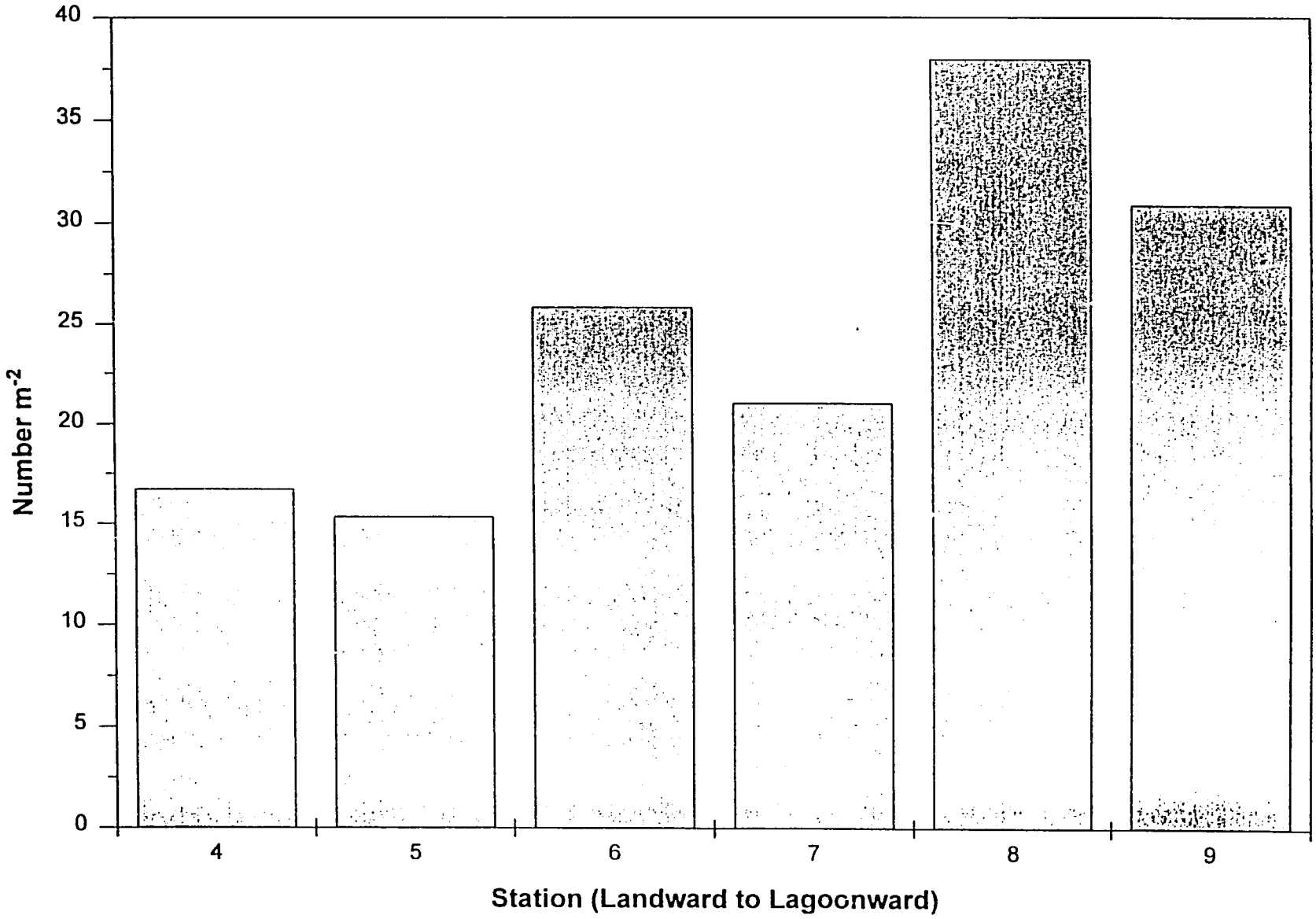


Figure 4 Mean population density of all mollusks encountered across South Tarawa sand flat (Stations 4-9, mid sand flat through seagrass bed and outer sand flat), for all transects.

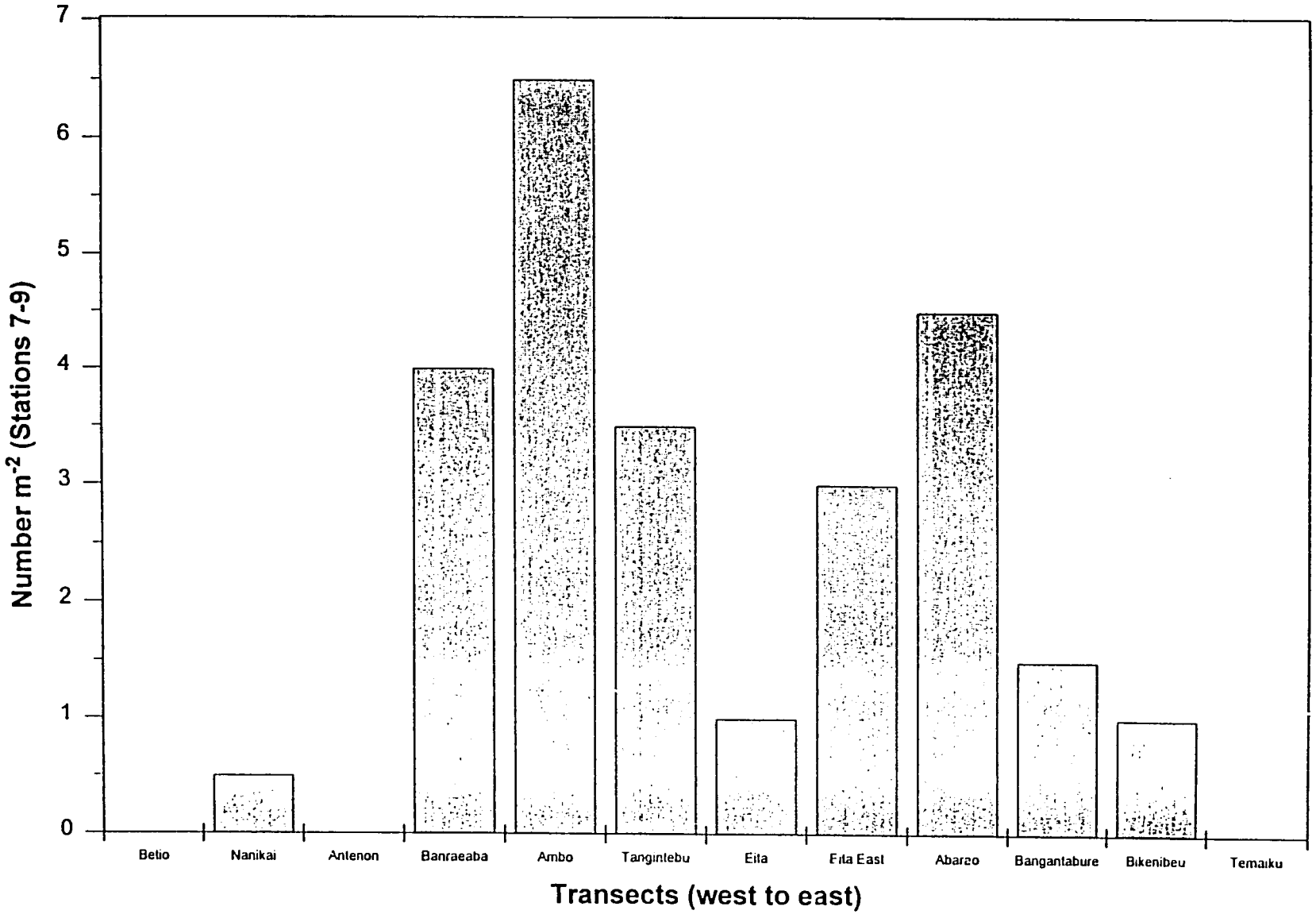


Figure 5 Mean population density of *Anadara* sp. along South Tarawa sand flat (per transect), for Stations 7-9.

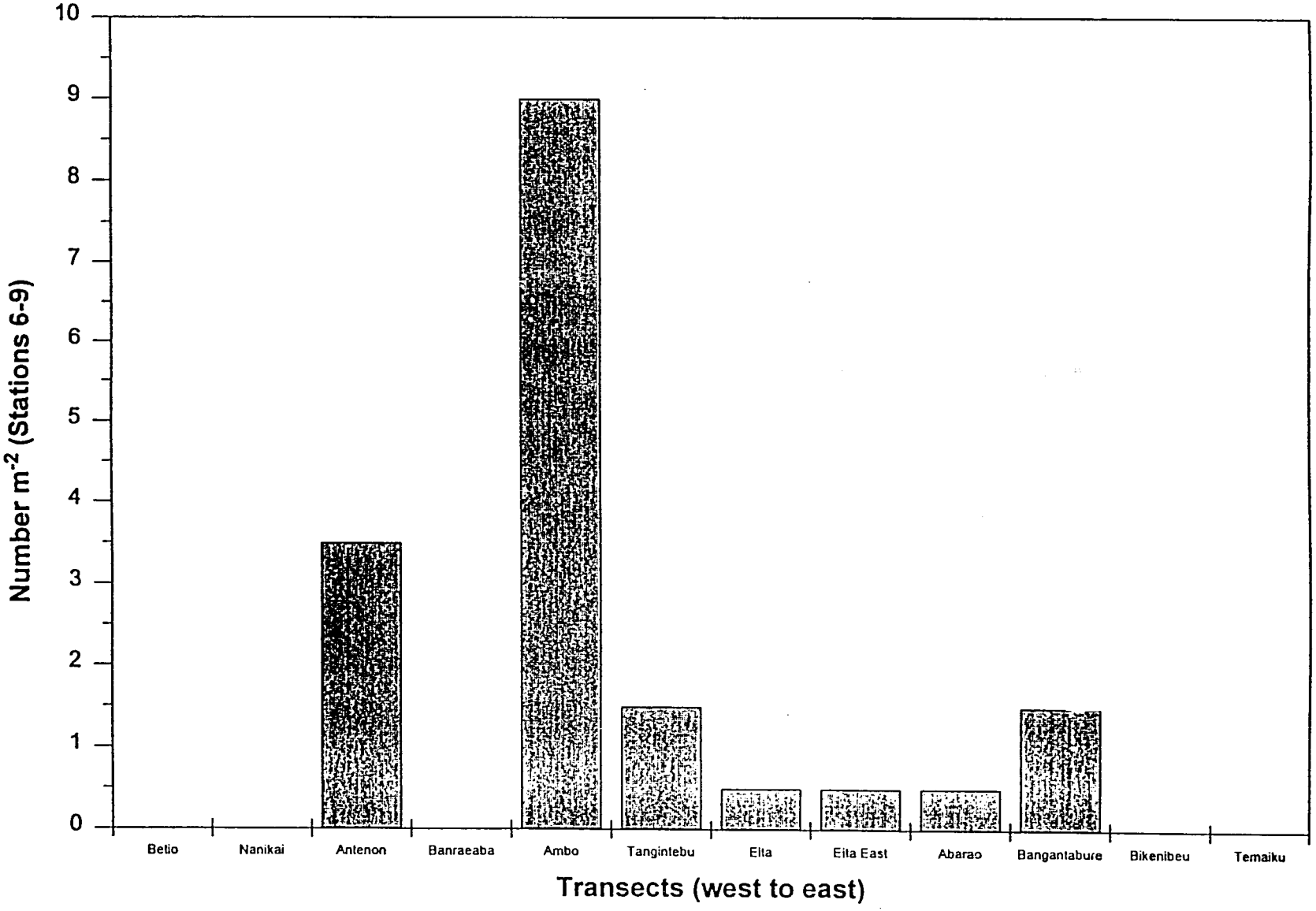


Figure 6 Mean population density of *Strombus luhuanus* along South Tarawa sand flat (per transect), for Stations 6-9.

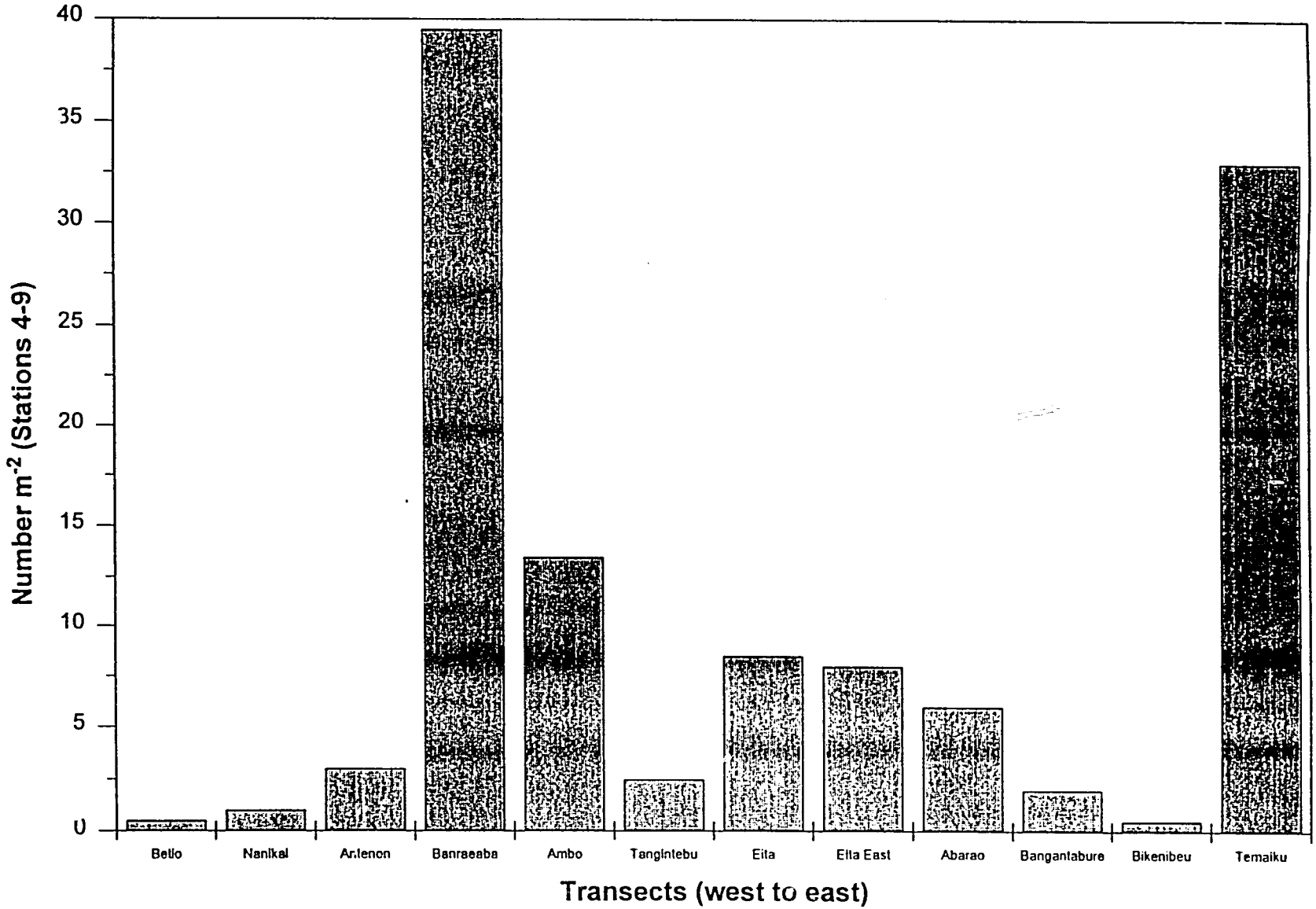


Figure 7 Mean population density of *Gafrarium pectinatum* along South Tarawa sand flat (per transect), for Stations 4-9.

An unidentified zoanthid (probably a *Zoanthus* species) covers large patches of the sand flat in some areas but is rare or absent in others. Zoanthids were encountered in four of the seven transects in which they were consistently sampled and were limited to Stations 5-9 on these transects (mid-sand flat to lagoon slope margin) (Figure 8). Bolton (1982a) found them in two of her six transects, and again found them limited to the lagoonward two-thirds of the sand flats. Zoanthid cover was consistently high (21 ± 13%; mean ± SE) in the three transects situated in the Abarao-Eita area, but low (0.39 ± 0.78%; mean ± SE) in the four transects situated east of there. In contrast, zoanthids dominated Bolton's (1982a) Bairiki and Teaoraereke transects.

Overall, zoanthids covered 9.2 ± 13% (mean ± SE) of the sand flat (Stations 4-9). Cover was highest in the Abarao-Eita seagrass beds (Station 7-9), where 36 ± 17% (mean ± SE) of all substrata were covered by zoanthids. At such densities, zoanthids must have an important effect on the benthos, especially in combination with high seagrass cover. They may limit access to the sediment or water column, limit recruitment by feeding on the larvae of infaunal organisms, and stabilize the sediment. Nevertheless, abundant shellfish occur even in such dense zoanthid beds.

Lysiosquilla maculata (*te varo*), the world's largest stomatopod (Manning 1978), is common along the lagoonward margin of the sand flats and is the focus of a specialized local fishery.

Seagrass Beds

Beds of the seagrass *Thalassia hemprichii* are well developed along the lagoonal margin of sand flats in southeastern Tarawa Lagoon and are the focus of much of the shellfish harvesting there (see below). The abundance of bivalves in the seagrass beds is striking, and many of the best shellfish grounds are clearly in areas of seagrass abundance. Seagrasses are well known to host a greater abundance of benthic animals, because they can serve as refuges from predation, provide greater habitat complexity and stable substrata, create hydrodynamic conditions that are especially favorable for larval settlement, and provide increased food supplies (Peterson 1986; Orth 1992). Bivalve populations have also been found to have greater growth rates within seagrass beds, probably because of increased food supplies (Peterson et al. 1984). Tebano (1990) showed that the density of *Anadara* is significantly correlated with seagrass density; several other shellfish species also appear to show a preference for seagrass habitats.

Seagrass beds extend in a largely unbroken band from Banraeaba to Bikenibeu (Figure 1), are somewhat discontinuous between Bikenibeu and Buota, and are reportedly widespread around Buariki. These areas correspond to the longest islets on Tarawa. Seagrass beds are rare from Antenon westward and from Abatao northward, at least through the southern three-fourths of North Tarawa. South of Buariki, the only seagrass encountered was a single small (a few square meters) patch around Abatao Islet. Aerial photographs from 1943 indicate additional small patches of seagrass lagoonward of the passage between Tabangaroi and Tabonimata islets. whether these patches survive today is unknown. Aerial photographs from 1984 show that the average width of the South Tarawa seagrass bed was 100-150 m, reaching a maximum of 250 m.

The geographic spread of seagrass beds does not appear to have changed much between 1943 and 1986 in South Tarawa; however, the width of these beds has more than doubled. In 1943, a narrow seagrass bed extended virtually continuously from Banraeaba to Bikenibeu, as it does today; however, most of it was less than 100 m wide. The width of the beds was quantified by evenly spaced measurements for two stretches that were clearly discernible in both the 1943 and 1984 photographs. In the Abarao to Eita area, the seagrass bed was 37-46 m wide in 1943, but by 1984 had increased to 52-100 m (N = 2 x 11 points, $P < 0.05$, t test). Similarly, in Eita-Taborio, the seagrass bed was 16-43 m wide in 1943 and 47-136 m wide in 1984 (N = 2 x 11 points, $P < 0.0001$, t test).

Lagoon Slope

The lagoon slope, as defined here, begins at the deeper edge of the seagrass bed, approximately 0.5 m deep at low tide. It slopes gently and evenly to a depth of about 8-10 m at 1 km from the sand flat margin. *Anadara* beds appear to be confined to this marginal slope, within 1 km of the sand flat margin, largely at depths of less than 8 m. The bottom has a pronounced crater or mound topography with 10-20 cm of vertical relief.

The most abundant species encountered in both surveys were the heart urchins *Maretia planulata* and *Metalia sternalis,* the sand dollar *Laganum depressum*, *Anadara* sp., and *S. luhuanus* (Table 1). Among smaller species, the gastropods *Turritella* sp. and *Strombus erythrinus* were particularly abundant, although not consistently sampled.

Table 1 Population density (m^{-2}) of dominant macrofauna in quantitative surveys of lagoon slope in Tarawa Lagoon.

Survey	*Anadara* sp.	*Strombus luhuanus*	*Laganum depressum*	*Maretia planulata*	*Metalia sternalis*	Echinoids[4]
Trans.[1]	4.8 ± 11.1	5.3 ± 18.5	11.2 ± 28.7	23.3 ± 40.7	8.5 ± 10.8	42.9 ± 53.9
Bed[2]	14.6 ± 16.2	9.9 ± 20.5	18.8 ± 27.9	12.3 ± 12.3	7.2 ± 7.3	38.3 ± 32.2
Comb.[3]	7.8 ± 13.6	6.7 ± 19.1	13.5 ± 28.5	19.9 ± 34.8	8.1 ± 9.8	41.5 ± 48.2

[1]Trans. = data from transect survey across slope (N = 90 quadrats).
[2]Bed = data from survey of Taborio-Bangantebure *Anadara* bed (N = 40 quadrats).
[3]Comb. = combined data from the above two surveys.
[4]Echinoids = combined data for three irregular echinoids.

Most species exhibited little obvious zonation across the 900-m-wide transects (Figure 9). The abundance of *L. depressum* tended to increase lagoonward, and the abundance of *Anadara* fell at the lagoonward station. This pattern supports our general observation that *Anadara* is no longer abundant more than 1 km lagoonward of the sand flat margins.

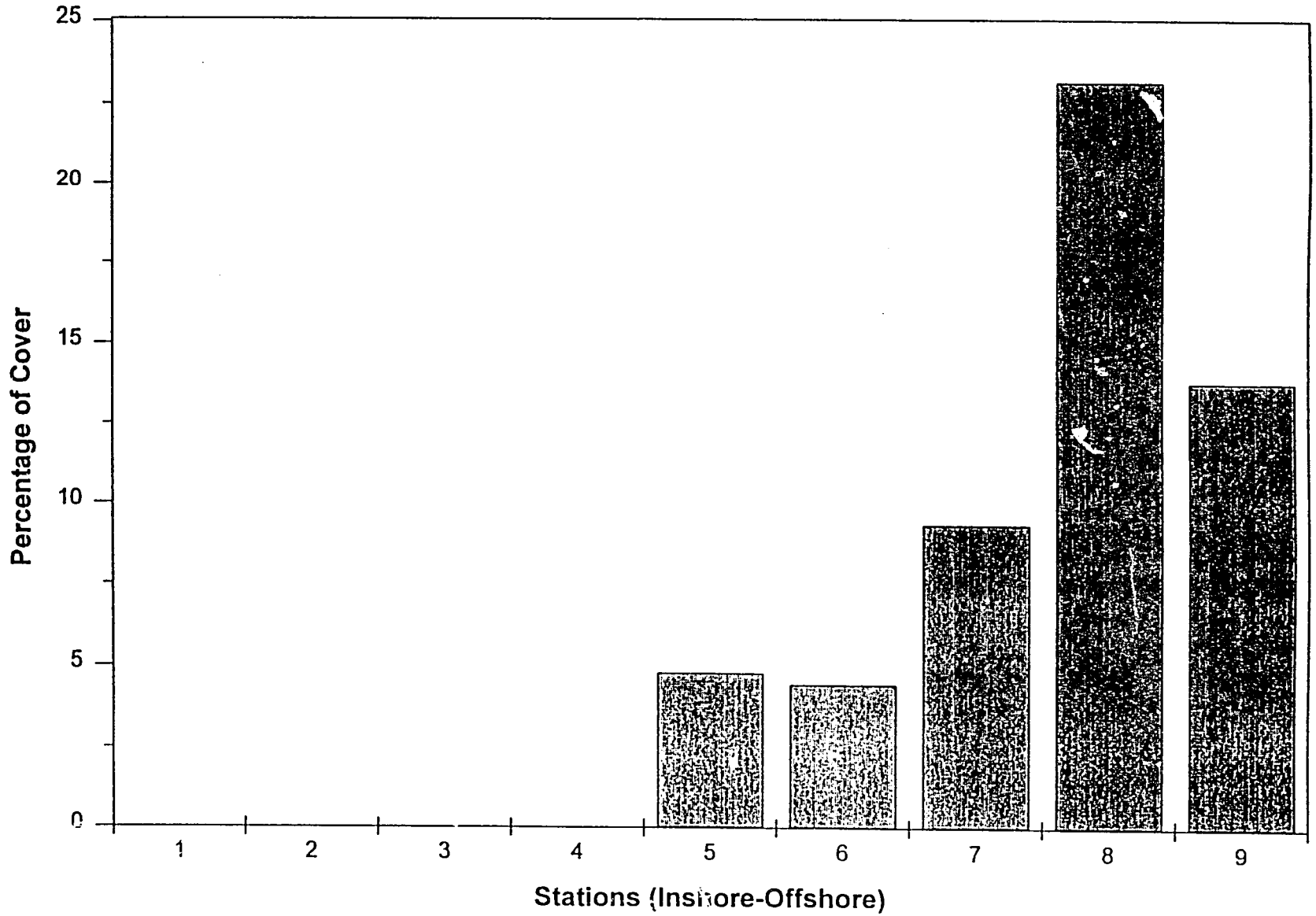


Figure 8 Mean percentage of cover of sand flat substrata by zoanthid (?*Zoanthus* sp.) colonies across South Tarawa sand flat (Stations 1-9), for seven transects with zoanthid data (see text).

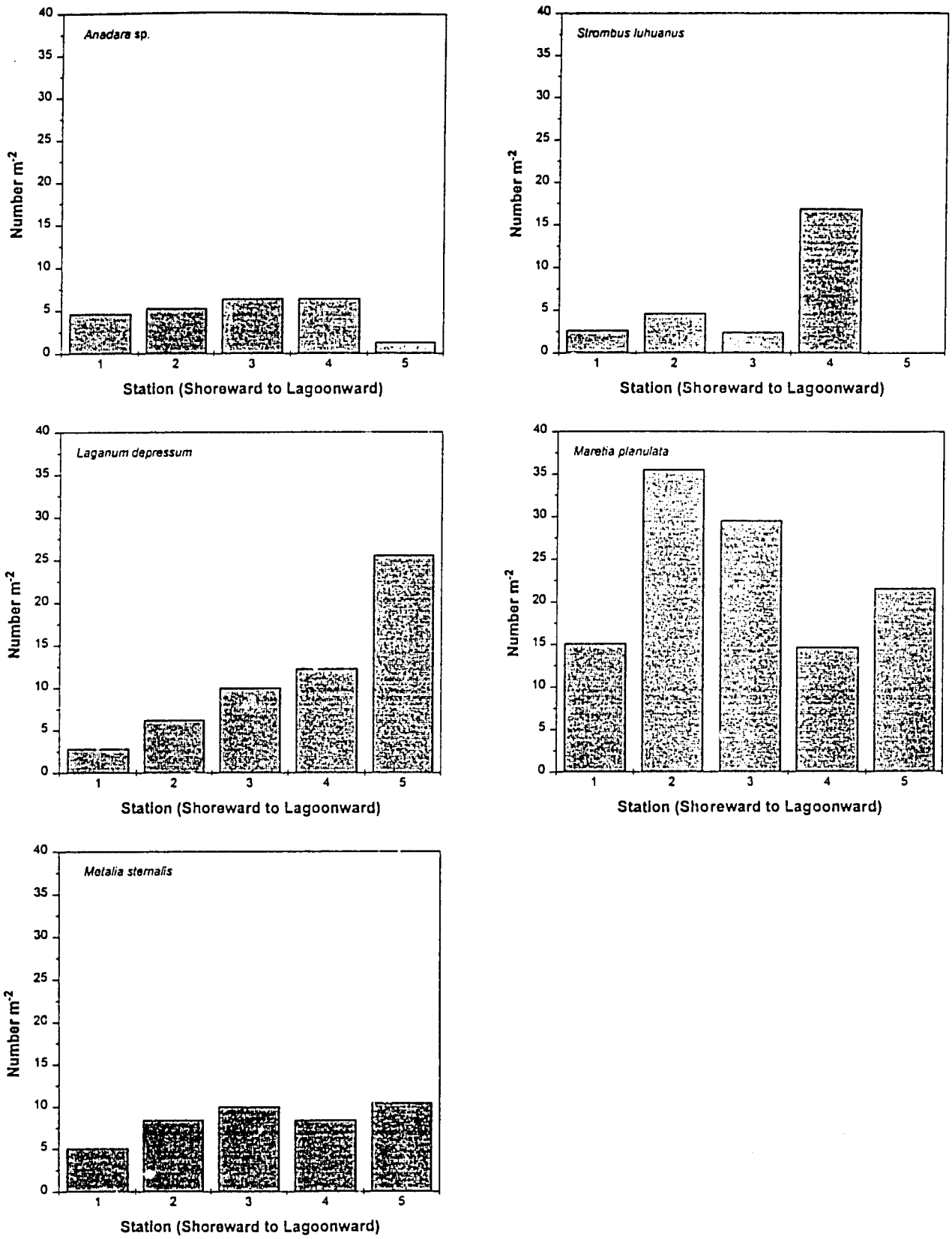


Figure 9 Mean population density of *Anadara* sp., *Strombus luhuanus*, *Laganum depressum*, *Maretia planulata*, and *Metalia sternalis* across South Tarawa lagoon slope (per station), for all nine transects.

The distribution of these five species is patchy; one or a few often dominate areas tens of meters or more across. Particularly striking are areas dominated by the two dominantly epibenthic species, *L. depressum* and *S. luhuanus*. Variation along the coast of South Tarawa is more noticeable for the two mollusks than for the three echinoids (Figure 10), partly because *Anadara* appears to be localized to a few well-defined beds.

Anadara sp.

Anadara was absent from most of the stations, but was abundant at some sites, giving rise to a highly variable population density of 5 ± 11 m^{-2} (N = 90 quadrats). No *Anadara* were found on two transects, and density was greater than 2 m^{-2} on only four of the nine transects. Along transects 6 and 7, which traversed the well-known Taborio-Bangantebure *Anadara* bed, *Anadara* occurred at all stations except the five closest to land. In contrast, on transects 3 and 4, which also crossed dense populations, and on transects 5, 8, and 9, which encountered the remaining sparser populations, dense *Anadara* patches only occurred at single stations. Furthermore, at transects 3, 8, and 9, the beds were at the station closest to land, only 90 m from the margin of the sand flat near the periphery of the seagrass bed. These surveys corroborate that the only significant *Anadara* bed on the lagoon slope is in the Taborio-Bangantebure area, although a few small beds exist elsewhere.

Spot surveys of the Taborio-Bangantebure *Anadara* bed show that it extends from about 173°03.2′E to 173°05.7′E (approximately 4,600 m long) and is 640 ± 210 m^2 wide (N = 4 transects, 420-900 m wide), encompassing a total area of 2.9 ± 1.0 km^2. Within this area, rapid spot checking revealed that *Anadara* was abundant enough in 87% of the sites (N = 30) to be visually apparent within one to three free dives. This pattern was also true for all the sites (N = 10, 90% of 40 quadrats) that were quantitatively sampled (Figure 11). The few sites in the survey that lacked *Anadara* appeared to be off the bed; adjacent landward or lagoonward sites always supported the shellfish. Thus, *Anadara* appears to form a largely contiguous bed in this region.

Although *Anadara* is found throughout this bed, abundance varies markedly (Figure 11), averaging 14 ± 15 m^{-2} (N = 60, combined data from transects 6 and 7 [13 ± 14 m^{-2}, N = 20] and second shellfish bed survey [15 ± 16 m^{-2}, N = 40]). Some of this patchiness is probably the result of intense human predation. Free divers focus their attention on the densest beds and probably find that moving on before an area is completely exhausted is economically advantageous (see below).

The spatial variability of *Anadara* abundance on the lagoon slope limits the accuracy of population size estimates. Nevertheless, results of the two surveys are similar: the transect survey of the 15-km-long, 1-km-wide lagoon slope yielded an estimated population size of 7.2 ± 16.7 x 10^7, while the *Anadara* bed survey (excluding transect data from within the bed), over a 3-km^2 bed, yielded an estimated population size of 4.4 ± 4.9 x 10^7 *Anadara* larger than 1-2 cm.

Dominance of local populations by single or a few size classes appears to be common throughout all habitats occupied by *Anadara*, probably reflecting high spatial and temporal variation in

recruitment. This species exhibits a bimodal size distribution on the lagoon slope (Figure 12), with different areas often dominated by different size classes (Figure 13). For example, transect 4 was dominated by 25-mm-long animals, while *Anadara* at transect 7 were between approximately 17 and 56 mm long.

Strombus spp.

The patchy distribution of the two abundant *Strombus* species, *S. luhuanus* and *S. erythrinus*, is strikingly apparent on dives over the lagoon slope; a third species, *S. variabilis*, is less common. Mature and juvenile *S. luhuanus* and *S. erythrinus* tend to aggregate and segregate by species, and *S. luhuanus* also by maturity. Thus, in any given area, either mature or juvenile *S. luhuanus* or *S. erythrinus* dominates. *S. luhuanus* tends to be most common where exposed rubble is present, probably because it feeds on benthic macroalgae that attach to rubble. In contrast, *S. erythrinus* feeds on the red alga *Grateloupia* sp. that lies on the sand in large (typically 10-50 cm), loose, or poorly attached fluffy masses.

S. luhuanus had a mean population density of 7 ± 19 m^{-2} (combined surveys); both surveys resulted in comparable densities (Table 1). As is *Anadara*, *S. luhuanus* is restricted to the marginal 1-km portion of the lagoon bottom. The population estimate for this species on the 15-km-long, 1-km-wide lagoon slope off Bairiki-Bikenibeu is $1 \pm 3 \times 10^8$. If densities toward Betio are similar, then the South Tarawa lagoon-slope population size may be 150% of this value. *S. erythrinus* and *S. variabilis* were counted regularly only in the *Anadara* bed surveys, where densities were 8 ± 14 m^{-2} and 1 ± 3 m^{-2}, respectively.

The occurrence of *Anadara* and *S. luhuanus* were significantly associated ($P < 0.0001$, G test, combined data from both surveys); although *S. luhuanus* occurred in only 28% of the quadrats, it co-occurred with *Anadara* in 89% of them. The mean density of irregular echinoids was somewhat, but not significantly, higher (50 versus 32 m^{-2}) in quadrats where *Anadara* occurred, rather than where the shellfish was absent.

Two hypotheses may explain this association between a benthic algal grazer and a suspension feeder:

1) *Anadara* needs hard substrata (rubble or adult shells) for attachment when young, whereas *S. luhuanus* feeds on benthic algae, which also need hard substrata for attachment. Thus, the correlated abundance of these shellfish may be a function of the availability of exposed hard substrata. Alternatively, dead *Anadara* shells provide much of the rubble for algal attachment, which in itself may attract *S. luhuanus*.

2) The abundance of both species may correlate negatively with that of irregular echinoids, and, thus, they may congregate at the few sites where irregular echinoids are uncommon. Irregular echinoids bulldoze soft bottoms and greatly influence small infaunal organisms (Highsmith 1982). Even if such disturbance does not affect adults of these two mollusks, it may negatively influence the settlement of new recruits.

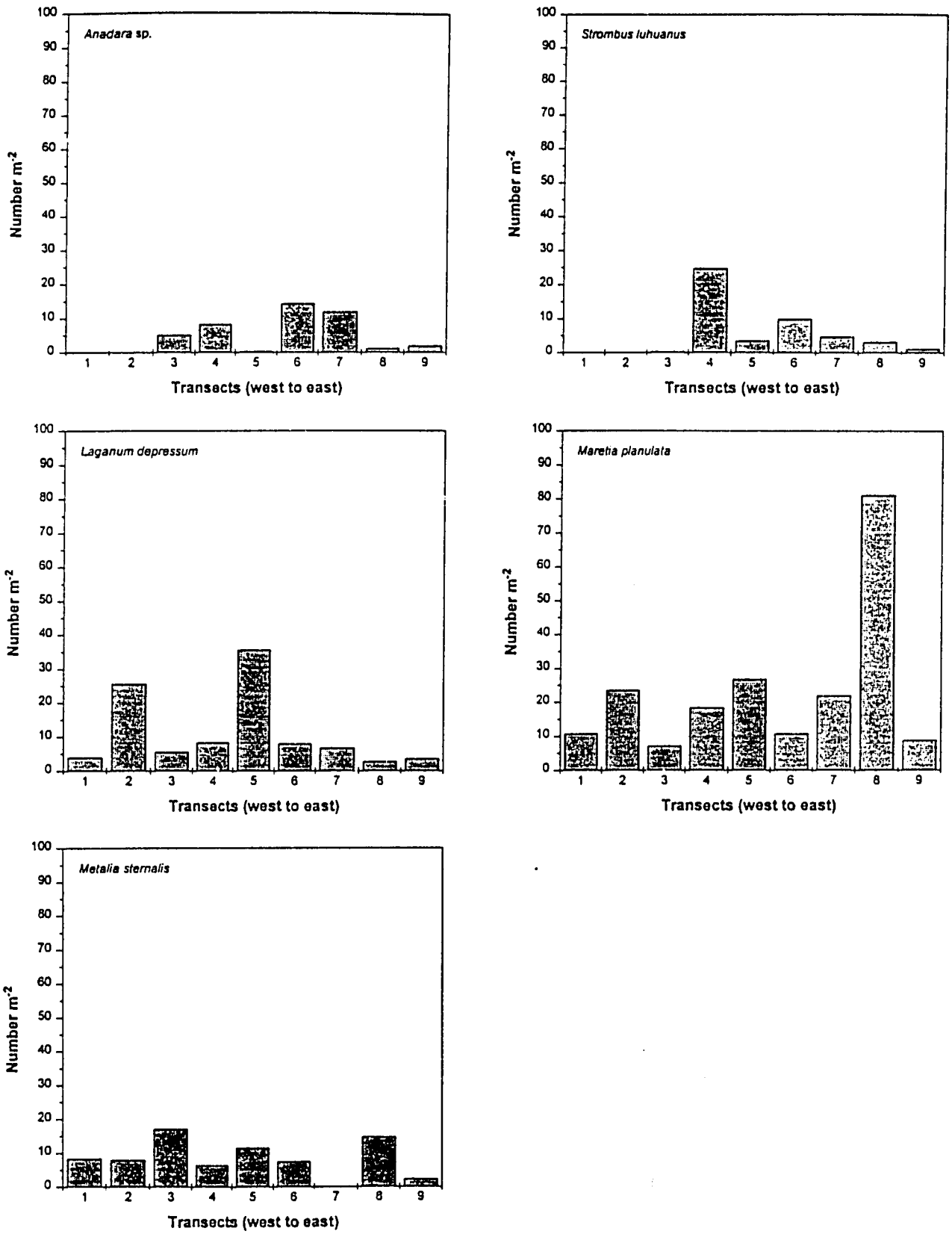


Figure 10 Mean population density of *Anadara* sp., *Strombus luhuanus*, *Laganum depressum*, *Maretia planulata*, and *Metalia sternalis* along South Tarawa lagoon slope (per transect), for all five stations.

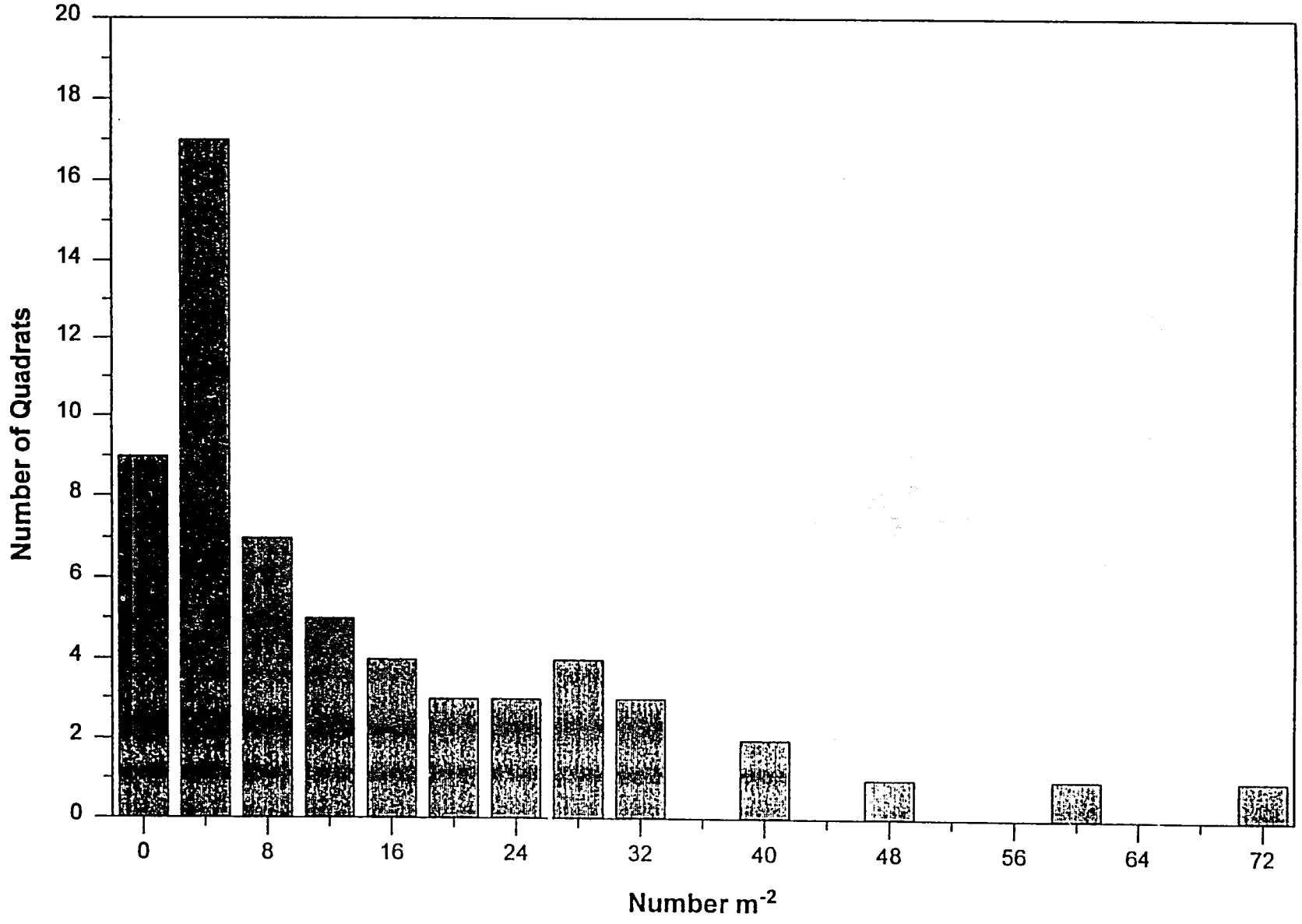


Figure 11 Frequency distribution of per-quadrat population density of *Anadara* sp. within Taborio-Bangantebure seagrass bed in Tarawa Lagoon. Based on combined data from transects 6 and 7 and second shellfish bed survey (n=60).

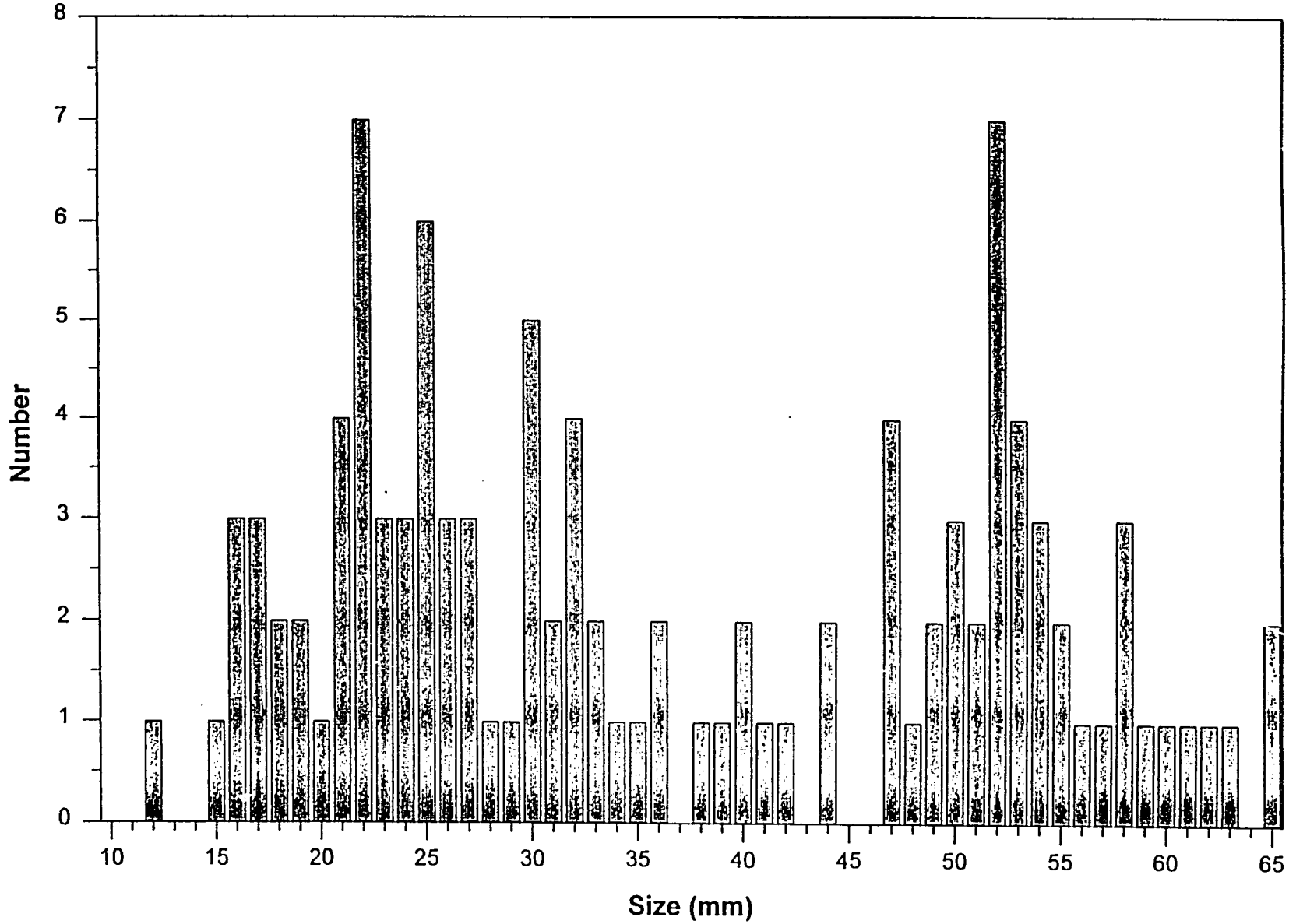


Figure 12 Size-frequency distribution of *Anadara* sp. samples from all quadrats on South Tarawa lagoon slope.

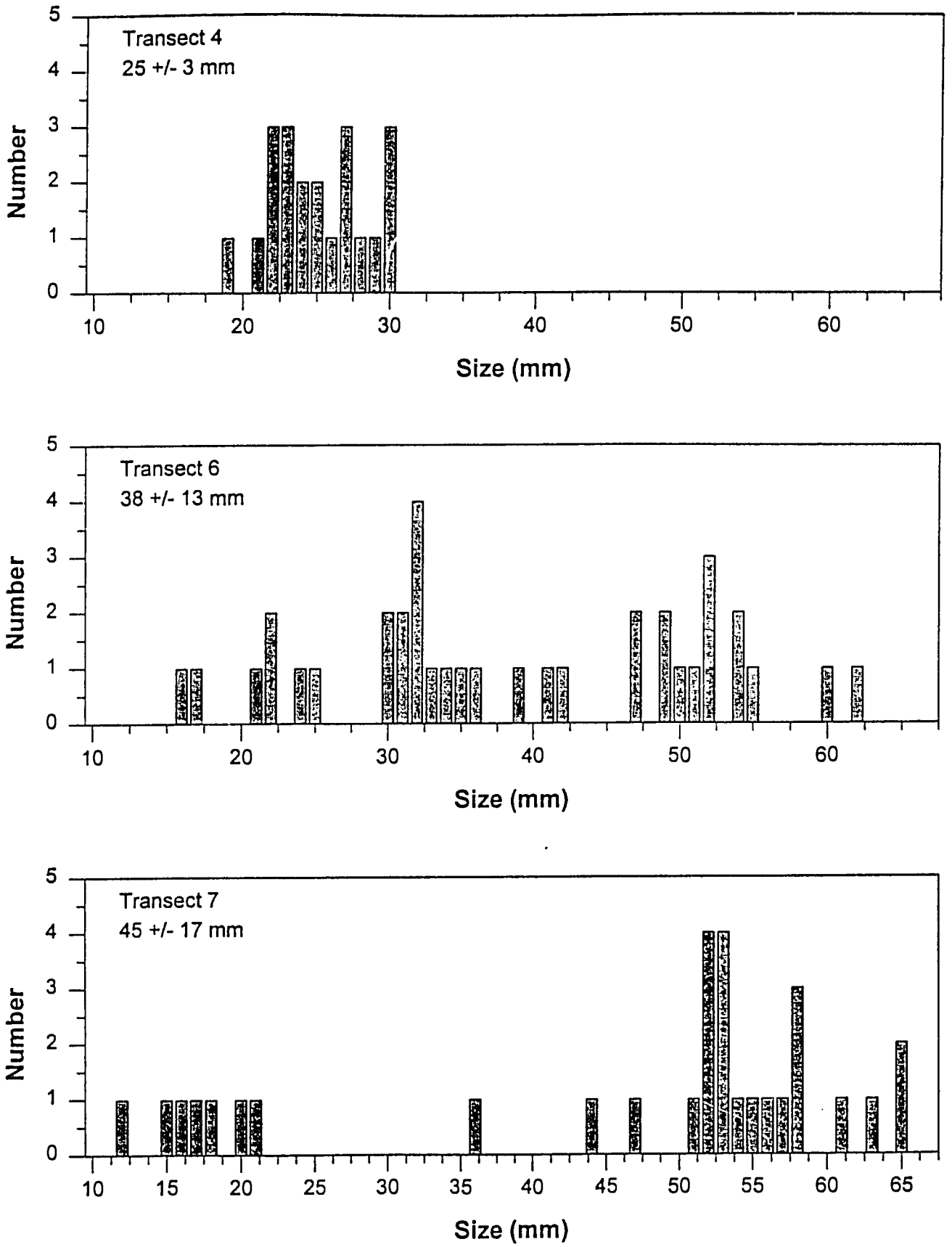
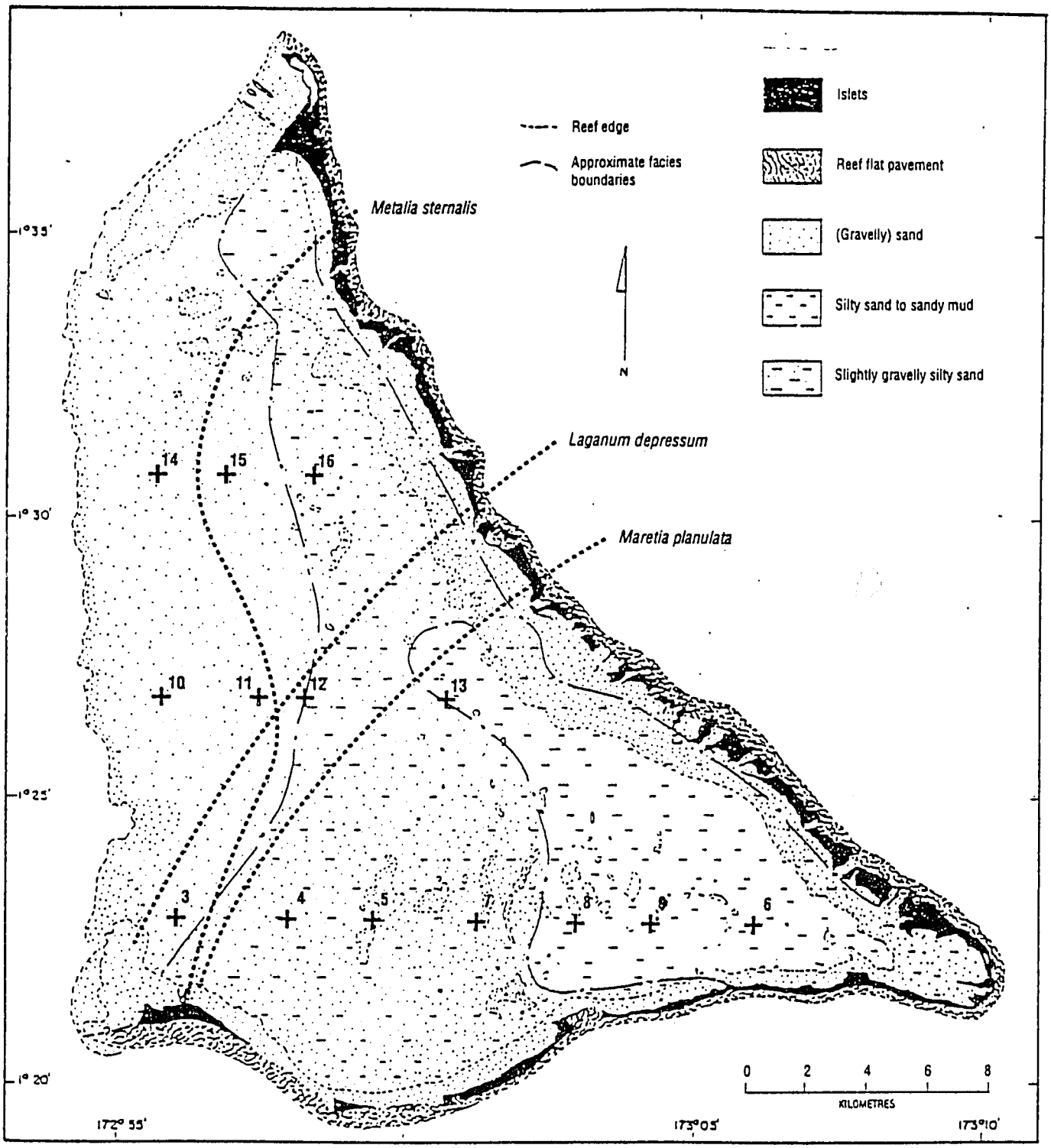


Figure 13 Size-frequency distribution of *Anadara* sp. samples from transects 4, 6, and 7, along South Tarawa lagoon slope. Mean ± SD given per transect.



Prepared by BioSystems Analysis, Inc./1994

Figure 14 Distribution of major sediment types (after Richmond 1990), of the irregular echinoids *Laganum depressum, Maretia planulata* and *Metalia sternalis,* and location of lagoon floor sampling stations.

Other Species

Fish are uncommon on the open sandy expanse of the lagoon slope (although stingrays were occasionally seen), but small acanthurids, lutjanids, small serranids, occasional balistids, and other reef fish hover around the scattered bits of reef. Most reefs are less than 2 m across and built by *Porites*, which was the only coral other than *Pocillopora damicornis* seen in the fringing patch reefs of the southeastern lagoon. Off Betio, *Montipora* and *Acropora* also are common (Zann and Bolton 1985). The areas around the coral heads are thickly strewn with shells, especially of *Anadara*, apparently gathered by predators. Some of the shells have been crushed near their posterior end, indicating possible attack by trigger fish. Others, however, are intact; therefore, the organisms that consumed them are unknown.

Lagoon Floor

Most of Tarawa Atoll consists of lagoon floor from 5 to 20 m deep (maximum depth of 25 m) (Bolton 1982a). This relatively flat zone lies between the intertidal sand flats and the western barrier reef. Numerous patch reefs and shoals rise above the plane of the lagoon floor. Even though no significant invertebrate resources are taken from the lagoon floor, a limited survey was conducted to characterize its biota because it dominates the lagoon in terms of area.

The lagoon floor exhibits marked west-to-east and north-to-south gradients in habitat, species composition, and abundance of both mollusks and echinoids. Although the depth at all 14 stations was similar (6-20 m, with all but two being 11-20 m), sediment grain size (Weber and Woodhead 1972; Richmond 1990) and coral cover and diversity decreased markedly from north to south and west to east. Although only occasional *Porites* and *Pocillopora damicornis* colonies were noted on the southern transects, diverse coral communities were encountered on the much coarser, gravelly sand bottoms of the northwestern and west-central stations.

Three species of large irregular echinoids (*Laganum depressum*, *Maretia planulata*, and *Metalia sternalis*) dominate large areas of the inner lagoon floor, while mollusks are uncommon and constitute only a small fraction of the biomass. The distribution of these echinoids corresponds reasonably well to the distribution of sediments (Figure 14). Huge groups of *M. planulata* cover much of the silty and muddy bottom of the southeastern lagoon. This species was encountered at all seven stations (in 12 of 14 quadrats) in the southeastern lagoon, at a mean population density of 55 ± 69 m^{-2} (Figure 14). Within this area, the density of *M. planulata* was correlated with sediment type. Densities were highest at the four stations in the muddier sedimentary zone than at the three stations in the gravelly sedimentary zone (Figure 14). In contrast, *M. planulata* was absent from the seven northwestern stations.

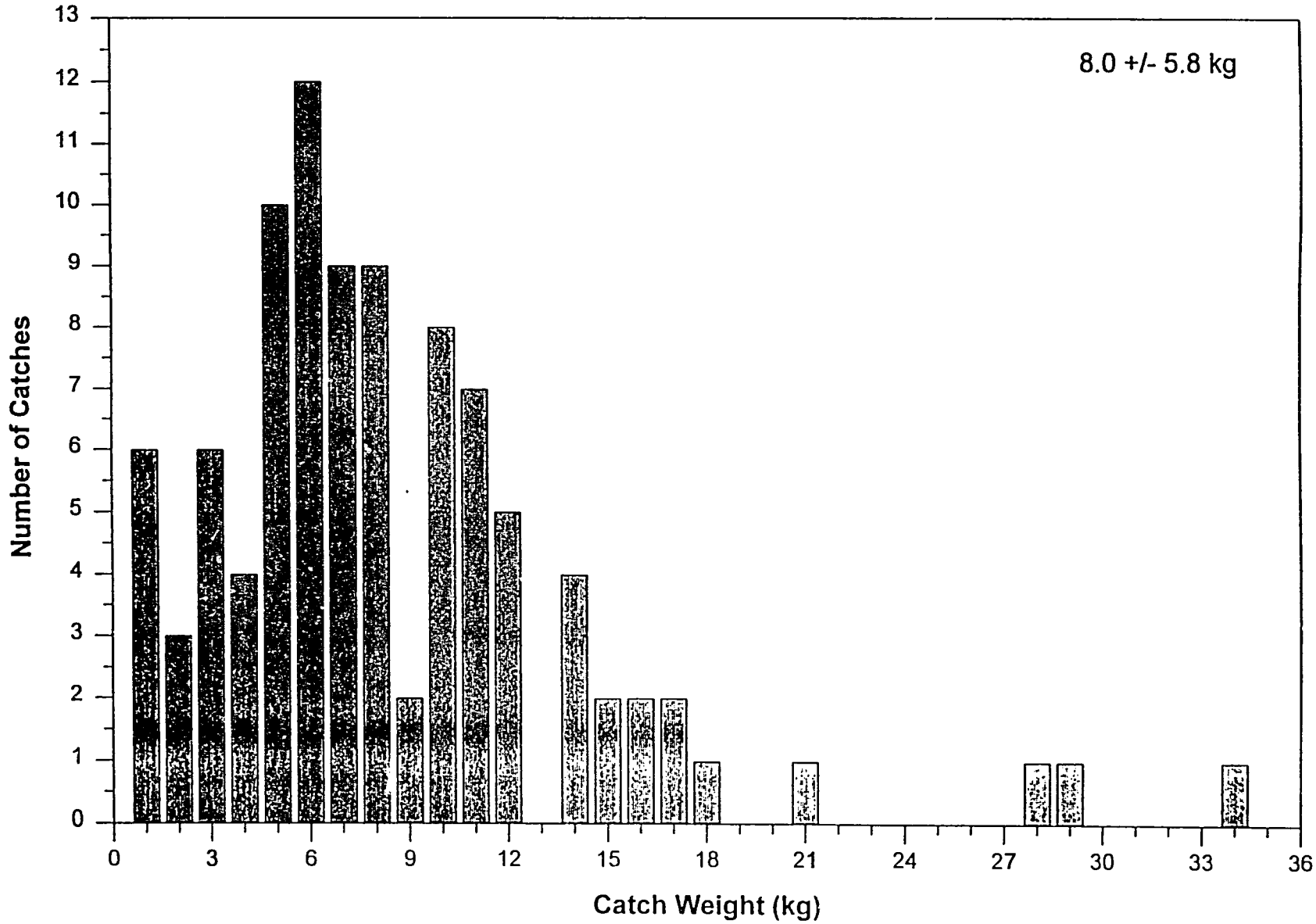


Figure 15 Frequency distribution of catch-per-person-effort for shellfish gatherers working South Tarawa sand flats. Mean ± SD given.

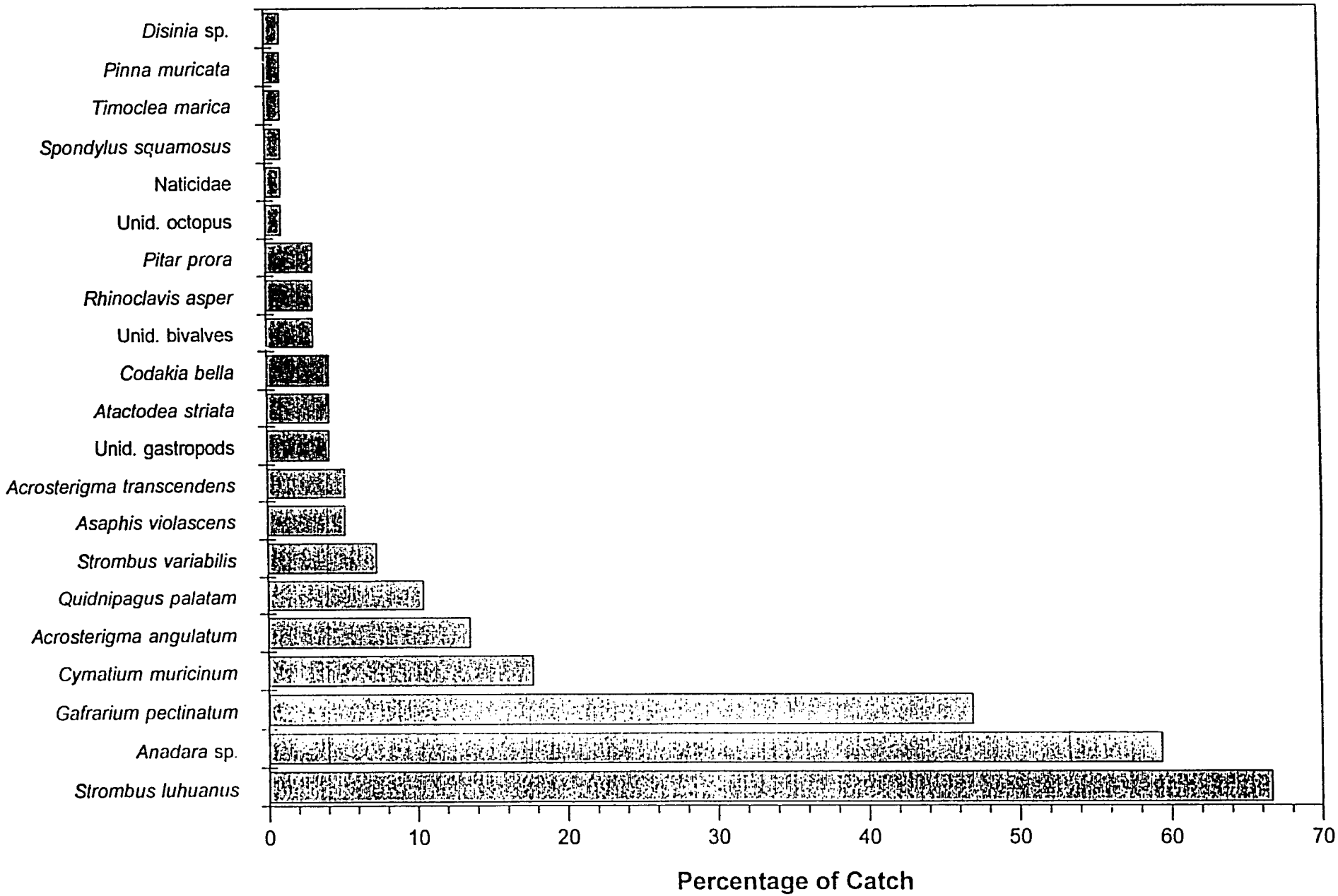


Figure 16 Frequency distribution of species per catch for landings from South Tarawa sand flat.

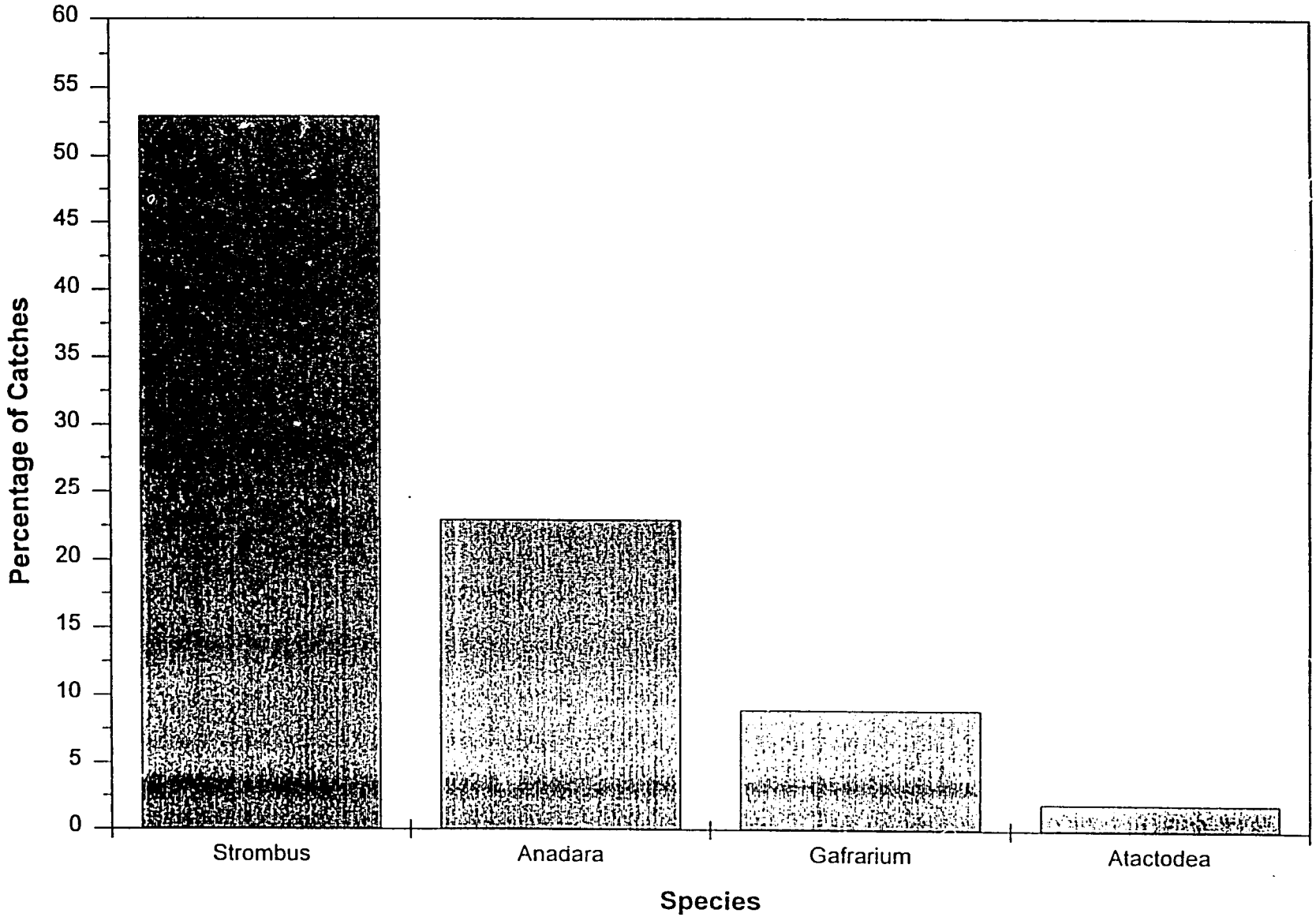


Figure 17 Dominant species in catches from Tarawa Lagoon. Indicates percentage of all gathering catches that were dominated (defined as constituting >75% of weight of catch) by single species. Species are *Strombus luhuanus*, *Anadara* sp., *Gafrarium pectinatum*, *Atactodea striata*.

Laganum depressum also was limited to the southeastern lagoon, where it was encountered at all nine stations (Figure 14) at a mean density of 4 ± 7 m^{-2}. In contrast, it was absent from the five stations to the northwest. *Metalia sternalis* was the most widespread species; it was ubiquitous (encountered in 19 of 20 quadrats) through the midlagoon and eastern lagoon, at a mean population density of 14 ± 10 m^{-2}, but was absent at the four western stations (Figure 14).

Thus, the distribution of all three large echinoid species is limited largely to lagoonal bottoms with a significant silt fraction. The combined density of these species is significantly different among stations located in silty mud, silty sand. and gravelly sand bottoms (Figure 14, One-Way ANOVA, $P < 0.0000$), with densities significantly higher at stations in areas with muddy (116 ± 77 m^{-2}, $N = 8$) rather than silty (19 ± 13 m^{-2}, $N = 10$) or sandy (1 ± 3 m^{-2}, $N = 10$) bottoms (Tukey's test, $P < 0.05$, latter two means not significantly different).

We found only a few live mollusks on the silty and muddy bottoms of the southeastern lagoon: a small, unidentified tellinid bivalve was the most abundant infaunal species; *Turritella* sp. occurred in large epibenthic aggregations; and an unidentified, small epibenthic trochid and *Tectonatica robillardi* were fairly common. The higher diversity of dead mollusks compared to live ones was striking. Although this discrepancy is partly a sampling artifact caused by the relative rarity of larger species and the durability of their shells, it also indicates temporal changes in lagoon floor assemblages. The presence of vast quantities of empty shells but no living individuals of several small, fragile species (e.g., *Musculus* sp., perhaps the most common mollusk on the lagoon floor) indicates that these species were much more abundant in the past than they are today. This trend may reflect periodic, short-lived blooms of certain species or the gradual, long-term turnover of bottom communities (see Holocene turnover in lagoon bottom mollusks in Enewetak Atoll in Kay and Johnson 1987; Paulay 1991).

Unlike the shallow-water environments of the lagoon, the deeper lagoon floor (but not the lagoon slope, see above) supports few shellfish resources. Lagoon floor communities differ in species composition from shallow (shoal and sand flat) communities, sharing only a few species. Most of the heavily exploited species of the sand flats are absent or rare on the lagoon floor. Thus, the lagoon floor does not hold significant broodstocks that could supply overexploited sand flat populations with recruits.

The only economically important species encountered regularly on the lagoon floor was *Anadara*, apparently a fairly eurytopic animal. Nevertheless, none were alive. *Anadara* beds like those found at a few locations on the lagoon slope may occur on the deeper lagoon floor as well; our limited survey may have missed these locations. Dense populations of *S. luhuanus* were encountered at sites on the slopes, on the tops of some patch reefs and shoals, and in the lagoon-slope *Anadara* beds, but the species is essentially absent from the plain of the deeper lagoon floor.

Gatherer Surveys

Sand Flats

Time constraints prevented a thorough assessment of the number of gatherers on the sand flat, as reflected by the variable results (Table 2). Nevertheless, a rough estimate of gathering pressure can be made. On a Saturday with a good low tide (LW 0.2 m, 12 February 1994), 691 people were observed gathering within a 3-hr period centered around low tide. Given that many people collected for only 1-2 hrs, many shellfish must have been missed during the spot checks. More than 1,000 people may have been active on that day. On a Monday with a moderately good tide (LW 0.5 m, 14 February 1994), 303 people were counted gathering within a 2-hr period centered around low tide. Again, more than 400 people may have gathered shellfish that day. Thus, perhaps twice as many people gather shellfish on Saturdays as on weekdays. In contrast, 60 people were counted on the Sunday (LW 0.3 m, 23 February 1994) between these days. The height of low water clearly makes a difference because little gathering activity occurs on days with poor tides (26 people were counted on 19 February 1994, tide 0.9-1.2 m).

Table 2 Number of shellfish gatherers counted on South Tarawa sand flats.

		Low Tide		Survey Time		
Date (1994)	Day	Height	Time	Start	End	Count
2 February	Friday	0.2	10:53	11:50	14:00	148
12 February	Saturday	0.2	11:24	10:40	13:20	691
13 February	Sunday	0.3	11:52	11:20	13:00	60
14 February	Monday	0.5	12:18	11:30	13:15	303
19 February	Saturday	~1.0	17:39[1]	14:25	15:50	26
22 February	Tuesday	0.6	07:45	08:10	09:20	112

[1]The 19 February count was not taken during low tide, tides changed from 1.2 m at 10:34 to 0.9 m at 17:39 on that day.

To estimate the total impact of gatherers, the increase in gathering on Saturdays was assumed to cancel the greatly decreased gathering activities on Sundays. Given an average daily gathering population that fluctuates from 500-1,000 during the best low tides to 0-100 during the poorest tides, with a mean of perhaps 200-400 people per day, the number of gatherer-days on the sand flat of South Tarawa would be 7.5-15 x 10^4 per year. The mean catch of gatherers on the sand flat was 8 ± 6 kg person^{-1} effort^{-1} ($N = 96$) (Figure 15). Thus, about 600-1,200 tonnes of shellfish are taken per year by people gathering on the sand flat.

S. luhuanus, *Anadara*, and *Gafrarium pectinatum* were by far the most common species in the catches studied, occurring in 67%, 59%, and 47% of the catches, respectively (Figure 16). A total of 19 species was identified in the catches sampled (Figure 16). Gatherers appear to consume all shellfish species of sufficient size (approximately greater than 1 cm), and many mollusks have common names (Appendix A), suggesting their importance as food. Most catches were dominated (defined as constituting greater than 75% of catch weight) by one of four species; the most common was *S. luhuanus* (61% of catches), followed by *Anadara* (26% of catches) (Figure 17).

The mean total weight of *S. luhuanus* for each catch in which it occurred was 8 ± 6 kg, the value for *Anadara* was 9 ± 8 kg, and the value for *G. pectinatum* was 1.2 ± 1.5 kg. These weights are probably slightly overestimated because better species-specific data were available for catches dominated by single species than were for catches of mixed species. Nevertheless, they should not be biased against particular species. Multiplying incidence in catch with weight per catch therefore indicates that the three dominant species were taken at a ratio of 5.4:5.1:0.6 (*Strombus*:*Anadara*: *Gafrarium*). Assuming that these three species constitute about 90% of the total catch, they constituted approximately 44%, 41%, and 5%, respectively, of the South Tarawa-wide sand flat shellfish catch. Given that about 900 tonnes (see above) of shellfish are harvested, the yearly harvest would be approximately 400 tonnes of *S. luhuanus*, 370 tonnes of *Anadara*, and 45 tonnes of *G. pectinatum*. An additional 1,000 tonnes of *Anadara* are taken by divers (see below). On the basis of a household survey, Bolton (1982b) estimated that about 1,730 tonnes of *Anadara*, 850 tonnes of *S. luhuanus* and 280 tonnes of *G. pectinatum* were taken in South Tarawa in 1982; she also noted, however, that the nature of her survey likely lead to an overestimate of the true harvesting pressure.

The mean individual weight of harvested *S. luhuanus* is 10 ± 2 g (mean ± SE from N = 17 harvests), that of *G. pectinatum* is 8 ± 2 g (mean ± SE from N = 15 harvests), and that of *Anadara* is 20 ± 13 (mean ± SE from N = 26 harvests). The low variance in *S. luhuanus* weight indicates that only large juveniles and adults of this species are taken, because it has determinate growth. In contrast, the high variance in *Anadara* weight reflects the great variability in this species' size among beds, caused largely by irregular recruitment. Thus, high recruitment in the southeastern elbow started a new *Anadara* fishery in 1993; those taken in the Temaiku area in early 1994 averaged 6 ± 2 g (mean ± SE from N = 8 harvests), compared with 26 ± 11 g (mean ± SE from N = 18 harvests) for *Anadara* taken elsewhere.

Given these average weights, the yearly numbers harvested, and estimated above, translate to approximately 4×10^7 *S. luhuanus*, 2×10^7 *Anadara*, and 6×10^6 *G. pectinatum*. These rough population size estimates can be compared with those of the sand flat (see above) for these species (7×10^6 *S. luhuanus*, 6×10^6 *Anadara*, and 6.5×10^7 *G. pectinatum*). As noted above, population estimates of *S. luhuanus* are probably underestimated. The disparity between the estimated *Anadara* population density and the higher annual harvest is partly a result of the immense recruitment event in the southeastern elbow that contributed to the harvest of that species in 1994 (when much of the

harvest data were collected). This event had not yet occurred when the sand flat populations were surveyed in 1992. Nevertheless, these estimates indicate that the harvests of *S. luhuanus* and *Anadara* are close to, if not in excess of, their rate of production.

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Offshore *Anadara* Beds

Anadara is frequently harvested by divers on the lagoon slope from 2 to 8 m deep. To work in this area, divers need a vessel to hold their catch. A variety of vessels are used, including floats (which are made from rubber inner tubes fitted to hold bags of *Anadara* and are most common), outrigger canoes, and aluminum dinghies; some dinghies are fitted with outboards and some canoes are fitted with sails.

Counts of divers on the Taborio-Bangantebure *Anadara* bed are much more accurate than counts of gatherers on the sand flat, partly because of the small size of the area and the gatherer population. Counts were made on 6 days; three surveys were conducted during the early afternoon, when more than 90% of the divers were likely onsite, and the other three were conducted during the late morning, when some divers had not yet arrived. An average of 34 ± 4 divers worked these beds on the 3 days when more comprehensive counts were taken (Table 3).

Table 3 Results of survey of divers collecting *Anadara* from offshore beds.

Date (1994)	Time	Number of Vessels	Number of Divers	Divers per Vessel[1]
15 February	11:00	14	25	1.79
17 February	10:45	9	17	1.89
18 February	11:15	15	27[2]	
21 February	13:00	21	35	1.67
22 February	13:30	17	30	1.76
23 February	13:00	21	38	1.81
Mean ± SD[3]		16.2 ± 4.6	28.6 ± 7.5	1.8 ± 0.1
Mean ± SD[4]		19.7 ± 2.3	34.3 ± 4.0	1.8 ± 0.1

[1]Divers per vessel = calculated mean number of divers per vessel.
[2]Not counted, estimated from divers per vessel ratio
[3]Mean of all values.
[4]Mean of 21, 22, and 23 February, when surveys were conducted during peak gathering times.

All divers pack their *Anadara* into standard-size rice bags that hold 34 ± 1.5 kg per bag ($N = 5$). Interviews indicated that the average diver takes 3.25 ± 1.6 bags per day ($N = 10$). Thus, about 3.8×10^3 kg of *Anadara* are taken overall by divers per day. Considering that little gathering occurs on Sundays and that gathering during stormy weather is not possible, divers gather on perhaps 275 days per year, with a yearly harvest of about 1,000 tonnes. Given that the large offshore *Anadara* have an average weight of approximately 50 g, this annual harvest weight translates to a harvest of 1.6×10^7 *Anadara*. With an estimated population of $4 \pm 5 \times 10^7$ clams in the Taborio-Bangantebure

bed, or 7 ± 17 x 10^7 clams in the entire South Tarawa lagoon slope, this figure represents a harvest of about one-third to one-fifth of the total adult population per year.

The growth rate of *Anadara* in Tarawa Lagoon is not fully known, but preliminary data indicate that the typically harvested 3- to 6-cm shellfish must be at least 2 to 3 years old. Recruitment of the species appears to be episodic, being highly variable in both time and space (Tebano and Paulay, this volume). Thus, the harvests in the offshore beds are near to, if not exceeding, sustainable rates.

In contrast to gathering shellfish on the sand flats, a practice primarily motivated by subsistence, diving for *Anadara* is a commercial venture, with 80% of the interviewed divers (N = 10) collecting *Anadara* for sale. These divers routinely collect *Anadara* 6 days a week (which is one reason for the low variance in the number of people seen collecting per day). With a bag of *Anadara* selling for A$6 on the roadside (February 1994; A$5 in 1993), they earn A$20 per day, a good wage by Tarawa standards. Although this venture is lucrative, the populations will be unable to support much of an expansion of harvesting.

The strenuous nature of harvesting limits overharvesting of offshore *Anadara* beds. Collectors must free dive to 3-6 m for many hours each day. Divers search for areas with high *Anadara* densities and good divers can grab as many as 50 clams per dive. Divers avoid portions of the bed with low shellfish density, so once population density becomes moderately reduced, harvesting may become unprofitable.

Summary and Conclusions

The abundance of benthic macroinvertebrates in Tarawa Lagoon is striking and unusual. Oceanic atolls typically support a relatively low abundance and biomass of macrobenthos. The major exceptions to this trend are "closed" atolls where water exchange with the surrounding ocean is limited and the residence time of lagoon waters can be several weeks to months. The lagoons of closed atolls tend to have low-diversity faunas dominated by one or a few extremely abundant species of high biomass (Salvat 1969). Frequently, the dominant species are photosymbiotic bivalves, which derive much of their nutrition autotrophically. Thus, giant clams (*Tridacna maxima*) are abundant in several closed atolls (e.g., Reao, Takapoto, Vahitahi [Tuamotu], and Caroline [Line]); the photosymbiotic cockle *Fragum fragum* is extremely abundant on the sand flats of others (e.g., Anaa and Tuamotu) (Salvat 1969, 1972; Richard 1977, 1982; Sirenko 1991). Some closed atolls also host abundant heterotrophic bivalve populations, especially the epibenthic species *Arca ventricosa, Pinctada maculata,* and *Chama iostoma* (Salvat 1969; Richard 1978, 1985a, b). These latter species presumably subsist on the relatively high, indigenous lagoonal productivity of closed atolls (e.g., Sournia 1976; Delesalle 1982).

In contrast to the macrobenthos of typical closed atolls, which are characterized by low diversity and high biomass, and the macrobenthos of typical open atolls, which are characterized by high diversity and low biomass, Tarawa hosts high diversity and high biomass in an open lagoonal setting. With the entire western side submerged, the residence time of lagoonal waters is about 1 week (Chen et al., this volume). Three species of large, irregular echinoids and a diversity of mollusks are abundant in a variety of habitats, and all the abundant species are heterotrophic. Also, unlike the situation in the well-studied closed atolls of the Tuamotus, most of the common species in Tarawa Lagoon are infaunal.

Because Tarawa lies in the equatorial upwelling region, the concentration of inorganic nutrients, phytoplankton biomass, and productivity are considerably elevated above that of atolls located in the subtropical gyres (Kimmerer and Walsh 1981). This enhanced planktonic, and probably benthic, primary production must be largely responsible for the abundance of macrobenthos. Although planktonic secondary production may be of insufficient magnitude to support the fishery yield of the atoll (Kimmerer, this volume), only an estimated 8%-10% of the planktonic primary production is consumed by zooplankton (Kimmerer pers. comm.). This percentage leaves open the possibility that much of the benthos is supported by planktonic primary production. The abundance of suspension and deposit feeders in the benthos is consistent with this hypothesis. Bonefish and many other fish species rely largely on suspension and deposit feeding invertebrates for their food (personal observation), and could therefore be supported in large part by planktonic primary production.

Suspension and deposit feeders dominate the macrobenthos. The deep lagoon bottom is dominated by three deposit feeding echinoids, a suspension feeding gastropod (*Turritella* sp.), a deposit feeding bivalve (unidentified tellinid), and a variety of suspension and deposit feeding polychaetes. The spectacular abundance of irregular echinoids indicates the importance of the detrital food chain. The muddy sediments (indicative of limited horizontal transport) and the absence of macroalgae or photosymbiotic forams indicate that the deep lagoon bottom community may ultimately be supported largely by planktonic production, although the possible role of benthic microalgae remains to be evaluated.

The shallower lagoon slope is dominated by a similar assemblage of echinoids and polychaetes, and some large suspension feeding (*Anadara*) and grazing (*Strombus luhuanus, S. erythrinus,* and *S. variabilis*) mollusks. The latter species feed on attached and free-living (*Grateloupia*) benthic algae. The sand flat community is dominated by bivalves (93% of all individuals encountered), including suspension feeding, deposit feeding, and chemo-symbiotic taxa. On sand flats and shoals, *Strombus* is also abundant.

Seagrasses are locally dominant producers in the benthos and support a greater abundance of shellfish than do adjacent areas. Seagrasses are known to facilitate the production of macrobenthos in a variety of ways (see above). The enhancement of particulate food supplies by hydrodynamic baffling and by production of seagrass detritus can be important (Peterson et al. 1984). The importance of

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benthic plant detritus as a food source for suspension and deposit feeders living under the plants has been demonstrated in temperate kelp beds (Duggins et al. 1989) and probably also applies to seagrass beds. The fact that the most productive *Anadara* beds lie within seagrass beds on the sand flats, or directly lagoonward of such beds on the lagoon slope, may indicate the importance of seagrass primary production for this community.

Both the seagrass beds and associated shellfish resources appear to have increased substantially since World War II, perhaps as a result of increased fertilization by sewage-derived nutrients. The width of seagrass beds has more than doubled off South Tarawa between 1943 and 1984. Since World War II, the population of South Tarawa has increased by 1,700%. Associated with this increase is a large increase in sewage-derived nutrients that enter the lagoon through each tidal cycle. Although sewage-derived nutrients are shown by Kimmerer (this volume) to not be important in the nutrient budget of the southern lagoon as a whole, these nutrients may have considerable influence over the intertidal sand flats through which they must travel. This influence is also demonstrated by high bacterial contamination on the sand flat but not in the offshore lagoonal shellfish populations (Danielson et al., this volume).

The effects of causeway construction on seagrass beds are unclear. A correlation seems to exist between the presence of extensive seagrass beds and the lack of passages: the largest seagrass beds lie off the longest islets. Many small seagrass beds, however, including all the seagrass beds in North Tarawa between Bonriki and Buariki, lie immediately on the lagoon side of the passages. Seagrass beds changed markedly, with some portions expanding and other portions contracting, off the Taborio-Ambo passage after causeway construction (based on aerial photographs taken before causeway construction [1943] and after [1968 and 1984]). Because the sand flats near passages receive a large portion (more than 40%) of their water supplies through these openings (Chen et al., this volume), causeways are not expected to affect sand flat communities.

Whatever the cause, the observed expansion of seagrass beds was probably responsible, in part, for the apparent increase in shellfish resources during the past several decades. Older residents of Tarawa recall a considerable increase in the abundance of *Anadara* and then *Strombus luhuanus*, and modest increases in the abundance of *Gafrarium pectinatum, Asaphis violascens* (*te koikoi*), and *Atactodea striata* (*te katura*) since World War II (Johannes 1992).

In contrast, Johannes (1992) noted that the edible sipunculan (*te ibo*) has become scarce in South Tarawa within living memory, and most of the worms now are taken in North Tarawa. This worm is generally found on sand flats that lie on the lagoon side of passes between islets (Nabuaka Tekinano pers. comm.). Thus, its disappearance from South Tarawa may be the result of closing the passages with causeways.

Biology of Important Shellfish Species

Tarawa Lagoon has a diverse and abundant molluscan fauna that is under considerable harvesting pressure. Information about the most economically important macromollusks are summarized below.

Strombus luhuanus (*te nouo*)

Strombus luhuanus has separate sexes and determinate growth. Population studies conducted in Papua New Guinea show that this species reaches sexual maturity at about 2 years of age (Poiner and Catterall 1988). Fertilization is internal; gelatinous, string-like, sand-bearing egg masses are laid seasonally in Papua New Guinea. Veliger larvae hatch from the egg masses and take up a planktonic existence of unknown duration (Poiner and Catterall 1988). Although adults are usually epibenthic during the day, juveniles commonly spend the day buried in sediment and emerge at night. This behavior offers an important refuge to juveniles from visual hunters, including most humans (Poiner and Catterall 1988); on Tarawa, however, gatherers who dig for clams harvest buried individuals.

S. luhuanus, like other conchs, feeds on benthic macroalgae. These conchs appear to be limited to areas with mixed soft and hard substrata where they can bury and find suitable algal foods attached to hard substrata. They are absent on pure sandy bottoms and larger expanses of hard reef grounds. *S. luhuanus* are numerous in areas with abundant dead *Acropora* rubble and are uncommon on thriving reefs. Thus, the demise of reefs in the southeastern lagoon (Paulay and Kerr, this volume) may have enhanced *S. luhuanus* stocks there.

S. luhuanus was abundant in most shallow water habitats surveyed in the inner lagoon, ranging from the low intertidal zone to about 8 m deep. Poiner and Catterall (1988) also found that this conch was common to a depth of 9 m in Papua New Guinea. The abundance and age structure of the species varies greatly on all scales. Although our quantitative surveys encountered this species almost exclusively at low densities, *S. luhuanus* is extremely abundant (greater than approximately 50 m^{-2}) in many areas not quantitatively surveyed, especially on the lower slopes of shoals.

Juveniles and adults commonly occur in different aggregations, and similar aggregations of this species are well known elsewhere (Poiner and Catterall 1988). These aggregations probably are behavioral, because aggregations of different age classes are often found near each other, well within the crawling range of this highly mobile gastropod. Catterall and Poiner (1987) suggested that this species is capable of migrating to shallow water. The *S. luhuanus* populations on sand flats may be continually replenished by migrants from deep water; however, we have no data on this hypothesis. Nevertheless, the calculated yearly harvesting pressure on this species appears to exceed the population on the sand flats. This discrepancy could be the result of replenishment of sand flat stocks by migration or to the underestimation of the sand flat population size (see above) of this highly aggregated species.

Offshore refuges protect *S. luhuanus* populations in Tarawa Lagoon from overharvesting. Although the harvesting pressure on this species on sand flats is high, the large beds on the lagoon slope, accessible only by diving, and those on shoals, accessible only by boat, are essentially unfished. The bulk of this conch's stock is in these refuges. In Papua New Guinea, similar deep water populations and the frequent burial of juvenile stages offer this species refuge from overexploitation (Poiner and Catterall 1988). In contrast, however, *S. luhuanus* populations have been decimated by overharvesting in the Ryukyus (Yamaguchi pers. comm.). The species forms the basis of artisanal fisheries throughout much of its range in the western and west-central Pacific.

Anadara sp. (*te bun*)

Anadara sp. is reviewed by Tebano and Paulay (this volume) and is not discussed further here.

Gafrarium pectinatum (*te koumara*)

Gafrarium pectinatum is widespread throughout the Indo-Pacific and is harvested in many areas, including Pacific islands. In Hong Kong, Morton (1990) showed that the species has separate sexes, matures at 1 year of age to 16-20 mm, and lives up to 3 years, reaching a maximum length of just over 35 mm. It reproduces at a low level throughout the year but has a seasonal peak during spring and fall.

On Tarawa, *G. pectinatum* appears to be almost ubiquitous on intertidal sand flats and many lagoonal shoals, but it is rare or absent in reef areas of the western lagoon. Except in the Temaiku Bight, this species is rarely the focus of collecting in South Tarawa; it is, however, an important bycatch. This resource is protected by its offshore populations, large population size, and probable rapid growth rate.

Asaphis violascens (*te koikoi*)

Asaphis violascens is widely distributed throughout the Indo-West Pacific and is traditionally collected on most Polynesian and Micronesian islands. It is restricted to the high intertidal, where it burrows deeply in gravelly sands. On Tarawa, *A. violascens* is common in a narrow zone on beaches on the lagoon side and in similar habitats on the ocean sides of islets. It is the dominant and often the only bivalve in this habitat.

Although studies on the biology of *A. violascens* are unknown, the closely related and, according to some authors, conspecific Atlantic *Asaphis deflorata* has been studied in the Bahamas. It was found to have separate sexes, have a 1:1 sex ratio, and reach sexual maturity at a length of 25 mm

in perhaps 2-3 years. In the Bahamas, mass spawning is seasonal (summer). The planktotrophic veligers go through their development and metamorphose 11-14 days after spawning (Berg and Alatalo 1985).

On most islands, *A. violascens* is harvested individually, with people searching for the siphonal openings and then extracting the shellfish. On Tarawa, however, gatherers dig up large areas of suitable habitat, usually with spoons, to uncover all the clams in that area. This difference in method implies that these clams are more abundant on Tarawa (as are many other shellfish) than on many other central Pacific islands, thus making wholesale digging productive. Although we did not get good data on the abundance of *A. violascens*, based on observations of gatherers, the species appears to occur in densities of tens per square meter in appropriate habitat.

Because *A. violascens* inhabits a zone accessible on even the worst tides, it is a valuable resource for subsistence gatherers. Because its habitat is used for toilet purposes by the population, however, it is generally shunned on beaches adjacent to villages. All the observed gathering of this species occurred along causeways or in front of the hotel; these areas are not regularly used for defecation.

Although the narrow zonation of the species in an accessible habitat makes it vulnerable to overharvesting (Catterall and Poiner 1987), much of this habitat is in areas shunned by collectors, providing a refuge for the species. The size range of harvested *A. violascens*, however, appears to be well below the maximum size attained by the species, perhaps as a result of overharvesting. Because no *A. violascens* gatherers were surveyed, no quantitative data exists. In contrast, the abundance of the species implies abundant recruitment.

The actual importance of *A. violascens* as a shellfish resource is unclear. No *A. violascens* collectors were encountered in the gatherer surveys, although people were seen collecting this species on several other occasions. The importance of *A. violascens* relative to other shellfish appears to be minor. In contrast, on the basis of a household survey, Bolton (1982b) estimated that about 464 tonnes of *A. violascens* were harvested throughout North and South Tarawa in 1982; she also noted, however, that the nature of her survey probably lead to an overestimate of the true harvesting pressure. Bolton's values for *A. violascens* collecting may also be excessive because the indigenous name for the species, *te koikoi*, is often inappropriately applied to a wide range of shellfish.

Atactodea striata (te katura)

This small surf clam is abundant on high intertidal lagoon beaches around Tarawa and is the focus of a minor fishery, mostly as a favored baby food or as a side catch with *A. violascens*. It is avoided in heavily populated areas for the same reasons that *A. violascens* is avoided. *Atactodea striata* has separate sexes and an extended breeding period in New Caledonia (Baron 1992).

Appendix A.

I-Kiribati Names of Marine Invertebrates

Appendix A. I-Kiribati Names of Marine Invertebrates

Names that apply to a large class of organisms are labeled generic and listed under the wider taxonomic category they are used for. I-Kiribati names that appear to be inconsistently utilized or otherwise are deemed to need further verification, are noted with a "?." A "?" preceding a scientific name implies that the identity of the organism was difficult to ascertain, generally because no specimens were seen and the name was based on a description. Names are based on interviews with a small number of people on Tarawa 1992-1994, and do not include compilations from the literature (Banner and Randall 1952; Lobell 1978). Numerous names in the latter two compilations are clearly in error, hence my disregard of their lists. An "S" indicates name is from South Tarawa and potentially distinct from North Tarawa name.

Scientific Name		I-Kiribati Name
CNIDARIA		
CUBOZOA		
?Carybdea alata	not seen	*te baitare*
SCYPHOZOA/Rhizostomeae		
?Cassiopea sp.	not seen	*te tia*
ANTHOZOA/Scleractinia		
Branching corals (including *Pocillopora, Acropora*)		*te enga* (generic)
Massive corals, at least of *Porites*		*te atitaai* (generic)
Fungiids		*?te wenei* (generic)
MOLLUSCA		
BIVALVIA		
Arcidae		
Barbatia velata		*?te nikarinei*
Anadara sp.		*te bun*
Spondylidae		
Spondylus squamosus		*te koikoi n anti*
Pteriidae		
Pinctada margaritifera		*te baeao*
Pinnidae		*te bwere, te katati* (generic)
Atrina vexillum		*te bwere, te katati* (generic)
Pinna sp.		*te bwere, te katati* (generic)
Lucinidae		
Codakia bella		*te kairebwe, ?te nikarewerewe*
Cardiidae		
Acrosterigma angulatum		*te koikoi n tari*
Acrosterigma ?transcendens		incorrectly called *te koikoi n tari* by some
Tridacnidae		
Tridacna maxima		*te were*

Appendix A. I-Kiribati names of marine invertebrates (cont.).

Scientific Name	I-Kiribati Name
Tridacna squamosa	*te were matai*
Tridacna gigas	*te kima*
Hippopus hippopus	*te neitoro*
Mesodesmatidae	
Atactodea striata	*te katura*
Tellinidae	
Quidnipagus palatam	*te nikatona*
Tellinella crucigera	*?te kabwere*
Tellinella virgata	*?te kabwere*
Psammobiidae	
Asaphis violascens	*te koikoi*
Veneridae	
Gafrarium pectinatum	*te koumara*
Timoclea marica	*te koumai*
GASTROPODA	
Trochidae	
?trochid, possibly *Tectus pyramis*	*te baraitoa*
Turbinidae	
Turbo spp.	*te matanin* (generic)
Neritidae	
Nerita spp.	*te kaban* (?generic)
Naticidae	*te tumara* (generic)
Polinices melanostoma	*te tumara* (generic)
Polinices mammilla	*te tumara* (generic)
Strombidae	
Strombus luhuanus	*te nouo*
Strombus variabilis	*te newenewe*
Lambis truncata	*te ang, te anga, ?te rotu*
Cypraeidae	
Cypraea spp.	*te buro* (small) (generic), *te bure* (large) (generic) *te kabaau* (some spp.) (generic)
Ranellidae	
Cymatium muricinum	*te nimakaka, te wiiaau*
Charonia tritonis	*?te buu, ?te tau*
Cassidae	
Cypraecassis rufa	*?te buu, ?te tau*
Olividae	
Oliva miniacea	*te burebangaki*
Terebridae	
Terebra spp.	*te buki kakang* (generic)
Opisthobranchia	

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Appendix A. I-Kiribati names of marine invertebrates (cont.).

Scientific Name		I-Kiribati Name
?Dolabella auricularia	not seen	*?te ingke* (from "ink")
UnID slug, aplysiid?	not seen	*te ubaraniti*
UnID slug, aplysiid?	not seen	*te non*
Pulmonata/Elobiidae		
Melampus spp.		*te ningo ningo* (generic)
CEPHALOPODA		
Octopus sp. large	not seen	*te kika*
Octopus sp. small	not seen	*te kikao*
Octopus sp.	not seen	*te kaonako*
Octopus sp.	not seen	*te riburibunimainuku*
?Sepioteuthis lessoniana	not seen	*te riro*
ECHINODERMATA		
Holothuroidea		*te kereboki* (generic)
Holothuria atra		*te n tabanebane* (specific)
		?te nautong (S, specific)
Bohadschia vitiensis		*te kereboki* (generic)
Synaptidae	not seen	*te robwe* (from "rope")
Echinoidea		
?diademids	not seen	*te batinou*
Maretia planulata		*te katuiaia*
Metalia sternalis		*te takataka*
Ophiuroidea sp.		*te kiko n ang*
Asteroidea		
Acanthaster planci		*te aa* (?generic)
ARTHROPODA/Crustacea		
Palinuridae		*te nnewe* (generic)
Panulirus penicillatus	not seen	*?te nnewe, ?te urataake*
Panulirus versicolor	not seen	*?te kouratake*
Scyllaridae		
?Parribacus sp.	not seen	*?te mnau, ?te n tabataba*
Coenobitidae		
Birgus latro		*te ai*
Brachyura		
Cardisoma sp.*?carnifex*	not seen	*te manaimeri, te manai, te meri*
Calappa sp.		*te nnon nnon*
?Grapsus tenuicrustatus	not seen	*?te kamakama*
Carpilius maculatus		*te tabanou*
land crab names, specific, from Makin	not seen	*te mama, te bukiroro, te batinana*
other, ?generic crab names		*te n tababa* (incl. *Zozymus aeneus*), *te kaveana*
Stomatopoda		

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Appendix A. I-Kiribati names of marine invertebrates (cont.).

Scientific Name		I-Kiribati Name
Lysiosquilla maculata		*te varo*
SIPUNCULA		
?Sipunculus indicus		*te ibo*
bigger sp.	not seen	*te ibo raro*
ANNELIDA/POLYCHAETA		
?Amphinomidae sp.	not seen	*te karau*
HEMICHORDATA/ENTEROPNEUSTA		
Ptychodera flava		*te bonubonu*

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Variable Recruitment and Changing Environments Create a Fluctuating Resource: The Biology of *Anadara* (Bivalvia: Arcidae) in Tarawa

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Variable Recruitment and Changing Environments Create a Fluctuating Resource: The Biology of *Anadara* (Bivalvia: Arcidae) in Tarawa

By

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Abstract

The arcid bivalve *Anadara* sp. (*te bun*) is the most important shellfish resource in central Kiribati, with a yearly catch of approximately 1,400 tonnes in South Tarawa alone. *Anadara* sp. is one of several species in the unresolved *Anadara antiquata* complex, several of which are important in artisanal shellfisheries on central Pacific islands. The Tungaru atolls that harbor dense *Anadara* beds lie within the highly productive zone of equatorial upwelling, while those occurring outside this zone have few *Anadara*. This shellfish is abundant in seagrass beds, lagoonal shoals, and shallow lagoon bottoms to approximately 8 m deep. It reproduces year round with lunar spawning periodicity and may be a sequential hermaphrodite. Size frequency data and observations of the occurrence of small juveniles indicate that, despite frequent reproduction, recruitment varies greatly over time and between areas within Tarawa Lagoon. Massive *Anadara* recruitment in 1993 created a new fishery in Bonriki village where none had been for 2 decades. Highly variable recruitment and changes in the extent of seagrass habitats may explain marked historical fluctuations in the abundance of this important resource.

Introduction

The arcid bivalve *Anadara* sp. is the most important shellfish resource in central Kiribati. Its importance stems in part from its abundance, large size, and accessibility. It is the largest of the commonly harvested shellfish species and is one of the most common; dense *Anadara* beds average 14 large (4-7 cm) shells per m^2 in South Tarawa. In South Tarawa alone, approximately 1,400 tons of *Anadara* are harvested annually. Mean daily *Anadara* catches average 9 kg each for the estimated 500 subsistence gatherers who collect daily on the sand flats and 111 kg for the approximately 35 commercial divers working from canoes in the offshore beds (Paulay, this volume). In contrast, Squires et al. (1973) found that near Suva (Fiji), where *Anadara* is also the most important marine shellfish, the average daily catch for gatherers was 2 kg. Most households gather *Anadara* because it is abundant and accessible, both in the shallow nearshore seagrass beds and in deeper areas.

Because of its importance, this shellfish plays a traditional role in Kiribati society. On Abemama, *Anadara* is presented at traditional gatherings in a meeting house (*maneaba*) if fish are not available. The shells are used on dancing costumes that women and girls wear around their waists. *Anadara* shells are still in use, especially by older men and women, for grating mature coconut meat and giant swamp taro (*Cyrtosperma chamissonis, babai*).

Methods

The size structures of several populations were surveyed during the benthic ecology study of Tarawa Lagoon (Paulay, this volume). In addition to the samples obtained in that survey, we sampled five shoals in the southeastern lagoon (global positioning system [GPS] locations are given in Figure 1 and Introduction to the Study, this volume). Ten 0.5- x 0.5-m quadrats were haphazardly tossed on the top of each of these shoals and all *Anadara* found within were counted and measured. When fewer than 100 *Anadara* were found, other portions of the same area were systematically searched until at least 100 were found. All *Anadara* were measured with dial calipers to the nearest 0.1 mm. Shellfish gatherers were surveyed as described in Paulay (this volume).

Tebano evaluated the present distribution and qualitative abundance of *Anadara* on several atolls. Historical changes in the abundance of the species were recorded from the recollections of older informants on Abemama, Maiana, and Abaiang.

Identity of *Anadara* in Tarawa Lagoon

The *Anadara* in Tarawa Lagoon cannot be identified to species because the genus includes numerous closely related forms whose phenotypic variability and nomenclatural identity have not been determined. In particular, several species are associated with the *Anadara antiquata* (Linné 1758) species complex. In the western Pacific (e.g., in Fiji), several species in this complex co-occur (Gustav Paulay, personal observation). Taxonomic revisions (Lamy 1907; Habe 1965) have not resolved this complex.

All the *Anadara* in Kiribati appear to be the same species. Although usually labeled *Anadara maculosa* (Reeve 1844) in the past, Tarawan *Anadara* differ from *A. maculosa* (described from North Australia) in shape, color pattern, periostracal character, and rib count. For example, Reeve differentiated his *A. maculosa* from *A. scapha* based on number of ribs (36 versus 33); in contrast, *Anadara* sp. only has an average of 30 ribs on its shell. Until the genus is revised, identifying which species is in Tarawa will be impossible. For this reason, the species is referred to below in the Kiribati vernacular, "*te bun.*" The taxonomic uncertainty in this complex also means that the specific identity of species in the literature labeled *A. maculosa, A. antiquata,* and *A. scapha* (Gmelin 1791) cannot be ascertained. It is likely that all such identified species do not belong in the *A. antiquata* species complex.

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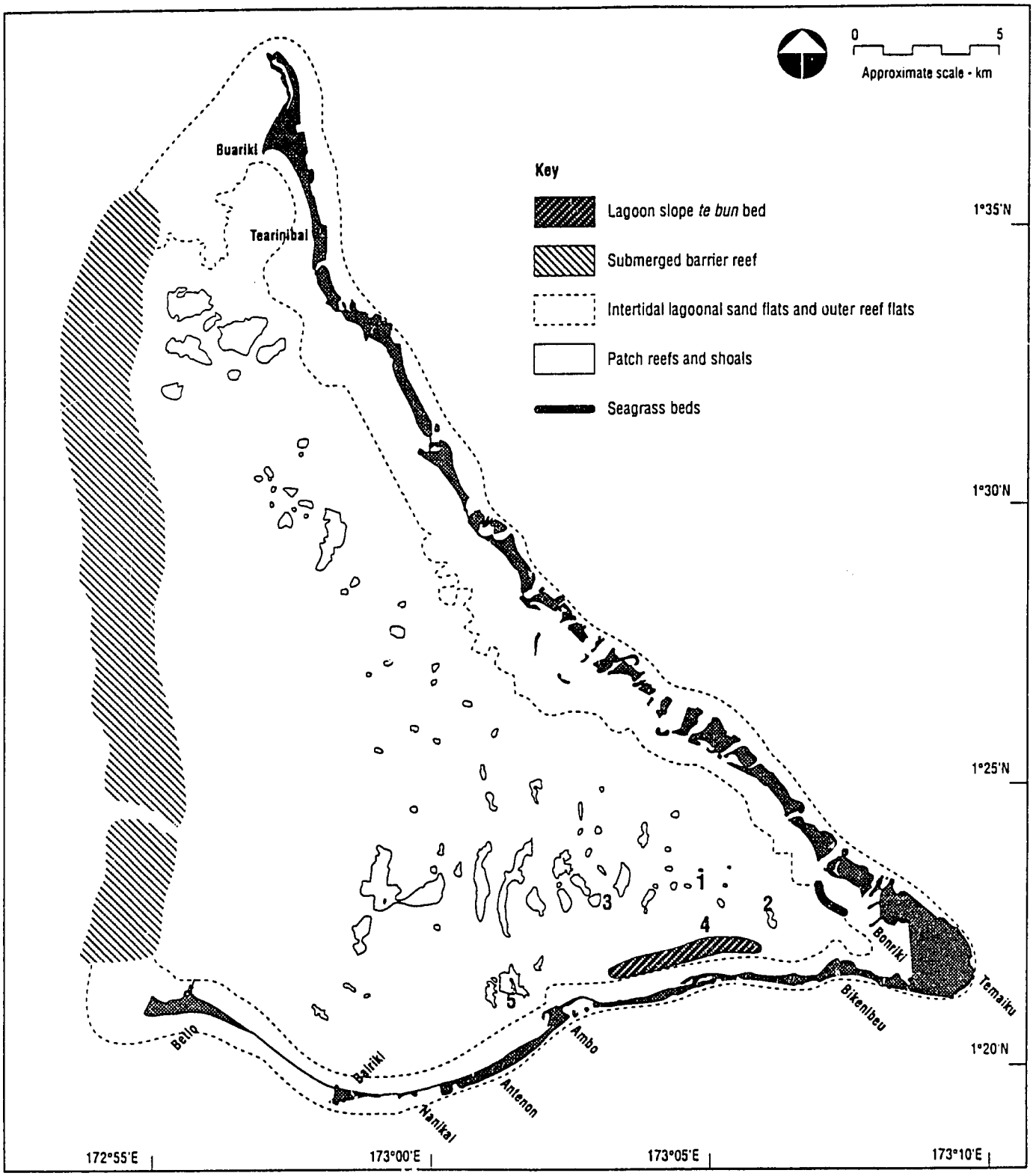

Figure 1 Map of Tarawa Lagoon showing approximate location of lagoon slope *Anadara* bed, major seagrass beds, and five shoals sampled.

Species in the *A. antiquata* complex are important shellfish because of their abundance and size on many Pacific islands. Some of these islands are New Caledonia (Baron and Clavier 1992); Fiji (Squires et al. 1973); Tonga (Spennemann 1987); Chuuk (Federated States of Micronesia; A. Davis pers. comm.); and, prehistorically, the Mariana Islands (see below) and Kiribati.

Distribution and Abundance

Anadara is known from several Kiribati atolls, and the same species occurs in Majuro (Marshall Islands). Within Kiribati, it is uncommon on the northernmost atoll of Butaritari, abundant on all the north-central atolls (Marakei, Abaiang, Tarawa, Maiana, and Abemama), rare in Nonouti, and unknown on other southern atolls (Table 1). The species is rare in Majuro. Attempts to transplant *Anadara* to atolls in southern Kiribati (Tabiteuea North in 1981 and 1984, and Onotoa in 1984) appear to have failed, although these projects have not been evaluated recently.

Table 1 The abundance of *Anadara* north to south in Kiribati and Majuro.

Atoll	*Anadara*	Latitude
Majuro	+	7°10'N
Butaritari	++	3°10'N
Marakei	+++	2°00'N
Abaiang	+++	1°50'N
Tarawa	+++	1°30'N
Maiana	+++	1°00'N
Abemama	+++	0°20'N
Aranuka	no data	0°10'N
Nonouti	++	0°40'S
North Tabiteuea	-/+	1°10'S
Beru	no data	1°20'S
South Tabiteuea	-/+	1°30'S
Onotoa	-/+	1°50'S

Abundance depicted as absent or very rare (-/+), rare (+), occasional (++), and abundant (+++). The other Tungaru islands (Makin, Kuria, Nikunau, Tamana, and Arorae) lack functional lagoons and thus appropriate habitats for *Anadara*.

The location of atolls with dense *Anadara* beds corresponds roughly to the location of equatorial upwelling centered 0-3° north of the equator. This pattern may indicate that large *Anadara* beds develop only where food supplies are abundant as a result of enriched productivity from upwelling nutrients (Kimmerer and Walsh 1981; Kimmerer, this volume). Bolton (1981), in one of her evaluations of Tabiteuea Atoll for *te bun* transplant, noted the general sparsity of shellfish, and speculated that this paucity may be the result of unfavorable environmental conditions for growth.

Ecology

On Tarawa, *Anadara* is most common in the seagrass beds at the lagoonward margins of lagoonal sand flats, on the lagoon bottom slope of depths from 1 to 8 m off of Bikenibeu-Taborio villages, and on the top of several sandy shoals that rise to within 0-2 m below the surface in the southeastern lagoon (Figure 1). Shells of *Anadara* are sparsely encountered on deeper lagoon bottoms, but these shells probably represent stragglers and not a significant resource. Abundance data and stock estimates of this and other shellfish on sand flats and the lagoon slope are presented in Paulay (this volume).

Unlike some other anadarine bivalves (such as *Anadara granosa*, Broom 1985), *te bun* is byssate even in its adult stage. All juveniles (<15 mm) encountered during our survey were attached to rubble or to adult shells (see below). This habit probably limits the distribution of *Anadara* to areas with at least some coral gravel or shell hash. All the large *Anadara* beds on Tarawa are in gravelly sand. Similarly, the two best *Anadara* beds on Maiana Atoll (according to locals) are uniquely characterized by the presence of both hard and soft substrata (Tebano 1990).

Although the most important predator of *Anadara* is undoubtedly humans (Paulay, this volume), several marine predators also take their toll. We observed numerous, freshly crunched *te bun* shells, especially on the shoals, that appear to be the result of ray predation. Rays, which were commonly seen in the southeastern lagoon, are the only species observed in the lagoon that could produce such damage. Shells of all sizes were seen crushed, including the shells of the much larger (to 13+ cm) bivalve *Periglypta clathrata*. Thus, *te bun* is not protected from these predators by its size.

Large piles of *Anadara* shells are frequently found adjacent to patch reefs along the lagoonward margins of sand flats and on the lagoon slope bottom inhabited by *te bun*. Most of the shells are intact or have only small nicks taken out of them. No predators that could be responsible for these piles were seen near these patch reefs, but it may be the activity of nocturnal octopuses or crabs, or possibly balistids (trigger fish).

Bonefish (*Albula glossodonta*) are probably the most abundant molluscivorous fish in Tarawa Lagoon (Beets, this volume). A study of bonefish gut contents revealed that *te bun* were a minor component of their diet, with only four shells seen in 111 stomachs (91 with contents) surveyed. All *te bun* shells and the shells of other bivalves in bonefish stomachs were small (<30 mm), indicating that only juveniles are vulnerable to bonefish predation.

Several naticid species and the raninid *Cymatium muricinum* are important gastropod predators on bivalves in Tarawa. Both taxa prefer bivalves other than *Anadara*, although *C. muricinum* has been observed feeding on *te bun* (Yamaguchi et al. no date). *C. muricinum* are routinely taken by shellfish gatherers, and their abundance is fairly low (0.05 m^{-2} in the sand flat transect surveys in Paulay, this volume). *Anadara*'s size certainly protects it from these species.

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Reproductive Biology

Work in progress (Tebano 1990) indicates that *Anadara* on Tarawa reproduce year round, spawning monthly around the full moon. A similar cycle of year-round spawning and a 1- to 2-month-long gametogenic cycle was reported for *A. antiquata* in the Philippines (Toral-Barza and Gomez 1985). In contrast, Baron (1992) found that *A. scapha* L. spawns only during the southern summer in New Caledonia. This difference could be attributable to the greater seasonality of New Caledonia (approximately 21°S) and/or potential interspecific differences.

Tebano (1990) has shown that gonadal development is first seen in *te bun* at a size of 27 mm, and mature gonads are seen at 38 mm in females and 42 mm in males. In southwest New Caledonia, *Anadara scapha* was found to contain developing gonads when 22 mm long and initially spawn when 30 mm long. Although we found that *te bun* grew to at least 73 mm, the New Caledonian form reaches a predicted maximum size (based on the von Bertalanffy equation) of 52 mm (Baron 1994).

Tebano (1990) found that, although the overall sex ratio of *te bun* among all samples was near 1:1, significantly biased sex ratios, ranging from 0.4 to 2.1, were observed in individual samples. No evidence for simultaneous hermaphroditism was found, and the males and females showed completely overlapping size distributions. Tebano (1990) suggested that *te bun* may exhibit some type of sequential hermaphroditism. Baron (1992) also found no evidence for simultaneous hermaphroditism in *A. scapha* in New Caledonia, but observed a male-biased sex ratio of 1.47:1. He also showed that small size classes were significantly male dominated and large size classes were female dominated; he proposed that the species may be a protandric hermaphrodite. Toral-Barza and Gomez (1985) also showed minor departures toward male-biased sex ratios in *A. antiquata* in the Philippines. These observations indicate that species in the *A. antiquata* complex may be sequential hermaphrodites.

Little is known about the larval biology of any species of the *A. antiquata* complex. Yamaguchi et al. (no date) found some arcid larvae in lagoonal plankton samples from Tarawa Lagoon. The life span of *Anadara* veligers is unknown, but it probably exceeds the lagoonal residence time of about 1 week (Chen et al., this volume), because a considerable pelagic period would be needed to initially colonize Kiribati.

Population Dynamics - Recruitment

Although *te bun* probably spawn monthly, successful recruitment appears to be rare. Young juveniles are usually rare but at times can be locally abundant, indicating high spatio-temporal variability in recruitment. Most *Anadara* populations are dominated by one or a few striking size classes, presumably reflecting heavy past recruitment events. Size frequency distribution of *Anadara* populations differ among sites within the lagoon, indicating that such recruitment events usually were localized.

Yamaguchi et al. (no date) noted the rarity of new recruits. They were unable to find new recruits in the field, although they obtained some settlement on spat collectors made of coconut husk. Our initial attempts to find juveniles also failed. Later, however, we occasionally observed small (9 mm mean, range of 5-25 mm) *Anadara* attached to the posterior one-third of the adults' shells in the dense *Anadara* population on the lagoon slope (Figure 2). In three population samples, the average adult had 0.15 ± 0.08 juveniles attached. Although we examined numerous potential substrata (e.g., dead *Anadara*, other shells, and reef rubble) and searched through large areas of sand, all juveniles encountered in the lagoon slope population were attached to living adults. These beds have an abundance of adults and little rubble. The smallest juveniles were attached near the posterior margin of adults, with progressively larger ones toward the middle of the shell. At about 20 mm, juveniles took up a free living existence (Figure 2).

In contrast to juveniles' association with adults in the *te bun* bed on the lagoon-slope, large numbers of juveniles were discovered attached to reef rubble at Shoal 2 (Figure 1 and Introduction to the Study, this volume) in June 1993. Adult clams were uncommon at this location and hosted only a few juveniles. No quantitative measures were made at the time, but juveniles occurred at estimated densities of tens to hundreds per square meter. Juveniles have also been observed on *Halimeda* and in the grooves of dead coral rubble in seagrass beds at Abarao and Banraeaba.

Anadara populations on both the lagoon shoals and lagoon slope tend to be dominated by single or few size classes that differ among sites (Table 2, Figures 2 and 3; Paulay, this volume). Thus, Shoal 2 was dominated by a 12- to 17-mm size class, Shoal 1 and Shoal 3 by a 20- to 30-mm size class, Shoal 4 by 25- to 30-mm and 42- to 48-mm size classes, and Shoal 5 by a wide range of size classes (during July-August 1993) (Figure 3). The *Anadara* populations on the lagoon slope were dominated by a 50- to 65-mm size class, and a much less abundant 25- to 30-mm size class (during June 1993) (Figure 2). An isolated lagoon slope population off Banraeaba was dominated by a 20- to 30-mm size class (during August 1993) (Paulay, this volume). The shoals and lagoon slope are excellent places to study these population variations because the shoals receive little human predation and the slope is affected only by divers who select nothing but large shells, which dominate these beds.

Table 2 Dominant size classes (mm) of *Anadara* at sites in southeastern Tarawa Lagoon.

Shoal	10-20	20-30	30-40	40-50	50-65
Shoal 4	+	++	+	+++	+
Slope 4	+	+++	+	-	-
Shoal 3	+	+++	+	-	-
Slope 6	+	+	++	+	++
Shoal 1	+	+++	-	-	-
Shoal 5	++	++	++	+	+
Slope 7	+	+	+	+	+++
Slope 10	+	+	-	+	+++
Shoal 2	+++	+	+	+	+

Abundance data for major size classes at nine lagoonal locations. Size class is recorded as absent (-), constituting 1%-19% (+), 20%-49% (++) or 50% or more (+++) of individuals sampled, with 0- to 10-mm individuals not counted. Sites are arranged east to west (Figure 1). GPS locations of shoals are in Introduction to the Study (this volume), and locations of slope sites are in Paulay (this volume), with each slope site corresponding to the transect of the same number, except slope 10, which is an additional site located at 173°05.3'E, 1°22.2'N. All samples were taken in June-August 1993.

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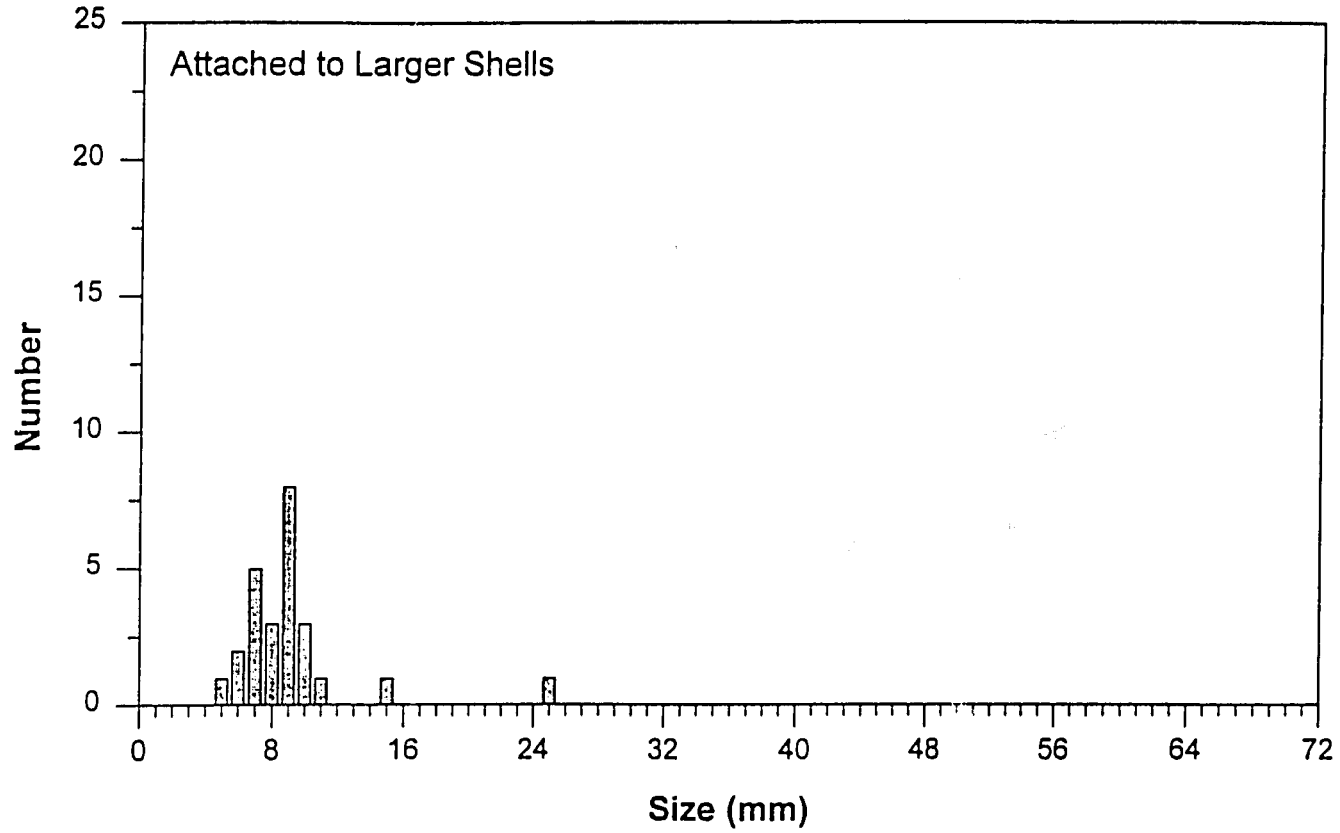


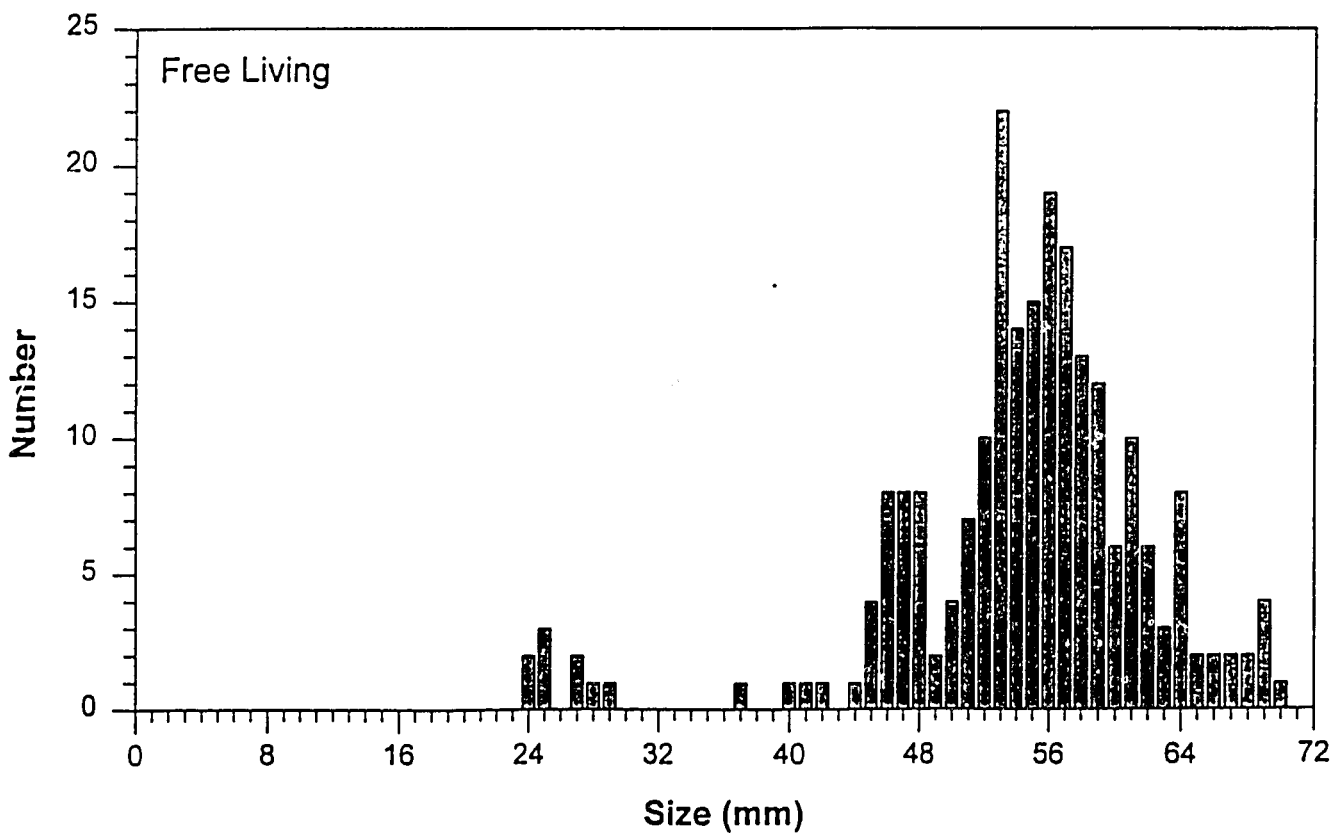


Figure 2 Size frequency distribution of free-living and attached (to larger conspecifics) *Anadara* at 173°05.3′E, 1°22.2′N in the Taborio-Bikenibeu lagoon slope bed in June 1993.

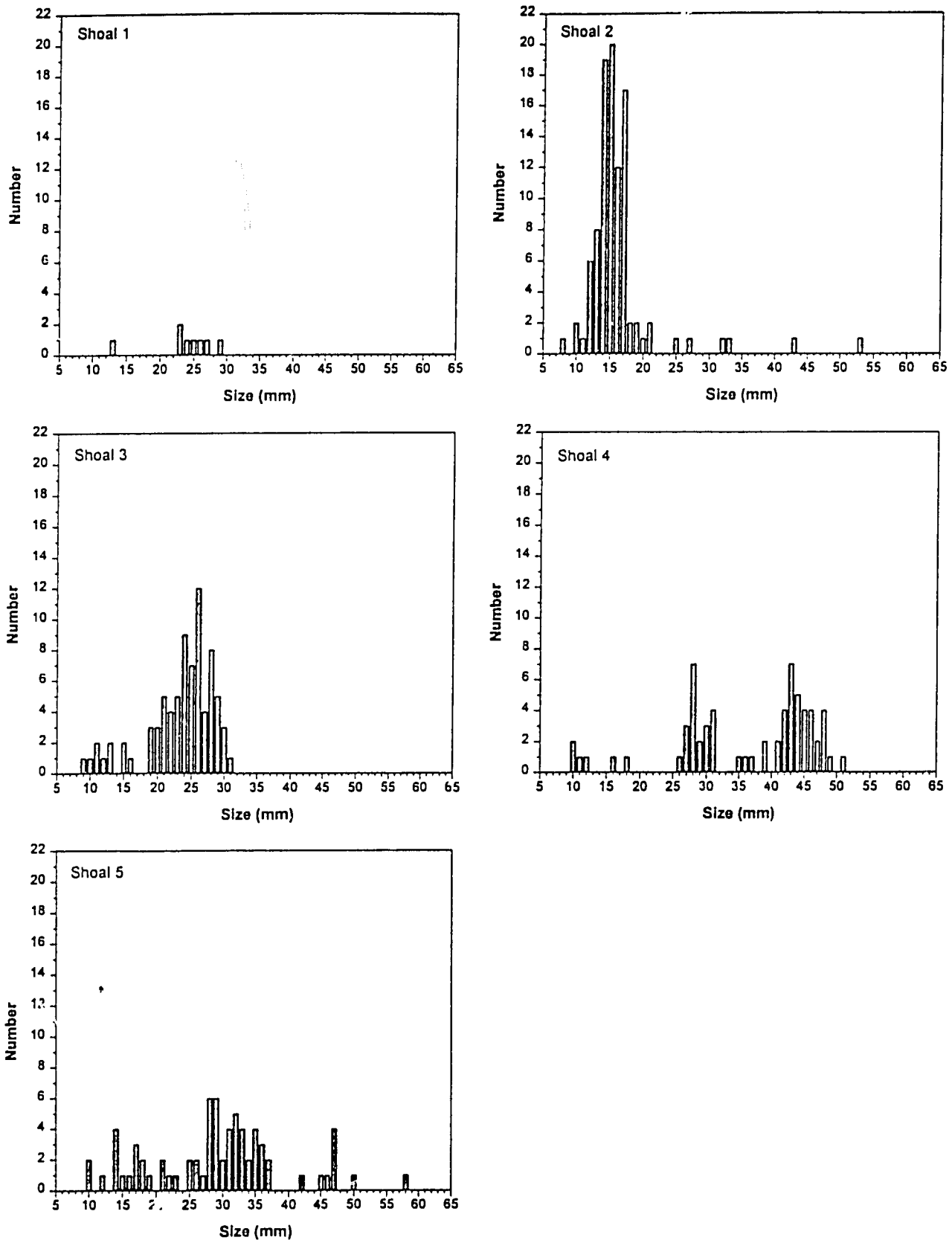


Figure 3 Size frequency distribution of *Anadara* at five shoals in the southeastern Tarawa Lagoon in July-August 1993.

Although the size frequency distribution of *Anadara* varies considerably among sites, the same size classes appear at several locations (Table 2). Specifically, the 10- to 20-mm, 20- to 30-mm, and 50- to 65-mm size classes were important at sets of generally mutually exclusive sites in June-August 1993 (Figure 4). This distribution suggests that different larval pools may have settled over limited areas of the lagoon at different times.

Evidence of a geographically limited, massive recruitment event in 1993-1994 can be seen in the easternmost lagoon. An abundance of small *Anadara* was first noted on Shoal 2 in June 1993. The clams grew rapidly (Figure 5), and by February 1994 the area had an abundance of *Anadara* in the 25- to 35-mm size range. Given this rapid growth rate, these *Anadara* probably settled at about the beginning of the year. By February 1994, this size class was indistinguishable from the next larger size class because they grew so rapidly (Figure 6), which indicates that older size classes may represent several recruitment events.

The 1993-1994 recruitment event created a novel fishery in adjacent Bonriki. Until June 1993, the venerid clam *Gafrarium pectinatum* (*te koumara*) was the targeted species in the Bonriki-Temaiku area, being particularly abundant on the wide sand flat (Paulay, this volume). No *Anadara* occurred in the catches. Subsequent interviews revealed that no *te bun* were known in the Bonriki-Temaiku area during the past 20 years. By February 1994, however, gathering activity had shifted largely to *te bun* and, consequently, from the mid-sand flat to the lagoon marginal seagrass beds adjacent to Bonriki village (Figure 4). Interviews established that this shift took place in the second half of 1993. An average of 30-40 people harvested *Anadara* in the Bonriki bed during good low tides, and the mean catch weight was 13 kg, compared to the lower overall mean shellfish catch weight of 8 kg in South Tarawa (Paulay, this volume). The harvested *te bun* were 26 $\pm$ 5 mm (N = 100) (Figure 7), within the same size range as the population at Shoal 2 (29 $\pm$ 6 mm). In contrast, *te bun* caught west of Bikenibeu were considerably larger (44 $\pm$ 8 mm; N = 80), with less than 30-mm shells virtually absent (Figures 7 and 8). East of Bikenibeu, adjacent to the Temaiku-Bonriki area, the *te bun* caught were of an intermediate size (35 $\pm$ 5 mm, N = 80), indicating that this massive recruitment was still significant in this area (Figures 4 and 7).

Population Dynamics – Persistence of Beds

The large spatial and temporal variability in *te bun* recruitment implies that populations may be recruitment limited and may fluctuate greatly over time. This hypothesis is supported by information gathered from older informants, who indicate that *te bun* has undergone marked fluctuations in abundance over the past 50 years on several islands. The elders of both Abemama and Maiana recalled that *te bun* fluctuated considerably in abundance over past decades. During the 1920s, *Anadara* was claimed to have "disappeared," but, during the 1930s and 1940s, the beds came back and *Anadara* was abundant. On Abemama, *te bun* was scarce during World War II, but became abundant again later. In the 1980s, *te bun* was scarce in most villages of Abemama and on Maiana.

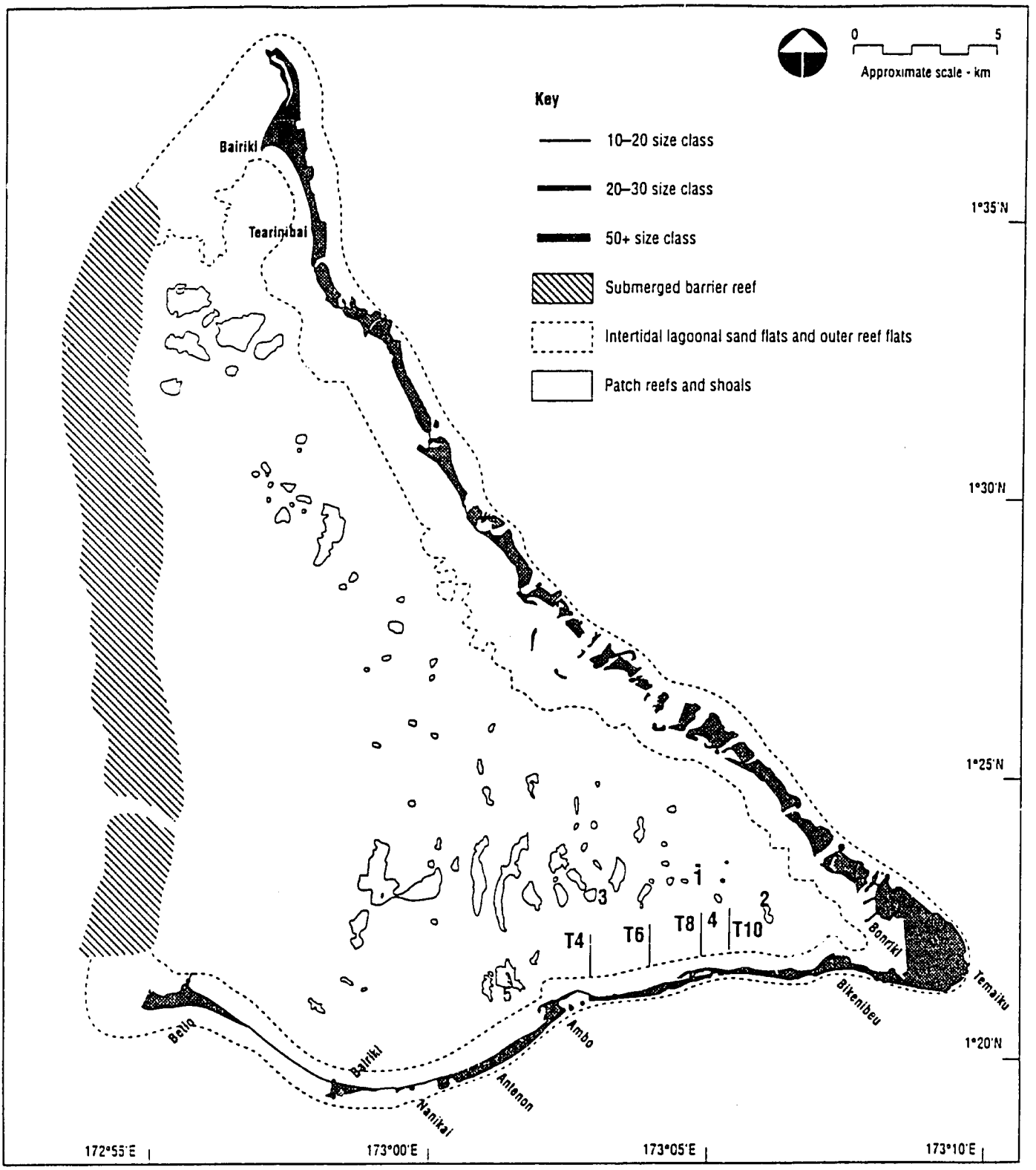
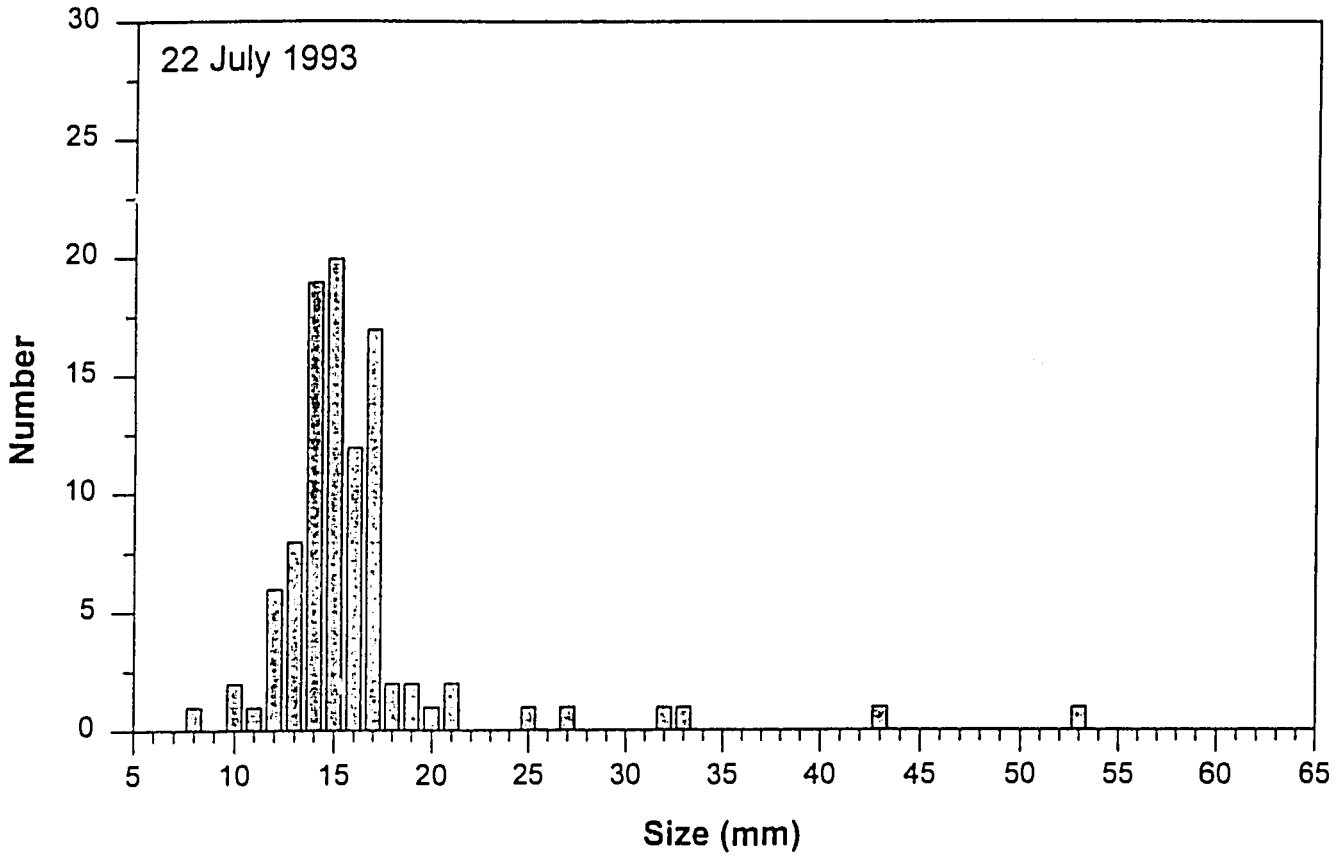


Figure 4 Distribution of dominant size classes in southeastern Tarawa Lagoon during June–August 1993. Locations depicted are shoals (S1–S5), lagoon slope *Andara* bed sites (T4, T6, T7, T10), and Bonriki seagrass bed (B) (Table 2). Areas encircled by solid lines are dominated by a specific size class (50% or more of all individuals), areas encircled by dashed lines are moderately well represented by that size class (20%–49% of all individuals). All locations are approximate.



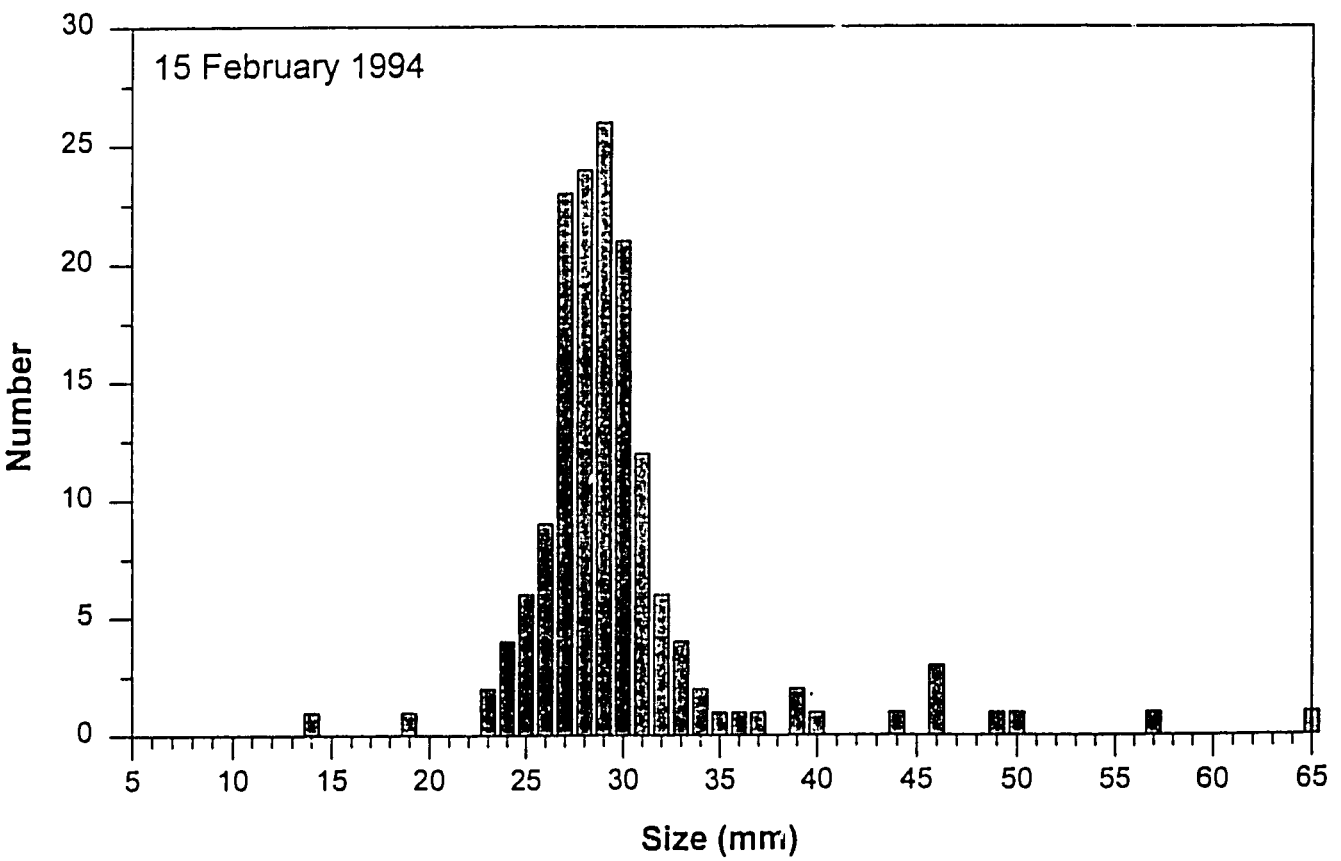


Figure 5 Growth of *Anadara* population from 22 July 1993 to 15 February 1994 at Shoal 2.

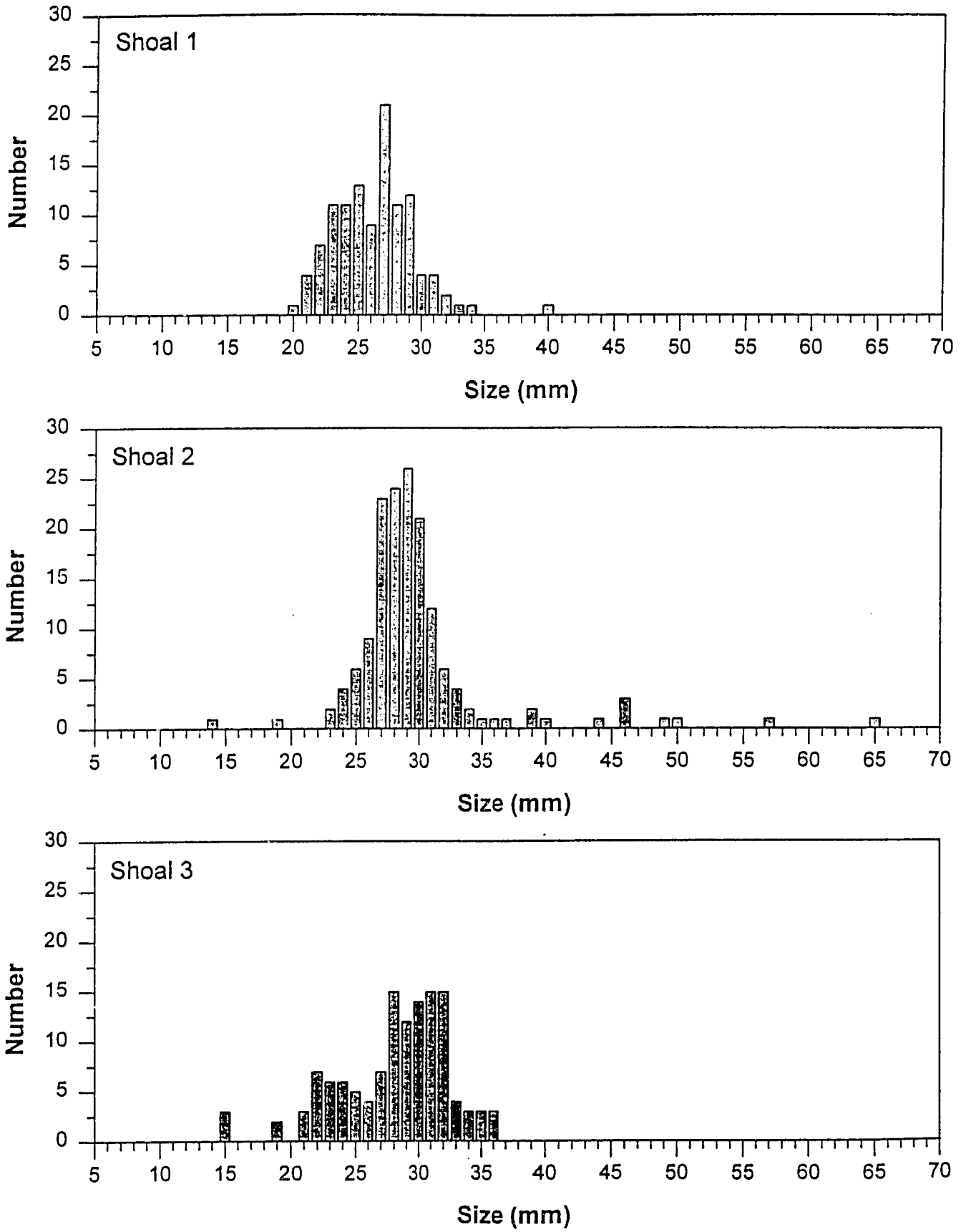


Figure 6 Size frequency distribution of *Anadara* at three shoals in southeastern Tarawa Lagoon in February 1994.

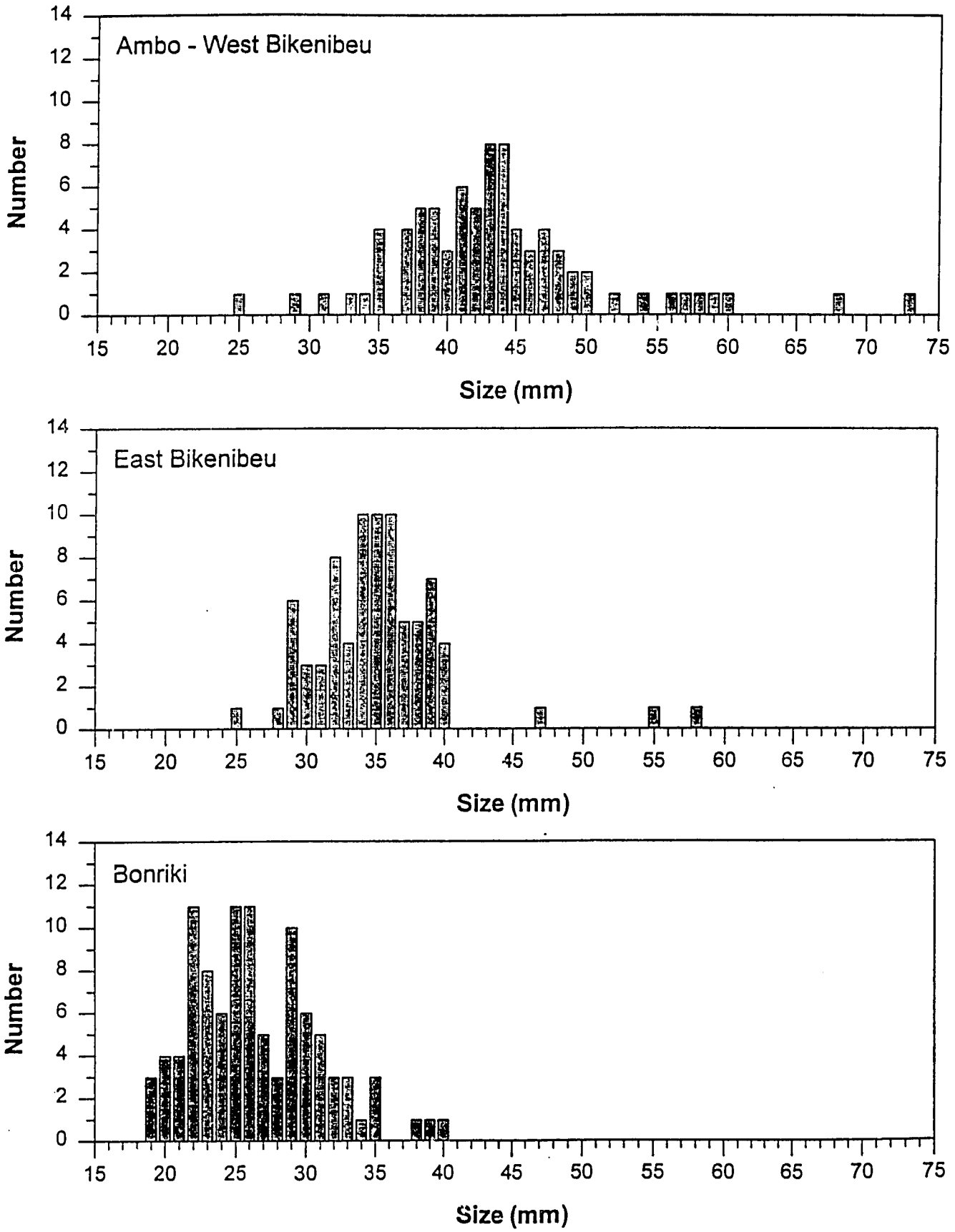


Figure 7 Size frequency distribution of *Anadara* in catches taken in Bonriki, in Bikenibeu east of the Otintaai Hotel, and at locations to the west. Based on $N = 20$ shellfish sampled per catch and four to five catches per location.

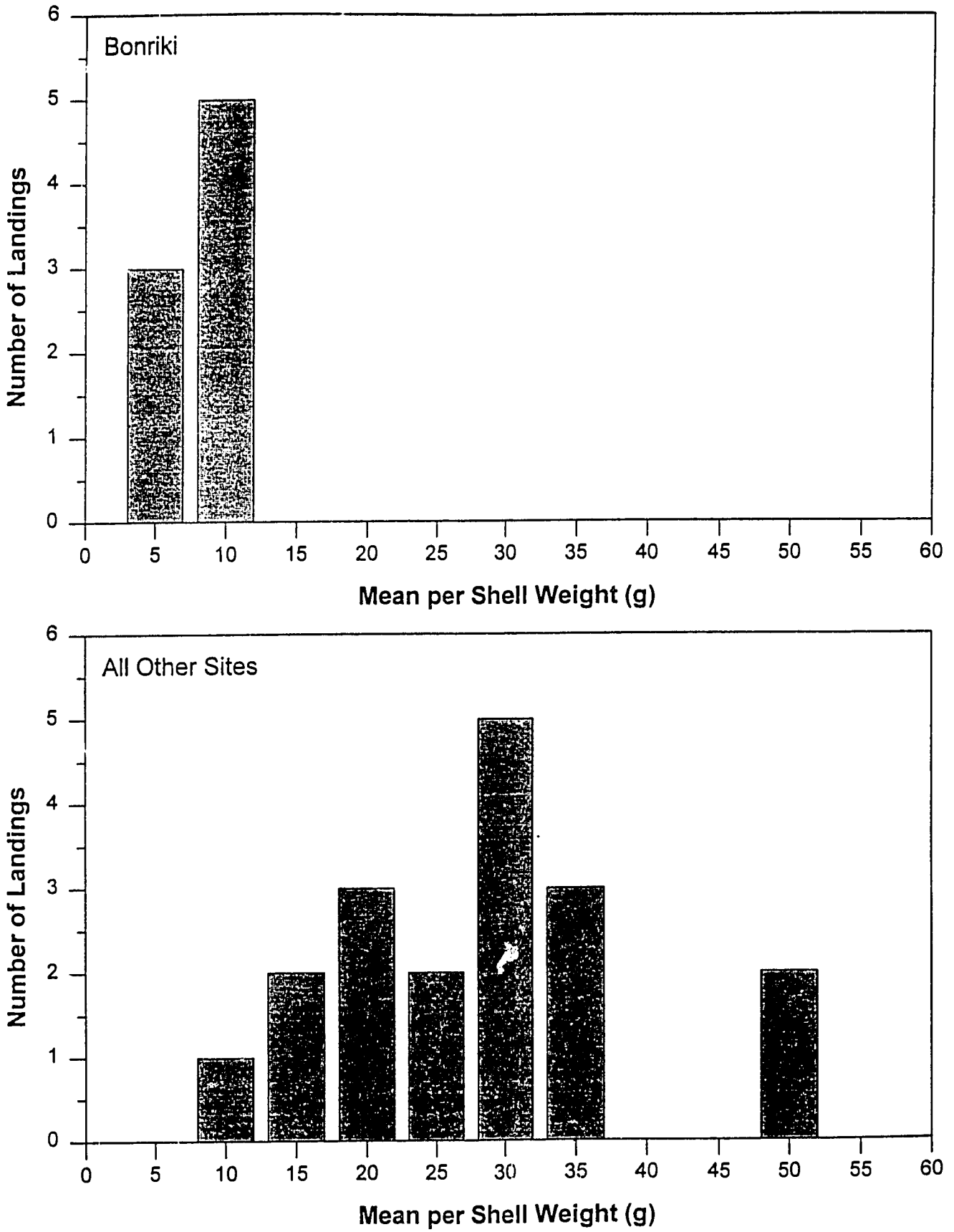


Figure 8 Distribution of average weight of *te bun* (based on weighing 20 shells per catch) in catches at Bonriki and elsewhere in South Tarawa.

Today, *Anadara* has disappeared from Maiana but is still abundant on Abemama. In contrast, *te bun* appears to have been fairly stable on Abaiang throughout living memory.

Te bun has been known in South Tarawa throughout living memory, although it has become much more abundant in recent years. *Te bun* abundance boomed in South Tarawa after World War II, but is reported to have declined slightly in recent years (Johannes 1992). *Te bun* is reported to be new to North Tarawa, however, having appeared only since World War II in the seagrass beds opposite the villages Buariki and Tearinibai.

In addition to the apparently important role of recruitment variation in controlling the abundance of *Anadara*, environmental changes also can have large-scale effects on *Anadara* populations. Paulay (this volume) demonstrated a major increase in the size of seagrass beds off South Tarawa since World War II (perhaps as a result of anthropogenic nutrient input from adjacent islets), which may be partly responsible for the expansion of *te bun* resources in the area. On Marakei Atoll, *Anadara* was once abundant but is now disappearing. This decrease may be attributable to the closure of the main western passage of this highly enclosed lagoon with the construction of a causeway.

These fluctuations demonstrate that, in the long run, *Anadara* is a fairly unreliable resource. This observation is supported by records of Holocene changes in *Anadara* abundance on other Pacific islands. In the Mariana Islands, a species in the *A. antiquata* complex was an important component of shell middens in southwestern Saipan and northern Guam during the Pre-Latte period (approximately 3500-2000 BP), but disappeared from middens thereafter (Amesbury pers. comm.). Recent searches in northern Guam have revealed no evidence that *Anadara* occurred in the area. In contrast, in the middens of southern Guam, *Anadara* gained prominence only during the past 500 years (Amesbury pers. comm.). Similarly, Gustav Paulay found abundant evidence that *Anadara* sp. was present in the Holocene in Aitutaki (Cook Islands), but intensive surveys there (as well as elsewhere in the southern Cook Islands) failed to reveal living individuals today.

Finfish Resources in Tarawa Lagoon: Documentation of Population Declines

By

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Finfish Resources in Tarawa Lagoon: Documentation of Population Declines

By

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Abstract

The status of finfish resources in Tarawa Lagoon was evaluated during 1992-1993 and compared with studies conducted in 1977. Data collected from fisher landings and fisheries-independent sampling demonstrated that the abundance of fish varied throughout Tarawa Lagoon and, when compared with historical data, stocks have declined. As with the distribution of corals, the abundance of finfish tends to increase from east to west in the lagoon. From 1977 to 1992-1993, the catch per unit effort (CPUE) and proportion of catch of several important fishery species, such as bonefish (*Albula glossodonta*), declined.

Bonefish have historically been an important fishery resource to the people of Tarawa. Unfortunately, many fishery parameters point to a declining stock. The mean length and weight of bonefish caught during studies in 1977 were 46.4 cm and 1.31 kg, respectively. Fisheries-independent gill net sampling in 1992-1993 yielded a mean length and weight of 37.6 cm and 0.84 kg, respectively. A survey of the bonefish catch of Tarawa fishers in 1992-1993 revealed a mean length and weight of 35.7 cm and 0.66 kg, respectively. In 1977, the mean length of male and female bonefish was 44.6 cm and 49.1 cm, respectively. The sex ratio of bonefish caught in the 1977 study was 24:17 (male:female), which is close to the 1:1 sex ratio expected of most healthy populations. In the 1992-1993 study, the sex ratio was 27:4 (male:female). These results suggest that the spawning stock of female bonefish within Tarawa Lagoon is very low. Fisher landings data suggest that a large percentage of bonefish caught in Tarawa Lagoon are prespawning individuals and that females, which are larger on average, have been selectively depleted.

Fisheries-independent sampling conducted during 1992-1993 demonstrated declines in CPUE since 1977, and a shift in the proportion of species caught. Reef fish species, which are caught in Tarawa Lagoon, demonstrated declines in proportion of abundance between samples taken in 1977 and 1992-1993. These species are extremely susceptible to continued overfishing. Sampling demonstrated that catches of all species are much lower in the eastern portion of the lagoon than in the western portion. Beach seine sampling demonstrated a major shift in species composition with severe depletion of some preferred bait species. These data suggest that the lagoon fishery is in a stressed condition.

Introduction

Historically, traditional fishing methods in Kiribati were diverse, varying greatly among atolls (Koch 1986; Teiwaki 1988). In Tarawa, many species of fish were caught within the lagoon, on the outer reefs, and offshore. With recent changes in human demographics and the growth of the human population of South Tarawa, however, the fishery has changed.

Johannes and Yeeting (this volume) review historical and traditional uses, recent changes, and present artisanal uses of fisheries resources in Tarawa Lagoon. Phillips (this volume) presents valuable data on human perceptions of fishery resources and changes in Tarawa Lagoon. Additional information on marine resources and traditional uses in Kiribati are presented in Koch (1986) and Teiwaki (1988).

The finfish resources of Tarawa Lagoon have been historically important, accounting for 27%-59% of total landings for Tarawa since 1981 (Mees 1987; Kiribati Fisheries Division unpublished). Resources outside of the lagoon accounted for 32%-49% of total landings. Invertebrate resources in the lagoon have increased greatly in importance during recent years as finfish resources have declined. The people of Tarawa prefer lagoon species, which account for a large portion of their diet (Johannes and Yeeting, this volume; Phillips, this volume). From 1981 to 1990, the human population of Tarawa increased by more than 60%, from 17,921 to 28,800 (Statistics Office 1991). The fishing effort in the lagoon also has increased greatly during recent years as the population has increased.

Fisheries data and analyses of Tarawa Lagoon resources are presented in several reports completed by the Kiribati Ministry of Natural Resources, Fisheries Division (Cross 1978; Marriot 1984; Mees 1987, 1988a, b; Mees et al. 1988; Wright and Yeeting 1988). This information demonstrates that the abundance of finfishes in Tarawa Lagoon has declined and that yield and CPUE are declining. The estimated potential sustained yield of Tarawa Lagoon has been exceeded in recent years and predictions suggest fishery decline (Mees 1987; Wright and Yeeting 1988). Several fish aggregations and migrations have ceased, or their migration patterns have changed. The predominant causes appear to be overfishing and altered or lost habitat and migration routes. The profile of the fishery also has changed greatly in recent years, with an increase in capitalization and the use of monofilament gill nets and boats with outboard engines and a decline in the use of traditional fishing methods. This change has increased the fishing effort and the landing of species selectively caught by gill nets.

Because of the high incidence of ciguatera on the outer reef, fishing efforts focus either on offshore tuna or flying fish or on lagoon species. Because most offshore fishing around Tarawa is a commercial effort that uses larger boats, the artisanal fishers target lagoon resources. In 1976, 87 outboard motors and 526 fishing boats were used around Tarawa, compared with 426 outboard motors and 1,312 boats in use in 1987 (Wright and Yeeting 1988). Although landings continue to

be high for Tarawa, CPUE of lagoon resources has declined in recent years. Data analyses in available reports describe a collapsing fishery.

With the rapid growth of the human population on Tarawa in recent years, lagoon resources are under increasing fishing pressure, which has resulted in changes observed by fishers (Johannes and Yeeting, this volume; Phillips, this volume). Because the population is largely dependent on the lagoon resources for subsistence, evaluating the condition of the resources was imperative. One important aspect is the abundance and sustainability of finfish resources within the lagoon. This study component focused on an evaluation of finfish resources in Tarawa Lagoon.

Methods

Following a review of the available data for Tarawa Lagoon, we decided to use fisheries-dependent and fisheries-independent sampling to provide data for an adequate evaluation of finfish fisheries. Sampling began after sampling protocol was established and after training in April 1992.

Fisher Landings Data - Fisheries-Dependent Sampling

The frequency with which finfish landings were sampled depended on staff availability and logistic constraints. The sampling design incorporated the recommendations of numerous authors (Mackett 1973; Bazigos 1974; Ulltang 1977; Caddy and Bazigos 1985; Caddy and Sharp 1986). Sampling was scheduled for at least 1 day per week, and additional sampling was scheduled when possible. A village area was assigned per sampling date, which required traveling along the coastline to intercept fishers returning to shore. This practice allowed data collection on a complete landing. Frequently, data were only available from road vendors or fishers who had sold part of their catch. These latter data were classified as partial catches and not used in CPUE calculations. Because of logistic constraints, only fishers from South Tarawa were intercepted (Betio to Bonriki). Information was recorded on gear type and amount, boat type, fishing area, landing area, fishing time, complete or partial catch information, and climatic conditions. All fish from each fisher landing were identified to species, measured to the nearest 0.1 cm, and weighed to the nearest 5 g.

At least 100 bonefish greater than 35.0 cm long were collected from fisher landings for diet analysis and determination of additional fisheries parameters. All specimens were measured to the nearest 0.1 cm and weighed to the nearest 0.5 g, their sex and gonadal conditions were recorded, and their stomachs were removed. The contents of each stomach were removed and separated by food item, and dry weight was determined. The results of the diet analysis are presented in Yeeting (this volume).

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Gill Net, Handline, and Seine Data - Fisheries-Independent Sampling

Fisheries-independent sampling was designed to assess finfish resources throughout the lagoon and to provide data for comparison with historical information. We used gill nets, handlines (hook and line), and seine nets to collect data on finfishes. Fish traps were initially used in sampling but were eliminated because of extremely low catch rates. Sampling was scheduled for 3 nights per month at one of eight permanent stations (sites) for gill net and handline sampling (Figure 1). A random sampling schedule was devised based on eight sampling stations, four lunar phases, and four solar seasons.

Four gill nets were set adjacent to shallow areas at least 100 m apart and within 1.0 km of the global positioning system (GPS) coordinates for each predetermined station. Net dimensions were 50 m by 2 m; two nets had 2.5-in. (6.3 cm) stretch mesh and two nets had 3.5-in. (8.9 cm) stretch mesh. Each net was set from shallow water to deep (2-8 m). Normally, two sets per night were conducted, with soak times of 3 hours per net set.

Handline fishing was conducted during gill net sets with standard soak times. Each sampler used standard gear (i.e., 30-lb [13.6 kg] test monofilament, No. 9 hooks, leads) and fished in the same manner. Juvenile milkfish (*Chanos chanos*) (*awatai*) obtained from the Fisheries Division fish farm were used as bait. Field technicians recorded all parameters in field notebooks.

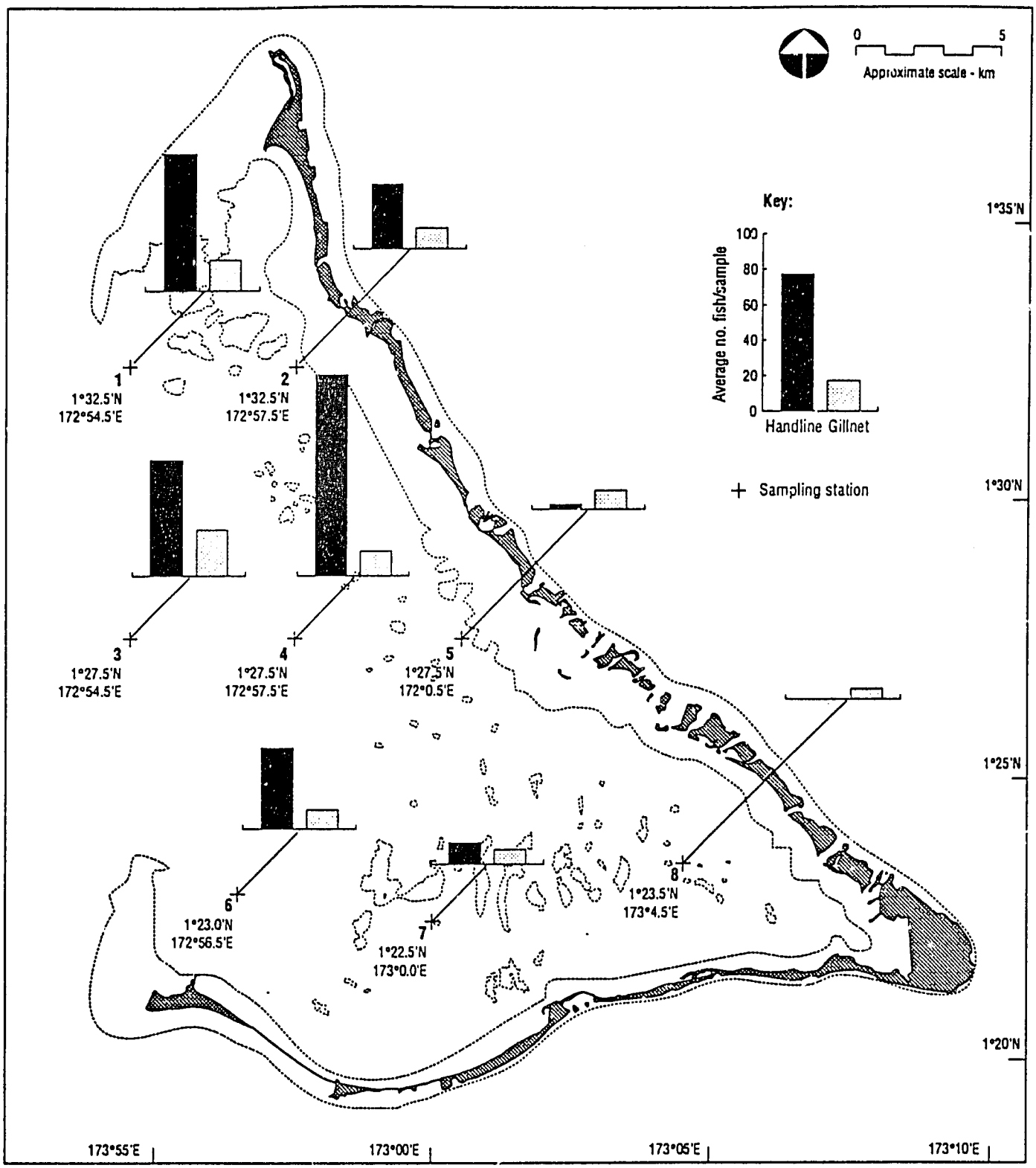
The catch from each gear type was placed in a separate bag and processed at the laboratory. Data recorded on each specimen included fork length in centimeters, weight in grams, sex, and gonadal condition. Training and quick identification sheets for all species collected allowed for accurate species identification.

The design of the seine sampling program was based on the previous study conducted by the Fisheries Division (Cross 1978), in which samples were taken in each of four major areas: North Tarawa, South Tarawa, Betio, and Bikeman Island. Bikeman Island was eliminated from the 1992-1993 survey because of the drastic reduction in its size since the last study.

Results

Fisher Landings Data

The fisher landings surveys revealed that gill net fishers who target bonefish in Tarawa Lagoon and land in South Tarawa rely almost exclusively on the splash fishing method because of the low catch rates with only gill nets (see description of splash fishing method in Johannes and Yeeting, this volume). In this method, fishers splash the water with large metal rods to herd fish and capture them in their nets. Surveyed fishers use up to 1,000 m of net per night, although most fishers use less than 100 m.



Prepared by BioSystems Analysis, Inc./1994

Figure 1. Map of Tarawa Lagoon showing average number of fish sampled per sampling date for each area (sampling site). Global positioning system (GPS) coordinates are listed for each sampling site.

Bonefish dominated fisher gill net landings (number of fish: 56.1%; weight: 76.7%), followed by *Gerres* sp. (number of fish: 14.8%; weight: 15.7%) (Table 1). Bonefish landed by fishers were almost exclusively caught with gill nets. *Lutjanus gibbus*, which was a dominant species in fisheries-independent gill net samples in 1977 and 1992-1993, was less important in fisher gill net landings. This species' lesser importance is a result of targeting bonefish by using selective fishing methods. *Gerres* sp. and goatfishes (Mullidae), which are also abundant in fisher gill net landings (number of fish: 6.4%; weight: 1.2%), are commonly caught with small-mesh gill nets in selected areas (Johannes and Yeeting, this volume). Therefore, these species were not abundant in the fisheries-independent gill net samples that were conducted with larger mesh gill nets.

Table 1 Comparison of dominant species in fisheries-independent gill net sampling, 1977 and 1992-1993, and with fisher gill net landings data, 1992-1993. Data are percentages of total number of fish sampled.

	Gill Net Sampling				Fisher Landings	
	1977		1992-1993		1992-1993	
Species	Number	Weight	Number	Weight	Number	Weight
Albula glossodonta bonefish (*ikari*)	44.6	66.5	7.5	12.9	56.1	76.7
Lutjanus gibbus paddletail snapper (*ikanibong*)	25.0	11.3	24.9	14.0	1.7	0.9
Gerres sp. silverbiddy (*amori/ninimai*)	7.6	3.4	4.8	1.9	14.8	15.7
Lethrinus nebulosus spangled emperor (*morikoi*)	5.4	6.7	0.4	1.6	1.5	2.9
Lutjanus fulvus flametail snapper (*bawe*)	0.0	0.0	6.6	3.4	5.4	2.6
Lethrinus obsoletus orangestriped emperor (*okaoka*)	0.0	0.0	4.4	2.4	3.0	1.6
Lethrinus olivaceus longnose emperor (*taabou/rou*)	0.0	0.0	5.3	5.0	1.0	1.2
Others	17.4	12.1	49.5	58.8	16.4	12.6

The handline landings of South Tarawa fishers were dominated by snappers (Lutjanidae) and emperors (Lethrinidae). The dominant fishes landed by handline fishers were *Lutjanus gibbus*, *Lethrinus obsoletus*, *Lutjanus fulvus*, and *Lethrinus olivaceus* (Table 2). This ranking is similar to data obtained in fisheries-independent handline sampling, although the number of flametail snapper

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and longnose emperor was larger in fisher handline landings, probably because these species were targeted for catch.

Table 2 Comparison of dominant species in fisheries-independent handline sampling, 1992-1993, with fisher handline landings data, 1992-1993. Data are percentages of total number of fish sampled.

	Handline Sampling		Fisher Landings	
	Percentage			
Species	Number	Weight	Number	Weight
Lutjanus gibbus paddletail snapper (*ikanibong*)	39.8	29.8	27.5	18.9
Lethrinus obsoletus orangestriped emperor (*okaoka*)	17.6	17.4	15.6	11.0
Lutjanus kasmira bluestriped seaperch (*takabe*)	8.8	3.3	4.4	9.5
Epinephelus merra dwarf spotted rockcod (*kuau*)	7.3	3.3	2.9	1.7
Lethrinus olivaceus longnose emperor (*taabou/rou*)	6.9	13.7	6.8	20.5
Lutjanus fulvus flametail snapper (*bawe*)	5.0	2.5	8.6	3.3
Others	14.6	30.1	34.1	43.7

A total of 87 species was identified in fisher landings. Several species were obviously targeted by fishers because they were not abundant in fisheries-independent sampling. This trend is apparent in a review of rank abundance by family (Table 3). Goatfishes (Mullidae) and mullets (Mugilidae) are targeted fisheries in Tarawa Lagoon (Johannes and Yeeting, this volume). These species were much lower in relative abundance in fisheries-independent sampling data than in fisher landings data (Table 3).

The average catch per trip was calculated for fisher landing samples in which no fish had been sold or given away (complete trips). Although the variability was large because numerous parameters, such as amount of gear, fishing method, soak time, and number of fishers, varied greatly, such data may provide useful baseline information. Average CPUE for gill net fishers (N = 25) was 71.3 fish

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per trip (SD = 41.1) and 36.5 kg per trip (SD = 35.7). Average CPUE for handline fishers (N = 15) was 43.1 fish per trip (SD = 44.3) and 13.9 kg per trip (SD = 16.53).

Table 3 Relative abundance of dominant families in Tarawa Lagoon by number and weight sampled in fisher landings, 1992-1993, and in fisheries-independent sampling data, in declining order of relative abundance by number in fisher landings.

	Fisher Landings 1992-1993		Gill Net Sampling 1977		Handline Sampling 1992-1993	
	Relative Abundance (%)					
Family	Number	Weight	Number	Weight	Number	Weight
Albulidae Bonefish	41.6	62.3	8.4	12.9	0.0	0.1
Lutjanidae Snappers	19.5	11.2	45.4	25.6	59.0	46.8
Lethrinidae Emperors	12.2	12.8	17.3	17.2	27.5	36.8
Gerreidae Silverbiddies	10.4	1.2	5.4	1.9	0.0	0.0
Carangidae Travallies, Jacks	4.8	7.6	9.9	10.0	0.3	2.8
Mullidae Goatfishes	4.6	0.9	1.0	0.5	0.4	0.4
Holocentridae Squirrelfishes	3.6	1.5	11.6	4.8	2.9	2.5
Mugilidae Mullets	1.7	0.8	0.0	0.0	0.0	0.0
Serranidae Groupers	1.4	1.3	1.0	0.6	9.0	6.5
Balistidae Triggerfishes	0.2	0.3	0.0	0.0	0.7	4.1
Others	0	0.1	0	26.5	0.2	0

Gill Net and Handline Sampling Data

Analysis of fisheries-independent data from gill net sets for 1992-1993 demonstrated that paddletail snapper was the most commonly captured species (number of fish: 24.9%; weight: 14.0%), followed by bonefish (number of fish: 7.5%; weight: 12.9%) (Table 1). Snappers (Lutjanidae) and emperors (Lethrinidae) dominated gill net sample catches in the lagoon (Table 3). Squirrelfishes (Holocentridae) and trevallies/jacks (Carangidae) accounted for a large proportion of the catch.

Comparison of average CPUE between the 1977 and 1992-1993 studies demonstrated important differences (Table 4). For the study site used in the 1977 study (Cross 1978), the average gill net CPUE for 3.5-in. (8.9 cm) stretch mesh nets was 7.04 fish per set (SD = 5.45; N = 13) and 6.20 kg per set (SD = 5.50). During the 1992-1993 study, the average CPUE for 3.5-in. (8.9 cm) stretch mesh nets in the same area was 1.57 fish per set (SD = 2.10; N = 37) and 0.92 kg per set (SD = 1.52). Similar declines in CPUE were observed for dominant species in catches (Table 4).

Table 4 Comparison of catch per unit effort (CPUE) for total fishes and important taxa in fisheries-independent gill net sampling, 1977 and 1992-1993. Data are mean CPUE for 3.5-in. (8.9 cm) gill net sets in 1977 (N = 13) and 1992-1993 (N = 127) within the same area. Data in parentheses are one standard deviation from the mean.

	Gill Net Sampling CPUE Values			
	1977		1992-1993	
Taxon	Number	Weight	Number	Weight
Total fishes	7.08 (5.45)	6.20 (5.50)	1.57 (2.10)	0.92 (1.52)
Albula glossodonta bonefish (*ikari*)	3.15 (4.39)	4.14 (5.19)	0.16 (0.83)	0.16 (0.86)
Lutjanus gibbus paddletail snapper (*ikanibong*)	1.77 (2.77)	0.70 (1.15)	0.78 (1.70)	0.31 (0.67)
Lethrinus nebulosus spangled emperor (*morikoi*)	0.38 (0.65)	0.42 (0.76)	0.03 (0.16)	0.07 (0.41)

Handline catches for 1992-1993 fisheries-independent sampling were dominated by paddletail snapper (39.8% of total number of fish caught) and orangestriped emperor (17.6%) (Table 2). Snappers, emperors, and groupers (Serranidae) dominated handline catches. These species also were important in fisher landings (Table 2).

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For both gill net and handline sampling, catches were significantly greater in northern and western lagoon sampling sites (sites 1, 3, and 4) than in southern and eastern sites (sites 2, 5-8; Kruskal-Wallace tests, $P < 0.01$) (Figures 1-3).

Data Collected on Bonefish

Shacklee et al. (1982) demonstrated that at least two species of bonefish occur within this region of the Pacific. Meristic counts of bonefish obtained from fisher landings and fisheries-independent sampling were always in the exclusive range of those given for *Albula glossodonta* (lateral line counts: 75-82) (Shacklee and Tamaru 1981). Although two species may be present in Tarawa Lagoon, bonefish are referred to as a single species, *A. glossodonta*, in this report.

Bonefish sampled in fisher landings during 1992-1993 had a mean length and weight of 35.7 cm and 0.66 kg, respectively (Table 5). The mean length and weight of bonefish collected during gill net sampling was 37.6 cm and 0.84 kg, respectively (Table 5). The sex ratio was 27:4 (male:female) with the mean length of male and female bonefish being 37.4 cm and 37.8 cm, respectively. The smallest reproductive male and female bonefish sampled were 32.0 cm and 35.0 cm long, respectively.

Table 5 Bonefish data from fisheries-independent sampling using gill nets in Tarawa Lagoon in 1977 and 1992-1993, and from fisheries-dependent sampling of South Tarawa fishers in 1992-1993. Data in parentheses are standard deviations.

	Gill Net Sampling				Fisher Landings	
	1977		1992-1993		1992-1993	
Mean length (cm)	46.4	(4.1)	37.6	(7.3)	35.7	(6.6)
Mean weight (grams)	1,313.4	(317.8)	835.2	(260.3)	666.0	(428.4)
Sample size	41		36		1,831	
Sex ratio (male:female)	24:17 [1:0.71]		27:4 [1:0.15]			
Mean length - male	44.6	(4.1)	37.4	(7.9)		
Mean weight - male	1,170.4	(322.1)	825.9	(236.7)		
Mean length - female	49.1	(3.0)	37.8	(6.2)		
Mean weight - female	1,515.3	(228.1)	935.8	(416.0)		
Smallest reproductive male	42.5		32.0			
Smallest reproductive female	46.5		35.0			

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The mean length and weight of bonefish sampled in 1992-1993 were significantly smaller than those sampled in 1977 (t-tests, $P < 0.01$) (Table 5). This change represented a 19.0% decline in mean length, but more importantly, mean weight declined by 36.4%. Mean length and weight calculated separately for males and females declined significantly (t-tests, $P < 0.01$) (Table 5). Interestingly, the smallest reproductive individuals sampled in 1992-1993 were smaller than those sampled in 1977. This finding could be the population's response to heavy selective fishing for larger adults, but it has not been demonstrated for bonefish or related families.

Comparison of length-frequency data for bonefish collected in 3.5-in. (8.9 cm) stretch gill nets during 1977 and 1992-1993 demonstrated the large shift in average mean length of bonefish (46.4 cm versus 37.6) (Figure 4). The abundance of larger individuals was much lower in the 1992-1993 samples. The average length of bonefish sampled in fisher landings during 1992-1993 was lower than in gill net samples (Table 5). Although the fish in fisher landings could not be sexed, a conservative estimate of the percentage of nonreproductive bonefish taken by fisher would be 30%, based on the smallest reproductive individual sampled in gill net samples (male: 32.0 cm) (Figure 5).

The results of the bonefish sampling of more than 100 individuals greater than 35 cm were biased but yielded important information. Because large individuals were sampled, larger females should have been overrepresented. For this sample, the sex ratio was 67:42 (male:female), or 1.6:1, which is still greatly biased toward males (Table 6). The mean length and weight of males and females in this sample was 40.1 cm per 959 g and 44.2 cm per 1,233 g, respectively. Food habit analysis showed that bivalves dominated the abundance of food items with echinoids and gastropods accounting for large proportions of food items (Yeeting, this volume).

Table 6 Results of bonefish sampling of individuals larger than 35 centimeters long.

Sex	Number	Length (cm)	Weight (g)	Stomach Contents (g dry wt.)
Male	67	40.1	959	2.05
SD		4.0	275	2.13
Range		23.4-51.3	500-2,250	0-12.41
Female	42	44.2	1,233	2.13
SD		4.9	465	2.97
Range		35.0-55.7	550-3,000	0-15.57

Sex ratio (male:female) is 67:42 (1.6:1), which is significantly different from 1:1 (P = 0.02 binomial test).

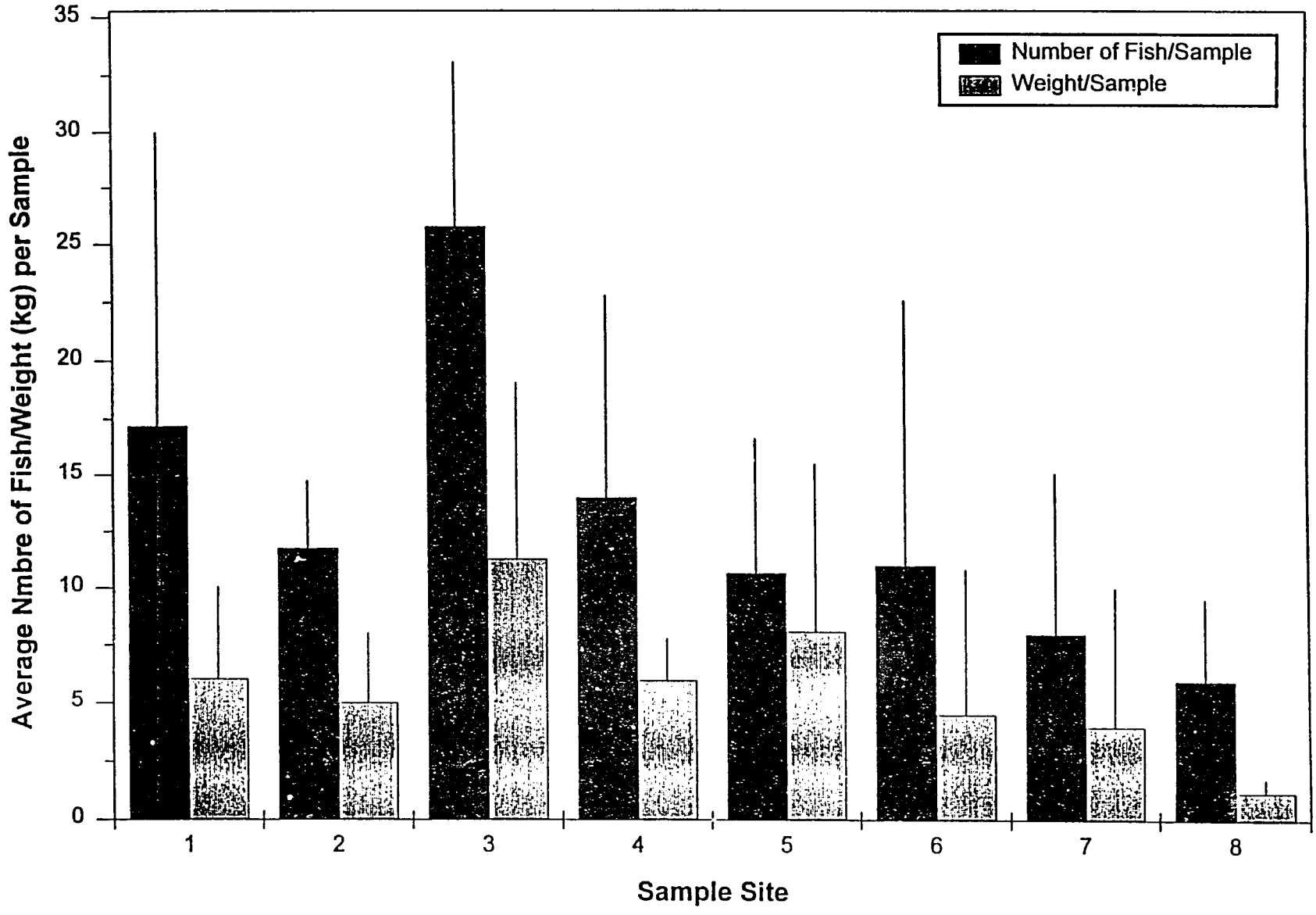


Figure 2 Average catch per unit effort for gill net at each sampling site in Tarawa Lagoon, 1992-1993. Error bars represent one standard deviation from mean.

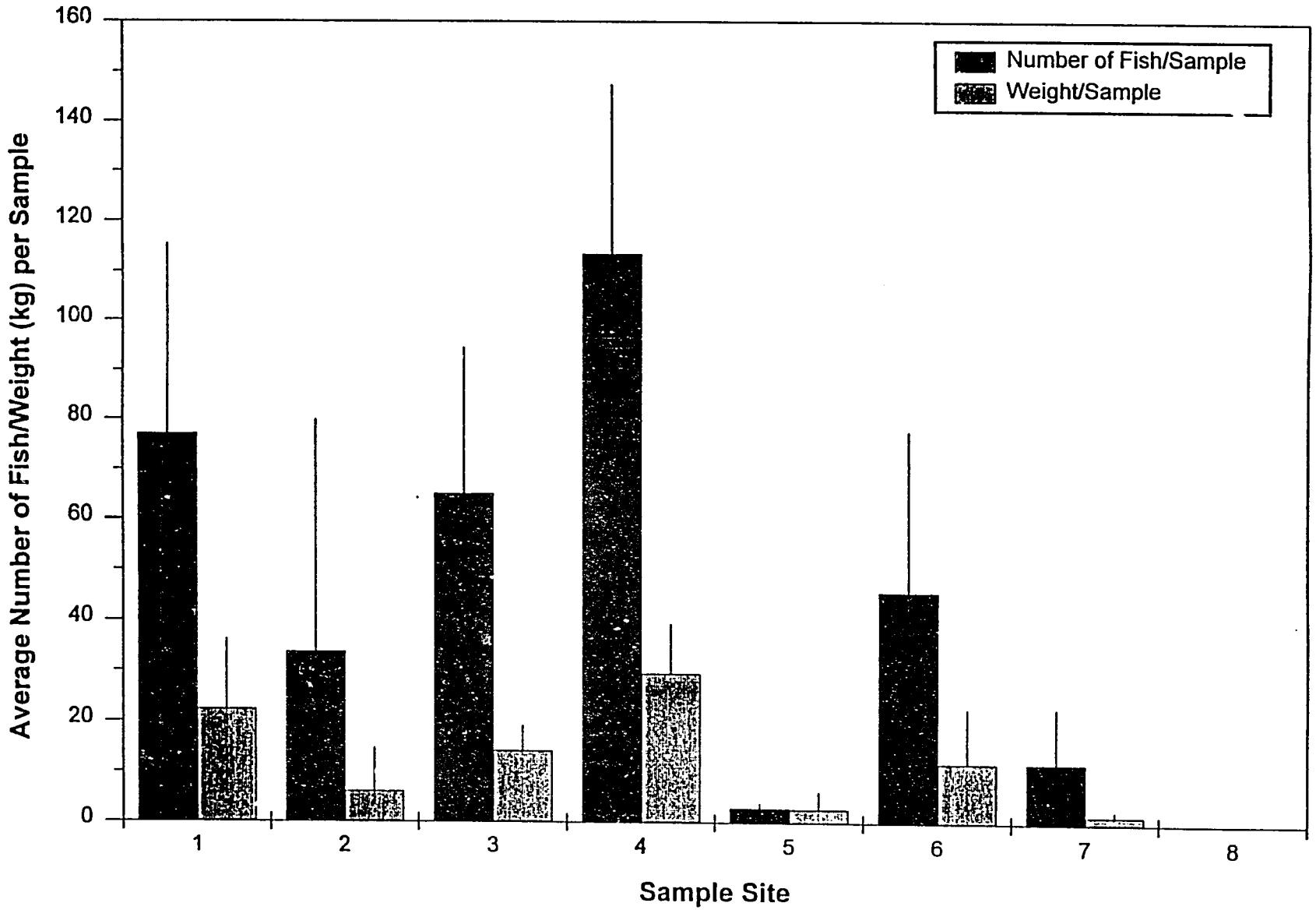
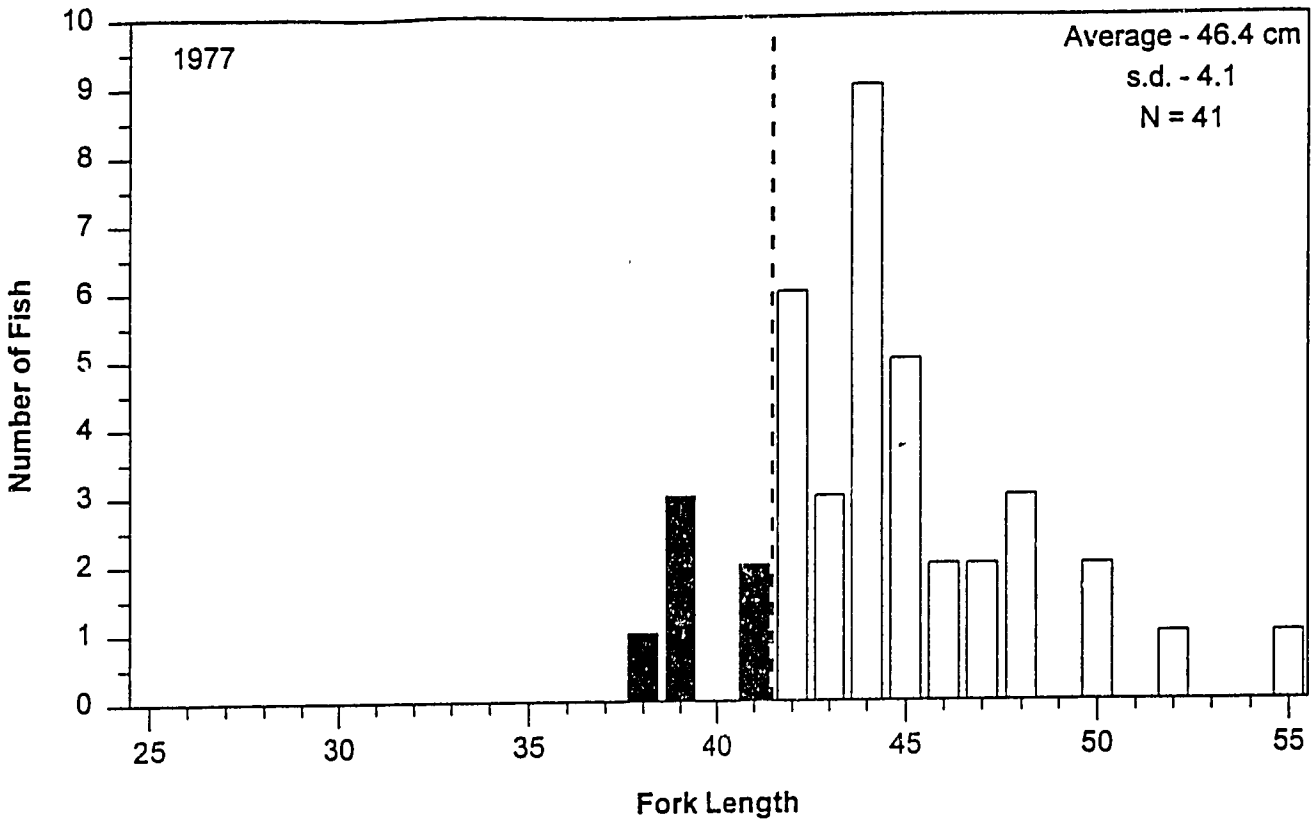


Figure 3 Average catch per unit effort for handline data at each sampling site in Tarawa Lagoon, 1992-1993. Error bars represent one standard deviation from mean.



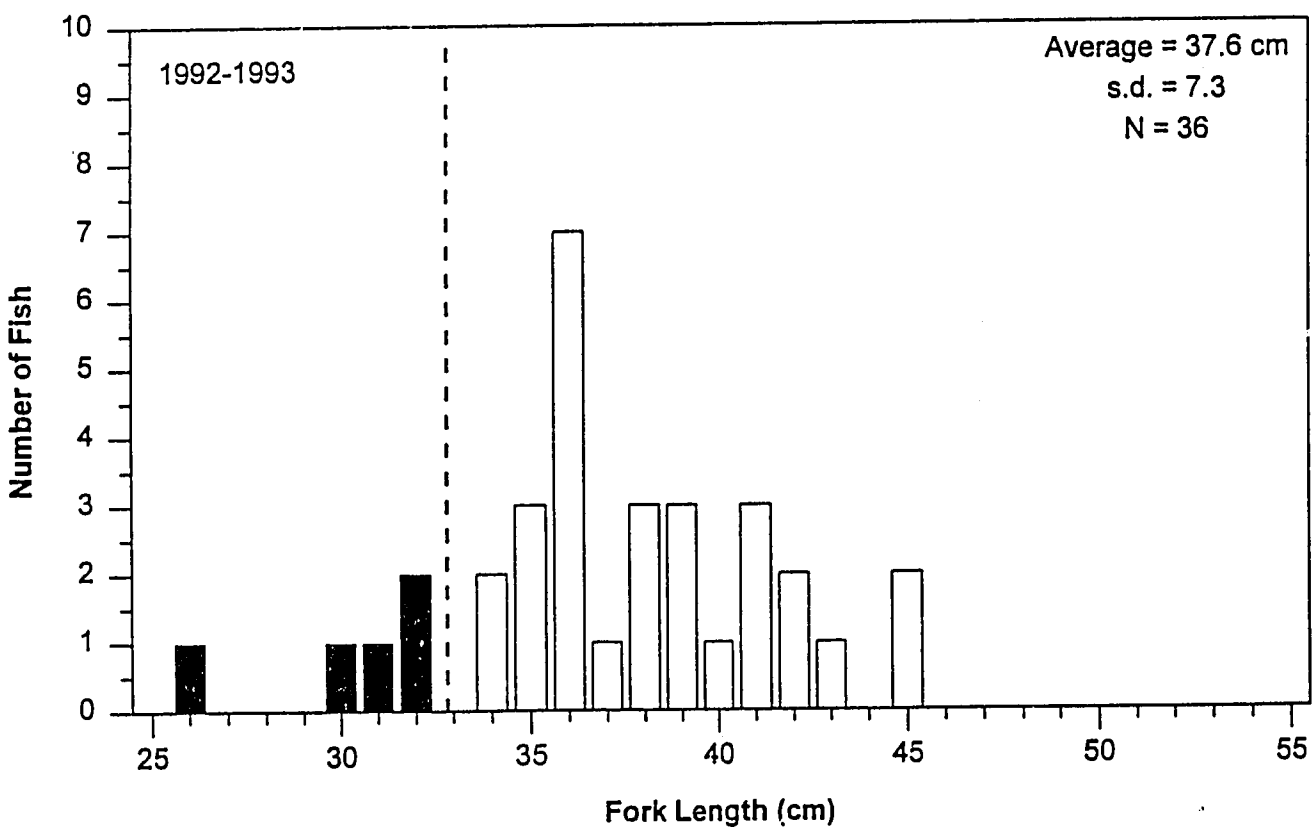


Figure 4 Comparison of size of bonefish collected in fisheries-independent studies using gill nets in 1977 and 1992-1993. Vertical lines designate the size of the smallest reproductive individual captured during each study. Dark bars represent a conservative estimate of the proportion of non-reproductive fish.

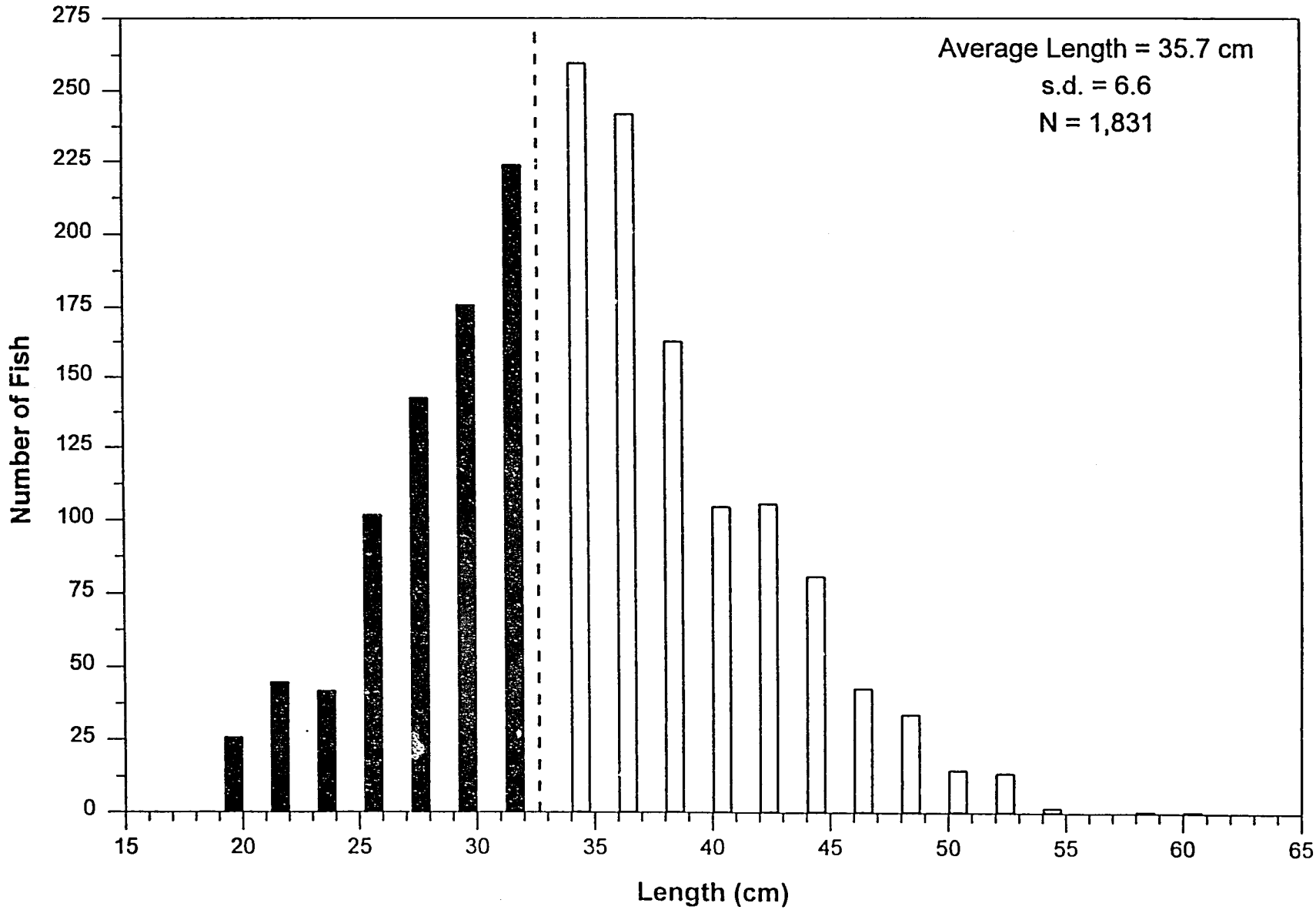


Figure 5 Size frequency distribution of bonefish in fisher landings in 1992-1993 study. Vertical line designates the size of the smallest reproductive individual captured in fisheries-independent sampling. Dark bars represent a conservative estimate of the proportion of non-reproductive fish.

Beach Seine Sampling Data

Thirty-eight species were sampled in 40 beach seine samples taken in Tarawa Lagoon (Table 7). Based on a comparison of data with the previous study conducted by the Kiribati Fisheries Division (Cross 1978), species composition has changed and the relative abundance of fishes captured by this method has declined along South Tarawa (Table 8). A few species, primarily baitfishes that were abundant in samples taken during the 1977 study, were not captured during seine samples in 1993 (Table 8).

Table 7 Number of each species captured during inshore beach seine sampling in three areas of Tarawa Lagoon in 1993.

Scientific Name	Total	South Tarawa	Betio	North Tarawa
Clupeidae				
Herlotsichthys quadrimaculatus	50	50		
Atherinidae				
Stenatherina panatella	1,062	50	1,012	
Hypoatherina ovalaua	80	79	1	
Atherinomerus lacunosus	70	70		
Belonidae				
Tylosaurus crocodilus	31	24	6	1
Hemirhamphidae				
Hemirhamphis archipelagilus	5	5		
Hemirhamphus far	2	2		
Hyporhamphis affinis	1	1		
Hyporhamphis dussumieri	1,986	1,065	919	2
Fistulariidae				
Fistulariidae commersonii	1	1		
Carangidae				
Carangoides laticaudis	2		2	
Caranx melampygus	616	402	198	16
Caranx papuensis	223	208	14	1
Caranx sexfasciatus	27	7	20	
Scomberoides lysan	90	68	18	4
Selar crumenopthalamus	1		1	
Gerreidae				
unidentified gerreid	6	6		
Gerres argyreus	2,163	1,673	201	289
Lutjanidae				
unidentified lutjanid	6	6		
Lutjanus ehrenbergi	9	8	1	
Lutjanus fulvus	50	50		
Lutjanus kasmira	5	5		

Table 7 Number of each species captured during inshore beach seine sampling in three areas of Tarawa Lagoon in 1993 (cont.).

Scientific Name	Total	South Tarawa	Betio	North Tarawa
Lethrinidae				
Gymnocranius sp.	120	120		
Lethrinus obsoletus	1	1		
Lethrinus harak	12	12		
Mullidae				
Mulloides flavolineatus	1,213	1,071	90	52
Mulloides vanicolensis	24	2	22	
Upeneus taeneopterus	16	12	4	
Labridae				
Cymolutes lecluse	1	1		
Mugilidae				
unidentified mugilid	73	72	1	
Crenimugil crenilabis	6	6		
Liza vaigiensis	80	54	23	3
Valamugil seheli	1		1	
Sphyraenidae				
Sphyraena barracuda	3	3		
Siganidae				
Siganus sp.	1	1		
Siganus argenteus	2	2		
Tetraodontidae				
Amblyrhincotus honckenii	10	10		
Arothron manilensis	2	1		1
Total number of fish	8,051	5,148	2,534	369
Total number of samples	40	25	11	4

Table 8 Comparison of results of inshore seine samples taken in three areas of Tarawa Lagoon in 1977 and 1993. Data in first column are percentage of total fish captured in South Tarawa for each taxon. Data in subsequent columns are total number of fish sampled by each taxon in area sampled. 1977 data from Cross (1978).

			Total Number		
Scientific Name Common Name	Kiribati Name	South Tarawa	South Tarawa	Betio	North Tarawa
Species Composition - 1977 (six dominant taxa)					
Atherinomerus lacunosus hardyhead silverside	*rerekoti*	33.14%	7,923	12,641	20,564
Herklothsichthys quadrimaculatus gold-spot herring	*tarabuti*	22.31%	3,281	10,562	13,843
Gerres argyreus silverbiddy, common mojarra	*ninimai*	14.62%	8,214	860	9,074
Spratelloides delicatulus blue sprat	*auan*	13.07%	1,410	6,700	8,110
Hypoatherina ovalaua ovalaua silverside	*rerekoti*	11.15%	1,024	5,894	6,918
Mugilidae mullets	*baua, bauamaran*	1.87%	1,108	55	1,183
Number of samples			47	43	22
Species Composition - 1993 (six dominant taxa)					
Gerres argyreus silverbiddy, common mojarra	*ninimai*	32.60%	1,679	201	289
Hyporhamphis dussumieri Dussumieri's halfbeak	*kabubu*	20.68%	1,065	919	2
Mullidae goatfishes	*tewe, maebo*	21.07%	1,085	106	52
Carangidae trevallies, queenfish	*rereba, nari*	13.30%	685	257	21
Mugilidae mullets	*baua, bauamaran*	2.56%	132	25	3
Stenatherina panatella panatella silverside	*rerekoti*	0.97%	50	1,012	0
1993 Data for Species Dominant in 1977					
Atherinomerus lacunosus hardyhead silverside	*rerekoti*	1.36%	70	0	0
Herklothsichthys quadrimaculatus gold-spot herring	*tarabuti*	0.97%	50	0	0
Spratelloides delicatulus blue sprat	*auan*	0.00%	0	0	0
Hypoatherina ovalaua ovalaua silverside	*rerekoti*	1.53%	79	1	0
Number of samples			25	11	4

Discussion

A review of pertinent literature and the results of our investigation suggest that the finfish resources of Tarawa Lagoon continue to decline. Reports completed by the Kiribati Fisheries Division during the past decade provide evidence of a declining lagoon fishery. This report supports and extends those conclusions with additional data and analysis. Because of the lack of suitable historical data for fisheries species in Tarawa Lagoon and scientific information on fisheries parameters for these species, stock assessments were not possible. This study has provided data and a monitoring base that could be used in future stock assessments.

Increased fishing pressure in Tarawa Lagoon is a response to increased population growth and the need for more fishery products. Unfortunately, many species in Tarawa Lagoon have declined in abundance, at least in part from increased fishing pressure. Johannes and Yeeting (this volume) have provided important documentation from fishers on declining resources. Several conditions point to declining stocks. For example, fishers have increased their use of the splash method of fishing gill nets in the lagoon because the catch rate with only gill nets is low. Such changes in fishing methods signal problems in lagoon fisheries.

Habitat alteration and loss, especially the construction of causeways, have caused a decline in fish migration to spawning sites (Johannes and Yeeting, this volume). Channels are vital to the migrations of lagoon species that migrate to offshore sites during their spawning period. Additionally, causeways may block the migration of larval fish through channels into the lagoon following their early planktonic development offshore. Currents that develop during tidal exchange in the lagoon may provide the necessary cue for migration. Causeway construction has obviously resulted in the loss of spawning migrations and may have contributed to declines in the abundance of some species, particularly bonefish.

The lagoon fishery appears to be overcapitalized. Considering the finite resources, the increase in the use of monofilament gill nets and outboard engines has contributed to the overfished condition. Historically, Kiribati fishers were noted for using many fishing methods to catch a diversity of species. The trend in recent years has been toward using efficient gear, such as gill nets, and targeting fewer species. Such a trend has the inevitable consequences of declining stocks.

The CPUE average weight and the average size of bonefish, the most important fish harvested in Tarawa Lagoon, have declined significantly, and spawning failure apparently has occurred (Johannes and Yeeting, this volume). The dominant species landed by fishers using gill nets in Tarawa Lagoon is bonefish. Bonefish caught in the 1977 fisheries study in Tarawa Lagoon (Cross 1978) were larger on average (36.4% by weight) than those caught in this study. This size decrease suggests that, at present, fishers must catch more fish per trip to provide the same amount of protein to their families as they did in 1977. Bonefish caught in the 1977 study had a sex ratio of 1:0.71 (male:female), which was closer to normal for an unexploited stock (1:1). During the 1992-1993 sampling, the

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bonefish sex ratio was 1:0.15, which suggests a stressed stock with a low proportion of egg producers.

The mean length of bonefish sampled in fisher landings also was much smaller than that of fish sampled in the 1977 study. Landings data show that the conservative estimate of the number of bonefish caught below reproductive size was 30%. This figure is based on the smallest reproductive individual captured during fisheries-independent sampling and is an underestimate because most reproductive fish are larger, especially females. These results suggest that the spawning stock of female bonefish in Tarawa Lagoon is very low. Fisher landings data suggest that a large percentage of bonefish caught in Tarawa Lagoon are prespawning individuals and that females, which have a larger mean size, have been selectively depleted. These data, in combination with the information obtained on spawning migration failure (Johannes and Yeeting, this volume), indicate a critical condition for bonefish in Tarawa Lagoon.

Analyses of other species demonstrated similar, although less severe, trends to those observed for bonefish. Several reef fish species occurred in lower proportions of total catch and lower CPUE in the 1992-1993 gill net sampling than in the 1977 study (Cross 1978). For example, the spangled emperor was documented as one of the most popular lagoon species targeted by fishers (Johannes and Yeeting, this volume; Phillips, this volume). During the 1992-1993 sampling, the proportion of total catch and CPUE for this species were less than 10% of the values obtained in the 1977 study (Tables 1 and 4). Similar trends were apparent for other emperors (Lethrinidae), snappers (Lutjanidae), and a grouper (Serranidae). Fewer of these fish were taken in fisheries-independent samples from the lagoon in 1992-1993 than in 1977. More information on this and similar species is needed to derive assessments and evaluate the need for future management strategies.

Several species of reef fishes, such as snapper, groupers, and related families, have been recognized as susceptible to overfishing (Munro 1987). These species, which are primarily large, long-lived predators, also are usually preferred species in tropical, multispecies fisheries. Therefore, they are important indicators of overfishing. As CPUE for abundant species declines, fishers will shift their effort to the next preferred or abundant species, resulting in sequential stock declines. If selective gears are used, species may recover as effort shifts. For nonselective gear, however, such as gill nets, stocks rarely have the opportunity to recover. As observed in Tarawa Lagoon, species composition changes within a fishery is indicative of a declining fishery.

The CPUE in fisheries-independent samples was lower in 1992-1993 than in 1977. This decrease supports the findings from interviews that fisher catch rates are lower than in previous years and that to land the same amount of fish, the amount of gear or time fished must increase and fishers must travel farther from home villages (Phillips, this volume). CPUE and landings data presented in previous publications were not always considered in terms of compensation by fishers (Mees 1987). Although these data provide useful information on trends and are useful in initial analysis using surplus production models, analyzing data by area and species composition is imperative to obtain sound management strategies. Yield estimates can vary greatly when calculated among different species groups. Data normally are unavailable for comprehensive stock assessments for every species

in a multispecies fishery; however, data must be analyzed to provide evaluations of important species groups.

The CPUEs for gill net and handline sampling were low in the southern and eastern portions of the lagoon. This same trend was determined for living coral abundance (Paulay, this volume) and correlates with a trend in the condition of reefs. Because most lagoon fishes depend on coral structure for shelter, the lower abundance in the southeastern portion of the lagoon may be a result of lower quantity and quality of habitat. The low fish abundance, however, also may be influenced by the blocking of passes and intense fishing pressure near the population centers. Because some lagoon fish species, such as bonefish, are not as dependent on reef structure for shelter, and because invertebrate abundance (food items) showed the opposite trend of increasing to the eastern portion of the lagoon (Paulay, this volume), these species' low abundance must be related to factors other than shelter.

Beach seine sampling demonstrated major changes in species composition since 1977. Based on a comparison with Cross (1978), species composition has changed and the relative abundance of fishes captured by this method has declined. A few species that were abundant in 1977 samples, primarily baitfishes, were not captured during the 1993 seine sampling. This finding supports the claims of fishers that baitfishes have declined dramatically since the Betio-Bairiki causeway was constructed and intensive baitfishing was initiated to support the tuna fleet.

The fishing pressure on the lagoon must decrease if stocks are to rebuild. This accomplishment will be possible only if the people of Tarawa are provided with other acceptable sources of fishery products. Other sources have been investigated. Two projects conducted by the South Pacific Commission, the Outer Reef Artisanal Fisheries Project and the Deep Sea Fisheries Development Project, provided information on additional resources (Crossland 1980; Crossland and Grandperrin 1980; Taumaia and Gentle 1983). These projects demonstrated good catch rates for valuable, deep reef resources. At present, these resources are subject to only minimal fishing pressure around Tarawa; however, the potential yield (55-165 tonnes y^{-1}) (Dalzell and Preston 1992) is small compared to present demand and previously estimated potential yield for Tarawa Lagoon (2,200-3,103 tonnes y^{-1}) (Mees 1987; Wright and Yeeting 1988). Although deep reef resources may alleviate some fishing pressure in Tarawa Lagoon, these stocks are also extremely susceptible to overfishing and effort should be monitored.

Tuna is the most obvious available resource because it is often abundant around Tarawa. Developing this fishery would require government incentives and training to improve fishing effort in Tarawa, but it should prove to be a sound ecological and economically important alternative.

Ciguatera in Tarawa

Ciguatera has a great impact on the fishery resources of Tarawa. The presence of ciguatera around Tarawa and other atolls has been well documented (McCarthy and Tebano 1988). No incidences of ciguatera have been reported in fishes caught within the lagoon; however, the incidence of ciguatera has been high in reef fishes caught on the outer reef, especially in recent years. This occurrence has resulted in reduced fishing effort for reef resources on the outer reef and increased effort in the lagoon. Ciguatera appears to be a problem only along South Tarawa and not around the rest of the atoll. This pattern is suggested to be a result of construction around the reef, a hypothesis that is consistent with what is known about ciguatoxic dinoflagellates. The incidence of ciguatera around Tarawa is apparently cyclic, not persistent. Use of shallow-water resources around the northern portions of the atoll could assist in removing fishing pressure from the lagoon. Without rapid, inexpensive tissue tests, however, documentation of the incidence in ciguatera and the identification of "safe" fish is not possible.

Bonefish Resources in Tarawa Lagoon

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Bonefish Resources in Tarawa Lagoon

By

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Abstract

Bonefish (*Albula glossodonta*) was once the most important fish in Tarawa Lagoon, constituting over 40% of the catch in 1977. Fisheries-dependent and -independent sampling and information provided by experienced fishers during interviews document that overfishing has severely depleted bonefish stocks in the lagoon.

Bonefish spawning migration patterns and the splash, or *te ororo*, fishing method are described in detail based on information obtained from interviews and personal observations. Bonefish stomach content analyses reveal a diet dominated by bivalves. The range of food items is similar to that of bonefish in the Bahamas, Puerto Rico, and Florida, suggesting that bonefish are generalized benthic carnivores.

Introduction

The bonefish is a primitive teleost related to eels, tarpons and ox-eye, and ladyfishes (Greenwood et al. 1966). As an elopiform fish, it has a distinctive long-lived, pelagic leptocephalus larval stage (Hollister 1936). Bonefish are distributed throughout the tropics. Although all were once considered to be *Albula vulpes* (Linnaeus), distinct species have now been described in the Red Sea, the Indian Ocean, the western Atlantic Ocean; and the western Pacific Ocean, including Australia. At least 20 synonymous species names for bonefish exist.

As discussed in Beets (this volume), two species of bonefish may occur within the Tarawa Atoll region of the Pacific Ocean (Shacklee and Tamaru 1981), but meristic counts indicate that those harvested in Tarawa Lagoon are *Albula glossodonta* (Forskal 1775). This species is phenotypically similar to one of two species in the Hawaiian Islands (Shacklee and Tamaru 1981).

The metamorphosis of bonefish leptocephalus larvae into juveniles has been studied extensively (Jordan 1905; Gill 1907; Hollister 1936; Fitch 1950; Rasquin 1955; Alexander 1961; Pfeiler 1984a and b). Warmkee and Erdman (1963) described the food habits of Florida bonefish and Bruger investigated the diet of Caribbean bonefish. The movements of adults have been described by Bruger (1974), Colton and Alevizon (1983), and Pfeiler (1984a), and sensory parameters were investigated by Tavolga (1974) and Myrberg (1981). Information on spawning behavior and other aspects of bonefish life history has been obtained from interviews with experienced fishers (Johannes 1981; Johannes and MacFarlane 1991; and Ruddle and Johannes 1990). Johannes and Yeeting (this

volume) investigated the traditional knowledge of fishers in Tarawa and obtained valuable information on the spawning behavior of bonefish, as well as previously unrecorded historical accounts of catches. Despite these studies, more research is needed to successfully manage and regulate bonefish.

Use and Importance of Bonefish

Bonefish is not a preferred food fish in most places that it occurs, including the Bahamas, Florida, Mexico, and Australia. In Kiribati, however, it is the favorite lagoon food fish and by far the most important lagoon fish species caught by artisanal fishers. Fisheries surveys in 1977 (Fisheries Division) revealed that bonefish made up almost 40% of the total catch in the lagoon.

Bonefish are traditionally barbecued, and the surplus is salted and sundried. The dried fish is considered a delicacy, and, because it keeps for a long time, the dried product can provide a source of protein during bad weather. Today, as more cooking ingredients become available, western methods of preparation are becoming more popular.

On Christmas Island, one of the Line Islands of Kiribati, bonefish is an important gamefish. Sport fishers from around the world travel to Christmas Island in the hope of catching the elusive, fast-running bonefish. These tourists benefit the local economy and provide income for the nation.

The Tarawa Lagoon bonefish fishery is in a serious decline from overfishing, construction of causeways, and other factors (Beets, this volume). The public participation meeting organized by BioSystems in September 1993 as part of the Tarawa Lagoon Management project discussed this concern and explored mechanisms to address the problem.

Methodology

The methods used to collect fisheries information and obtain information from Tarawa fishers are described in detail by Beets (this volume) and Johannes and Yeeting (this volume). The stomachs of 111 bonefish that were over 35 cm SL were opened, and Andrew Telm sorted and identified the contents to the lowest taxon. Benthic prey items were identified by Gustav Paulay.

Results

Fisheries-Dependent Studies

Beets (this volume) presents the mean lengths and weights, sex ratios, and length at maturity of the bonefish sampled. Although many fish were sampled in the fisher landings, only length and weight data could be obtained. Because the sex of specimens could not be determined, calculating length-weight relationships based on sex was not possible. Determining an overall length-weight relationship, however, is of limited use because males and females differ significantly in mean length and weight (Beets, this volume). From the data available, fishers are clearly catching smaller fish and the sex ratio is biased toward males, indicating a declining fishery. This trend agrees with the views expressed by fishers interviewed by Johannes and Yeeting (this volume).

Interviews with Experienced Fishers

Bonefish Spawning Migrations

Interviews with experienced fishers revealed new information about bonefish spawning migrations and fishing methods. According to their accounts, about 3 days before the full moon, bonefish began to aggregate in several areas, including an area in the northern part of the lagoon. These prespawning aggregation sites are known as *Te tao*. According to the observations of senior fishers in North Tarawa, prespawning aggregations would remain in this area, moving in a circle, until the tide rose and flooded the surrounding sandbanks. The bonefish would then swim over the sandbars, travel around the northern tip of Tarawa, and begin their southward journey on the ocean side of the island, staying close to shore. As the tide fell in the evening, the fish would move down into the surge canal along the coral reefs, reputedly to hide from predators such as sharks. In the early morning, as the tide rose and flooded the intertidal reef, the bonefish would swim onto the reef flats and begin their return trip into the lagoon. Fishers would take advantage of this return migration by trapping bonefish in numerous (150) stone traps along the ocean side of the island. Most of the bonefish caught in these fish traps were spent females, which led to speculation that the bonefish spawned sometime after they moved down into the coral reefs along the windward side of the island. Further research to substantiate these observations would be appropriate, but the consistency of the reports by fishers from all over Tarawa gives credence to this account.

Bonefish Fishing Methods

The methods used to catch bonefish have changed in recent decades. For centuries, bonefish were captured in rock fish traps specifically built for this purpose. Interviewed fishers reported that large numbers of fish were caught in these traps. This information is similar to the reports of two independent sources (Catala 1957; Sabatier 1977). Despite high harvest rates, bonefish remained plentiful for centuries. An important feature of these fish traps was that most of the bonefish caught in them were spent. The use of imported gill nets, which began in the 1950s, led to the exploitation of prespawning aggregations. This shift in fishing technology is probably responsible for much of

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the decrease in bonefish stocks that had occurred by the late 1960s. The impact of gill nets was further amplified with the development and intensive use of the *te ororo* fishing method in the early 1980s. Using this method, fishers could effectively exploit bonefish throughout the year, instead of only during the spawning season with set netting.

The *te ororo* fishing method requires at least two fishers; a canoe or boat with an engine; a long net or, more commonly, several fishing nets connected together into one long net of up to approximately 1,000 m; and a 2-m-long crowbar. One of the two fishers is in charge of driving the boat (or paddling the canoe), and the other sets the net, splashes the water with the crowbar, and retrieves the net and the catch. The net is usually set between submerged sand shoals (*aba*). In most cases, the long net lies along the deep edges of three to four shoals at a depth of 5-10 m, usually cutting across the deep passes between them. With the net set, the driver steers the boat on a course perpendicular to the net for 200-300 m, then turns back and slowly moves toward the net in a long wide arc at 1-2 knots. As the boat moves back, the second fisher splashes the crowbar into the water, driving the bonefish into the net. Once the boat is within 50 m of the net, it is steered toward the center. The net is retrieved and any fish that have been caught are removed. Once the net is back on the boat, another site is selected and the process is repeated. One set with a 1,000-m net usually takes about 45 min; when smaller nets are used, a set can take less than 10 min.

As many as 200-300 bonefish can be caught in 1 day using the *te ororo* method (personal observation). Bonefish usually make up at least 70% of the catch (Yeeting no date). Other fish collected include Lutjanids and Lethrinids; using smaller mesh (2.5-in. mesh) nets, Mullidaes and *Scomberoides lysan* are collected. Fishers interviewed claimed that one of the major causes of the decline of bonefish stocks and the loss of spawning migrations was the efficiency of the *te ororo* method (Johannes and Yeeting, this volume).

Bonefish Stomach Content Analyses

Of the 111 bonefish stomachs examined, 93 contained identifiable food items. A total of 27 species representing five phyla were identified (Table 1). Food items were counted and ranked by abundance. Bivalves were the most common food item, followed by echinoderms. Figure 1 summarizes the items found in stomach contents by major species groupings.

Food items were counted and ranked by abundance (Figure 1). Most of the bivalves were from 5 to 10 mm. Gastropods and crustaceans (mainly crabs) were the largest food items, with most measuring over 10 mm.

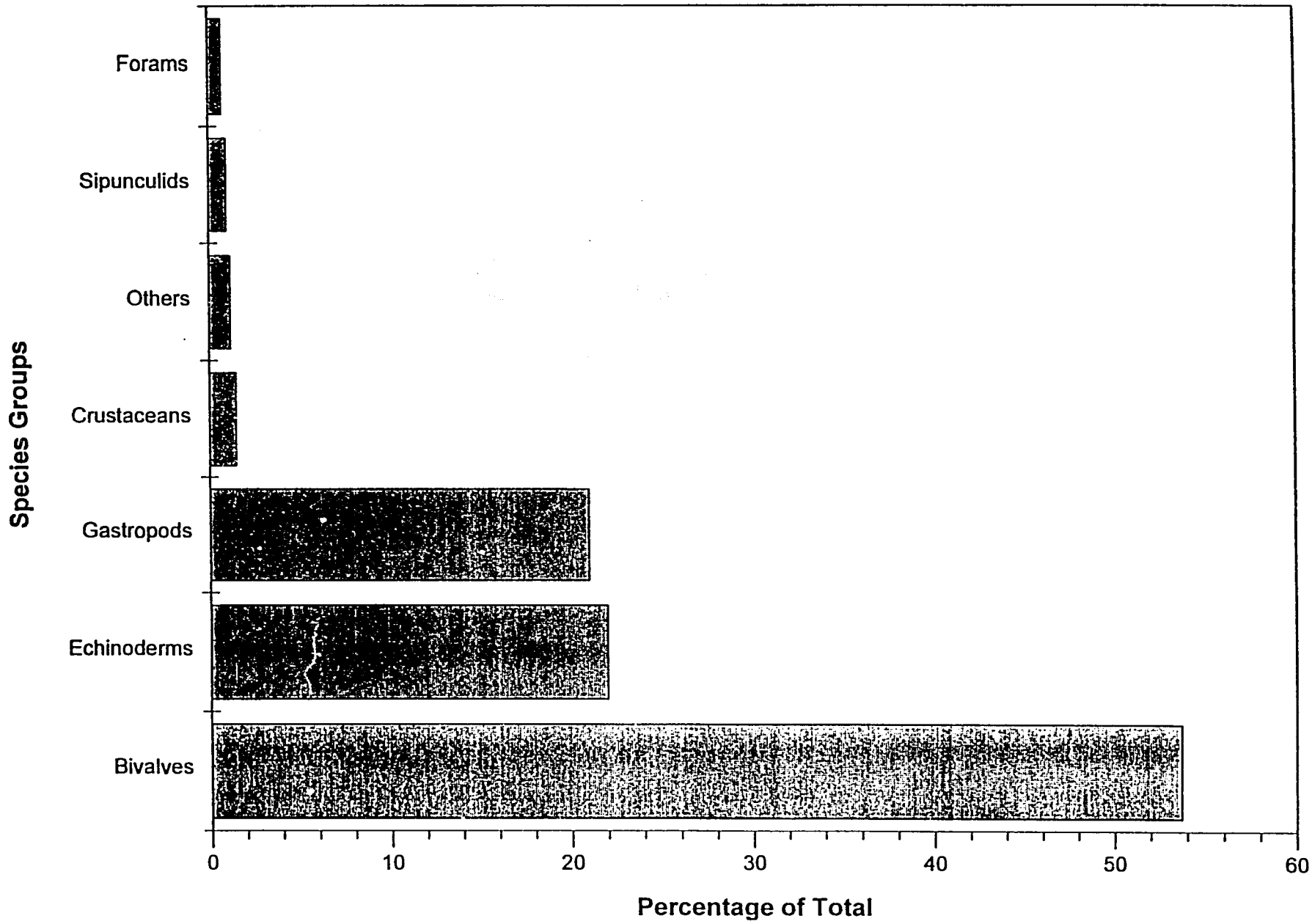

Figure 1 Proportions of major groups of benthic invertebrates found in the stomachs of 93 bonefish (*Albula glossodonta*) from Tarawa Lagoon. Fish collected from fisher landings in Tarawa Lagoon. All fish were over 35 cm standard length.

Table 1 Prey animals by relative abundance found in the stomachs of 93 specimens of bonefish (*Albula glossodonta*) from Tarawa Lagoon.

Species	Order of Abundance	Species	Order of Abundance
Bivalvia		**Echinoidea**	
Tellinidae sp. 1	1	*Fibularia* sp.	3
Timoclea marica	4	*Laganum depressum*	8
Musculus sp.	5	Spatangoida	6
Limatula sp.	7	Unidentified irregular echinoid	14
Fragum sp.5	9		
Acrosterigma transcendens	12	**Gastropoda**	
Laevicardium sp.	14	*Turritella sp.*	2
Pinguitellina sp.	15	*Nassarius sp.*	20
Limaria sp.	16	Others	17
Lioconcha sp.	16		
Anadara sp.	18	**Crustacea**	10
Timoclea sp.	19		
Tellinidae sp. 2	19	*Foraminifera*	13
Loxoglypta rhomboides	19		
Scissulina dispar	21	**Others**	11
Tellinella spp.	22		

Discussion

Beets' (this volume) information on the mean lengths of male and female bonefish and length at sexual maturity is important for formulating fishery regulations, such as net mesh-size limits. Reports of bonefish spawning migrations obtained from interviews with experienced fishers can also be used to develop management plans, but more research is needed to understand the mechanisms behind the spawning migrations. Research into the diet of bonefish is also vital to managing the fishery. For example, this information can be used to assess the relative value of lagoon areas as feeding habitat. Although much needs to be done, waiting until we have collected all the information about the fishery before we begin managing it is not necessary.

Bonefish in Tarawa Lagoon feed primarily on bivalves, gastropods, and echinoderms. A small unidentified tellinid bivalve was the most common prey species noted in stomach content analyses, and the gastropod *Turritella* was the second most common. The tellinid bivalve was the most abundant infaunal species on the southeastern lagoon floor, and *Turritella* occurred in large epibenthic aggregations (Paulay, this volume).

Bonefish diet studies in other parts of the range suggest that diet varies with the availability of prey. Puerto Rican bonefish feed mostly on *Codakia costata* (Warmke and Erdman 1963), and Bahamian bonefish prey primarily on *Tellina* spp. (Colton and Alevizon 1983). A study in Florida (Bruger 1974) revealed a diet dominated by crustaceans rather than bivalves. These studies suggest that bonefish are generalized carnivores that feed on a variety of food items.

Management Implications

Although research clearly shows that bonefish stocks are in danger of local extinction, managing the remaining resource must take into account many factors. Banning nets used for *te ororo* fishing would take away the livelihood of some families who depend on the income from fishing to pay for daily needs. Some of these *te ororo* fishers are still paying off loans for boats and fishing gear from the profits of bonefish sales. Many subsistence fishers need their nets to feed their families. These people would suffer if a total ban on nets were enforced. Prohibiting fishing during spawning migrations would be effective only if all fishers were willing to comply with this regulation or if strong enforcement were provided. In any case, some regulatory authority would be needed. Deciding who should have overall authority could lead to social conflicts between communities. Fishers, businessmen, and the general public must have a forum for interaction on this issue.

Ensuring that the public understands the purpose and reasons for the management plan, and the agencies and scientists preparing the plan understand the views of the public, is important. One effective way of achieving this goal is through public participation meetings, such as those held in September 1993 and July 1994 as part of this project. Information about the status of bonefish was presented at these meetings and management options and strategies were discussed with the public (Abbott, this volume).

The Use of Interisland Passages by Larval and Juvenile Fish to Enter Tarawa Lagoon

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The Use of Interisland Passages by Larval and Juvenile Fish to Enter Tarawa Lagoon

By

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Introduction

The bonefish (*Albula glossodonta*) population in Tarawa Lagoon has declined significantly (Beets, this volume; Johannes and Yeeting, this volume) as a result of overfishing and obstruction of migration routes by causeways constructed over the past few decades. No prespawning aggregations have been recorded for over two years, leading to concern that recruitment of larval bonefish into the lagoon may have ceased. This preliminary study was conducted to sample larval and juvenile fish entering the lagoon through an interisland pass and, in particular, to search for the leptocephali larvae of bonefish.

Methods and Materials

Samples were collected at night on 28 January, 13 May, and 19 July 1994 on a incoming tide in the boat channel under the Tenaea bridge at Buota. A standard 0.8-mm-mesh zooplankton net was used for the January sampling and a 3-m-long, 1.8-mm mesh, conical ichthyoplankton net with a circular opening with an area of 1-m^2 was used for the May and July samplings. The night of the January sampling was 1 day after the full moon, the May sampling was 3 days after the new moon, and the July date was 3 days before the full moon.

For each trial a net was hung from two nylon ropes attached to the bridge. Approximately 20 kg of weights were attached to the bottom of the frame to maintain the mouth of the net in a vertical position, but during strong tides the angle of the net varied and occasionally part of the net was above the surface of the water. Because the Buota passage is relatively shallow, the net was only partially submerged at low tide. We did not measure wind speed, direction, or current velocity or attempt to relate fish larvae abundance with the volume of water passing through the net. The net was pulled and cleaned often as it became clogged with debris. Net sets lasted approximately 30 min. and from three to seven sets were made during each sampling. The duration of strong incoming tides at night was 3 hr or less.

Samples were preserved in a solution of 5% formalin and 95% seawater, except for subsamples intended for otolith ring count analysis; these were preserved in a solution of 50% seawater and 50%

ethanol. A small amount of formalin was inadvertently placed in some samples, making it impossible to determine the age of larvae in those samples.

Dr. Jeffrey M. Leis of the Australian Museum in Sydney conducted taxonomic identifications. Dr. Jon Shanker and Mr. Raymond Mojica with the Florida Institute of Technology in Melbourne, Florida, performed the otolith ring counts and identified the leptocephalus larvae.

Results

Table 1 summarizes the catch for the January and May sampling. No larval or juvenile fish suitable for identification and no leptocephalus larvae were collected during the July sampling.

Table 1 Larval and juvenile fish collected during sampling on 28 January and 13 May 1994.

	Identification	
Family	28 January 1994	13 May 1994
Albulidae		Leptocephalus
Apogonidae	(just hatched)	*Apogon* sp.
		Apognichthys ocellatus
		Archamia sp.
		Foa or *Fowleria* sp.
Blenniidae	(just hatched, damaged)	*Petroscirtes* sp.
Carangidae		*Elegatis bipinnulatus*
		Scomberoides lysan
Clupeidae	*Spratelloides delicatulus*	*Spratelloides delicatulus*
Congridae		Leptocephalus
Exocoetidae		*Cypselurus* sp.
Gobiidae		*Callogobius* sp.
		Eviota sp.
Gonostomatidae	*Vinciguerria* sp.	
	Cyclothone sp.	
Hemiramphidae	(just hatched)	
Labridae		*Thalassoma* sp.
Microdesmidae		*Ptereleotris*
Muraenidae		Leptocephalus
Myctophidae	*Diaphus* sp.	
	Myctophum sp.	
	Bolinichthys sp.	
Ophichthidae		Leptocephalus
Pomacentridae	(just hatched)	*Chromis viridis* or *atripectoralis*
Pseudaminae		*Pseudamia*
Scaridae	Scarus (settlement stage)	*Scarus* sp.
Scorpaenidae		Scorpaenidae
Serranidae		*Pseudogramma* sp.
Syngnathidae	(Pipefish)	*Corythoichthys* sp.
Tetraodontidae		*Arothron* sp.
		Canthigaster sp.

Otolith Growth Ring Counts

Three leptocephali larvae were collected, identified and measured; one bonefish (54 mm TL), one moray eel (51 mm TL) and one snake eel (50 mm TL). The bonefish specimen could not be aged because of preservation error. The otolith count for the moray eel was 52 and the count for the snake eel was 44.

Discussion

Our collections show that many species of fish move into the lagoon through interisland passages on incoming tides. Most of the fish collected belong to the myctophidae or lanternfish family. These deep ocean fishes are passively pulled into the lagoon by the strong tidal currents. Many important food fish species were collected as they entered the lagoon, including Mugilidae (mullet), *Spratelloides delicatulus* (sprat), Serranidae (sea bass) and Carangidae (jacks).

The presence of a bonefish larva indicates that this species continues to be recruited into the lagoon, even though no bonefish prespawning aggregations have been identified in the last two years. Although small numbers of spawning-size, adult female bonefish are still caught in Tarawa Lagoon, the source of the bonefish larvae is unknown. Bonefish leptocephali may be from eggs fertilized in an unidentified spawning aggregation that originated in Tarawa Lagoon or they may be from another island in Kiribati.

Otolith ring counts suggest the eels collected in the samples had been spawned approximately two lunar months earlier. This assumes that the concentric rings on the otoliths correspond to the daily solar cycle. It is not known if leptocephalus larvae begin to lay down otolith growth rings before they hatch or if this occurs several days after they hatch. Because of this uncertainty, it is impossible to estimate the actual time of hatching from otolith ring counts.

I-Kiribati Knowledge and Traditional Management of Lagoon Resources

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I-Kiribati Knowledge and Traditional Management of Lagoon Resources

By
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Abstract

Local knowledge concerning Tarawa's marine resources, and local customs relating to exploitation and management of these resources can assist in formulating a contemporary marine resource management plan for Tarawa Atoll. Expert local fishers reported during interviews that stocks of bonefish (*Albula glossodonta*) (*te ikari*), Tarawa's single most important lagoon food fish, have been destroyed by overfishing and by causeways that have blocked spawning migrations. One of these runs may be resurrected if decisive, immediate action is taken; the local extinction of bonefish may otherwise be imminent. Customary marine tenure has been virtually eliminated in Tarawa; restoring it in a remodeled form appears to be the most practical means of addressing the "tragedy of the commons" that is underway in Tarawa Lagoon.

Introduction

Understanding local knowledge and associated customs concerning marine resources is essential for the sound management of artisanal fisheries (e.g., Ruddle and Johannes 1989). Government planning for marine resource management of village-based fisheries is more likely to be accepted by villagers, and thus be more effective, if it takes into consideration villagers' own management measures and related perceptions; plans should not conflict with local practices unnecessarily and should use or build on these practices where practical. In addition, villagers' knowledge concerning local resources can often provide fisheries biologists with valuable insights (discussed below) into the biology and status of exploited species.

Here we describe the results of an investigation of local knowledge concerning Tarawa's marine resources and the local customs that relate to the exploitation and management of these resources. For the study, 34 interviews with fishers and other knowledgeable I-Kiribati were conducted throughout the atoll over a combined period of 3 weeks during two visits to Tarawa in February 1992 and October 1993. Interviews were conducted on a total of 21 days during these two visits.

Informants were not randomly selected; we sought out individuals with high reputations in their villages for fishing expertise. For the most part, these people were between 40 and 79 years old.

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Some of them no longer fished because of physical infirmity but maintained an active interest in fishing and in the changes occurring in fishing conditions. The attitudes and knowledge revealed in these interviews should not be assumed to represent Tarawa's fishing communities as a whole, only Tarawa's most experienced fishers.

To test the reliability of informants (Johannes 1981), we asked them questions to which we knew the answers, and other plausible questions to which the informants could not possibly know the answers. Only one informant's assertions proved dubious, likely because of his apparent mistrust of us and his evasiveness, rather than because of misrepresentation. In general, informants appeared to be willing to answer the questions to the best of their ability because the questions were knowledgeable and concerned both expertise in which they took pride and issues of considerable importance to them and their communities.

The questions focused on the fishers' observations of perceived changes in the distribution, abundance, and behavior of marine resources during the fishers' lifetimes; presumed causes; and possible remedies in cases where the changes were seen as deleterious (not all changes have been for the worse; Paulay, this volume). We also asked about past and present village-based controls on fishing activities.

Interviews were unstructured; when unanticipated but promising subjects were touched on, we pursued them with further questions to obtain as much instructive knowledge from an informant as possible. To minimize potential constraints on the informants caused by our own limited knowledge and preconceptions, we did not use questionnaires or a survey format. Surveys are useful when well-defined and circumscribed questions are being pursued; they are inappropriate, however, in exploratory interviews concerning specialists' knowledge, where the interviewer is uncertain of what useful information may be forthcoming (Johannes 1993).

Being Yeeting, an I-Kiribati fisheries researcher, acted as the interpreter between Johannes and most of the informants. A few of the informants were at ease communicating in English. Most interviews occurred at the informants' homes, but occasionally groups of fishers were interviewed in their *maneaba* (village meeting house). Interviews lasted from 20 min to about 2 hr, with several informants being interviewed several times. Each night, the results of the day's interviews were transcribed.

Several students of I-Kiribati culture have claimed that intense secrecy surrounds special knowledge, including important fishing knowledge (e.g., Sabatier 1977). Our experience, however, suggests that such secrecy has either diminished considerably or was never as intensely guarded as claimed. Our experience resembles that of Koch (1986, p. xvii), who stated, "The techniques of even simple processes related to the daily provision of food are regarded as 'secret,' although, on account of the limitations of the environment, the resources and the methods of using them have long since become widely known." Secrecy today seems to be primarily associated with ritualistic aspects of preparing for fishing, such as what is chanted while a fisher prepares bait, and the locations of certain fishing

spots. Secrecy did not appear to seriously deter the informants from providing the information most relevant to our study.

Before the results of the interviews are discussed, the scattered literature on traditional knowledge and management of reef and lagoon resources on Tarawa and relevant information previously obtained by one of the interviewers while interviewing Kiribati fishers in 1979 (Johannes et al. 1979) are summarized.

Village-Based Fishing Regulations

Because marine resources were the only significant source of animal protein for the I-Kiribati, they developed not only a host of fishing methods (e.g., Banner and Randall 1952; Catala 1957; Lawrence 1977; Luomala 1980; Koch 1986) but also, according to several authors, a traditional marine conservation ethic (e.g., Sabatier 1977; Teiwaki 1988; Zann 1990). Koch (1986, p. 9) has a different perspective, however; he states, "There appears to be hardly any attempt at a controlled regeneration of resources. In places, the sipunculoidea are being wiped out without a second thought, young clams and other animals are gathered before they have reached the correct stage of growth and hiding places are destroyed, without regard for subsequent catches."

These two contrasting assertions are not contradictory. Examples of disregard for environmental limits coexisting with environmental wisdom can be found in many cultures. A local conservation ethic, however, can provide a valuable reference point when promoting conservation. If such an ethic is not present, as in some fishing cultures (e.g., Johannes and MacFarlane 1991), implementing a major education campaign is necessary to establish it.

Lawrence (1977) noted "continued and largely successful efforts to regulate fisheries on the island of Tamana. These are not new or recent efforts but stem, according to my informants, from pre-missionary times." Teiwaki (1988, p. 41) states, "Each island had its own rules about fishing; when to fish, how to fish and where to fish, and what should be done before, during and after each fishing expedition."

Sabatier (1977) noted that the I-Kiribati had many seafood taboos relating to age, sex, totem, and the whole community (see also Grimble 1933, 1989; Teiwaki 1988; Zann 1989). Other fishing regulations, also often viewed as taboos, were promulgated and strictly enforced. Punishment for not observing these regulations included threatened supernatural sanctions, fines, removal of fishing rights, and death (e.g., Bobai 1987). Public censure also was an effective deterrent. Such controls were in decline during Grimble's time, however, and have since declined further (e.g., Turbott 1949). Certain individuals who were interviewed on Tarawa during 1991-1993, however, stated that they still observe some totem-related seafood taboos.

Not all traditional controls were devised with conservation in mind. Regardless, however, of the original purpose of traditional controls, some probably would have functioned as conservation

measures for tabooed species that were overexploited or in danger of being overexploited, particularly when the taboo did not result in additional harvesting pressure on more heavily exploited species. Sea turtles, for example, were a taboo for pregnant women and for everyone during war and times of crisis; the turtle's "cowardly ways" were thought to be passed on to a person or unborn child when a turtle was consumed (Grimble 1933). This regulation apparently was not intended to help conserve sea turtles, but it nevertheless aided these species, which are well-known for their susceptibility to serious population depletion.

Whether such regulations arose out of the awareness of leaders of the need for conservation is unknown. In many cultures and religions, the primary reasons for prohibitions are unstated; instead, false but more persuasive reasons are given. The threat of supernatural retribution, for example, has proven to be a more effective deterrent in many cultures than the real consequences of undesirable activities.

As conditions changed after Western contact, the I-Kiribati responded with new conservation regulations. For example, nylon gill nets, introduced to Kiribati in the late 1950s, were subsequently banned on several islands because they were considered to be "too efficient" (Tikai 1980). Similarly, imported and local lures fitted with steel hooks were banned on several islands because they also were considered too efficient, as well as damaging to the mouths of fish that escaped (Lawrence 1977; Tikai 1980).

Other institutions reduced pressure on certain marine resources. For example, a variety of shallow water invertebrates and algae were not eaten by choice; they were instead reserved for consumption during times of hardship, when fish were unavailable in sufficient quantities, and as a form of "social security" for old people and other disadvantaged people who could not fish (Zann 1989).

For centuries, the I-Kiribati have raised milkfish (*Chanos chanos*) in specially constructed ponds (Catala 1957). Green turtles (*Chelonia mydas*) also were raised, with hand-feeding, in an enclosure on North Tarawa in the early 1980s, according to Zann (1989). Zann points out that the designation of tunas as high-prestige fish has also helped redirect fishing pressure away from limited shallow water resources and toward functionally unlimited migratory pelagic stocks.

Some of the islands' customary fishing results were embodied in the *Tuan Aonteaba* (Island Regulations) 1950, passed by the British colonial administration. These regulations were repealed in 1967, however, after local government was introduced to the islands. Island councils were given the responsibility to control all fishing activities on their islands, but every council fishing bylaw had to be approved by the central government. According to Teiwaki (1988, p. 41), "the central government has not been very receptive to the Island Councils' requests to pass certain fishing bylaws to protect the inshore fisheries and traditional fishing rights."

Customary Marine Tenure

Customary marine tenure (CMT) was the most important marine conservation mechanism in Kiribati and the foundation for most other fishing regulations. It gave tenure holders the right to exclude others from their fishing grounds. It underpinned villagers' marine resource management, providing them with the incentive to look after their marine resources by ensuring that they could retain for themselves the future benefits of doing so.

In precontact times, the island of Betio, now part of the Gilbert Islands' only urban center on South Tarawa, was divided, according to Teiwaki (1988, p. 37), "into eight different *Kaingas*. A *Kainga* is a cluster of households from the same families living together for their own common interests. Each *Kainga* had its own plots of land and designated marine areas. A member of a *Kainga* might have fishing and other similar privileges in other *Kaingas* because of inter-marriage, as a gift, or as a result of a *tinaba* . . . a special gift given to a woman who had provided sexual hospitality to a close male relative of her husband."

Teiwaki continues (p. 38), "The size of a *Kainga* in pre-contact Betio was very small, consisting of not more than a dozen households, with an average number of six people in a family. The population of the village was relatively small and there was no need to compete for the use of the sea amongst the village people, except in the case of aliens. *Nei Teba*, a rock formation about a mile eastward of Betio, was the designated maritime boundary between Betio and the next village, Bairiki. People from these villages could not extend their fishing or other sea-related activities beyond *Nei Teba*. It is understood that there was a passage named after a Bairiki person (Ten Taraia) who was killed by the Betio people because he was usually seen fishing beyond the boundary towards the Betio side."

Beginning in colonial times, government intervention contributed to CMT's decline and the subsequent decline in the ability of villagers of Tarawa and elsewhere in Kiribati to manage their marine resources. In 1892, the Gilbert Islands became a British Protectorate. At first, the British colonial government "allowed the customary sea tenure to prevail and ensured that the long-term fishing interests of the Kiribati people were protected from outside interests" (Teiwaki 1988, p. 38). In 1946, the first fisheries ordinance was initiated, recognizing traditional fishing rights and making specific provision for the registration of these customary rights. The Native Lands Commission, which was responsible for registering land rights, was also empowered to deal with similar issues regarding traditional marine tenure.

After the departure of the colonial official who spearheaded this initiative (anthropologist Harry Maude), however, little was done to follow through; no formal registration of marine tenure rights was ever undertaken. This lack of action apparently occurred because "the colonial administration favored the 'principle of open access to fish anywhere and at any time irrespective of traditional norms.' The local concept of marine rights was contrary to the British notion of public rights in the sea and its resources, the ownership of which were vested in the Crown or state" (Teiwaki 1988,

p. 38). Zann (1989) suggests another likely contributing factor to the decline of customary tenure. The British amalgamated small hamlets into larger villages on land chosen by the administration. The *utu* (extended families) who owned the fishing grounds adjacent to each hamlet were relocated to areas distant from those fishing grounds. Goodenough (1953) attributed the decline to the increased use of canoes when imported timber became available and, therefore, a greater emphasis on offshore fishing. This suggestion is unconvincing; many other Pacific Islanders who were well-endowed with canoe trees and who were expert in the art of offshore fishing (e.g., Hawaiians, Samoans) maintained strict marine tenure laws. Modern fisheries theory in general, and the United Nations Convention on the Law of the Sea in particular, constitutes a resounding global repudiation of this notion of the inherent "rightness" of open access, a principle that once held almost sacred status in Britain and throughout the Western world.

Traditional fishing rights were also seen as obstacles to implementing government projects, such as baitfishing by commercial tuna fishing interests in once-tenured waters. According to Zann and Bolton (1985), "On Tarawa, former sea owners have prevented *Te Mautari* from collecting milkfish fry for their baitfish aquaculture, but a confrontation between traditional interests and the national government was averted by the decision to pay villagers $5 per bucket of fry (Teiwaki, pers. comm.). Traditional owners of the lagoon floor at Ambo, in Tarawa, are currently complaining about an *Eucheuma* algae farm in their area, while those at nearby Bonriki are protesting the establishment of government milkfish ponds in their traditional waters."

Teiwaki (1988, p. 41) states, "The Island Councils were sensitive about the depletion of fishery resources in their vicinity because of the needs of their own people. There was no subscription to the government's argument that the fisheries resource was for the benefit of the public and not for the exclusive use of the people who were indigenous to a particular Council area."

Teiwaki (1988, p. 25) states that, "certain Island Councils had managed to recommend to the central government the institution of specific bylaws concerning the management of fishing activities within their own traditional fishing grounds. The ownership of fish traps had been previously registered in 1952 as part of the codification of land rights and ownership. Some islands, like Tabiteuea North and North Tarawa, have bylaws prohibiting fishing or sailing within a prescribed limit at a time of the fishing season (*te ikabuti*)." *Te ikabuti*, described in detail later in this report, refers to the phenomenon of the periodic lunar spawning migrations of bonefish, a time when they are especially vulnerable to exploitation.

Other limited marine rights recorded by the government included ownership of fish traps, sea walls, accretions, reclaimed lands, and fish ponds. Unfortunately, as Teiwaki relates, "the registration of these rights . . . was made in the name of an individual, usually the male head of the *Kainga* or *te utu*. Although the registered 'owner' had customary obligations towards other members of the *Kainga* or *te utu*, the law did not specify this social requirement. This tended to cause considerable ill-feeling amongst the relatives. The effect of this was that the registered owners could be oblivious of social obligations towards their own kin. . . The Lands Commission should have arranged the registration of the recognizable marine rights under the joint ownership or trustee of the leading

members in the *Kainga* or *te utu* to ensure the continuous access of those members to those rights" (Teiwaki 1988, p. 40).

Until overfishing and the construction of causeways destroyed bonefish spawning runs, and goatfish (*Upeneus* sp. and *Mulloidichthys* sp.) spawning runs dwindled (discussed below), private ownership of traps constructed to catch these species was reported to be generally respected in South Tarawa. We found no one who could remember a time when more general marine tenure rights were practiced in South Tarawa.

Today, the large number of outer islanders living in South Tarawa (Introduction to the Study and Phillips, this volume) places heavy pressure on nearby lagoon seafood stocks, especially shellfish. According to Teiwaki (1988, p. 12), "The Tarawa landowners (*Kain Tarawa*) moan and complain about foraging activities of the non-*Kain Tarawa* people (non-indigenous to Tarawa), but the government advised that the lagoon and its resources belong to the state and every I-Kiribati is entitled to harvest its resources. The Tarawa people argued that the shellfish grounds had always been a traditional source of food before the arrival of the British and other people from their outer islands. In their time, the village leaders had to be consulted before people from other places could collect the shellfish from their village. Failure to conform would result in a feud between the opposing parties. It would seem impossible for the Kiribati government to accept the complaints of the Tarawa people as it would mean that the individual islands could follow suit and claim rights over such shellfish. However, it is without doubt that the Tarawa landowners have become relatively disadvantaged as a result of their home island becoming the national capital."

Seaweed farming in shallow nearshore waters has fluctuated in recent years in Tarawa Lagoon. Because the government does not recognize customary marine tenure, no restrictions exist regarding where farmers can raise their seaweed. This has often resulted in conflicts between seaweed farmers competing for the best places and between seaweed farmers and fishers. Vandalism has disrupted several farms. Teiwaki (1988, p. 28) states, "Unless some amicable arrangements are made by the government and the lagoon users, the optimal utilization of the lagoon may be severely hampered."

A de facto form of marine tenure has replaced the old system in some areas. Teiwaki (1992) states, "In spite of their non-codification, traditional marine tenure is very much alive and respected in the rural villages." Local councils thus have limited access to certain fishing grounds of a particular village or island (e.g., Zann 1990), despite the central government's unwillingness to sanction such actions.

North Tarawa

The following section is a review of the status of CMT today in North Tarawa; a more thorough study would require longer periods of more narrowly focused interviews. In North Tarawa, where people remain closer to their original patterns of resource use than do people in South Tarawa, some forms of CMT are still exercised today, and others are remembered.

Traditionally, certain families exercised ownership over specific locations on the reef and in the lagoon in North Tarawa (discussed below). A 75-year-old, life-long Buariki resident and former North Tarawa senior magistrate, Ruka Kaburoro, told us that prior to British times, Buariki claimed ownership of adjacent waters. Because of the rich resource provided by bonefish and goatfish spawning runs, much fighting occurred over the locations of rock fish traps. People were killed in arguments over these sites, and certain rock traps are still identified by the names of some of the individuals who died fighting over them.

Arthur Grimble (later Sir Arthur), who was at one time British High Commissioner of the Gilbert and Ellice islands, decided, according to Kaburoro, to try to end this disharmony. He proposed that the fishing grounds be divided between different Buariki families. This was done amidst much bickering. Allocations were decided as much on the basis of political clout as on equitability. Grimble's strategy worked, however, and a sense of harmony prevailed over the fishing grounds.

When the British government first declared public ownership of most marine resources other than registered fish traps, some fishers took advantage of this, according to Kaburoro; they refused to continue to observe the Grimble-initiated allocations or the traditional exclusive right of Buariki people collectively over their fishing grounds. This attitude persists today, supported by various court decisions over the years discouraging villagers' efforts to control the activities of outside fishers. Buariki villagers have, however, chased off outsiders gathering shellfish for commercial purposes on the lagoon reef flat in recent years.

Other North Tarawa villagers told us that, traditionally, certain families or villages claimed exclusive rights over particular sand banks or rocky (i.e., coralline) outcrops in the lagoon where the fishing was good. The people of Nabeina, for example, had the exclusive right to fish over certain banks and coral outcrops stretching as far as Bikeman Island, according to one informant. Here they used special nets, hung with *te bun* (*Anadara* sp.) shells as weights, to fish for trevallies and other fish. As at Buariki, observance of these fishing rights at Nabeina faded when the government declared its ownership of Tarawa waters.

Local Knowledge of Marine Ecology

The Literature

Pacific island fishers often have knowledge about their marine resources that fisheries biologists do not. Some of this information can be invaluable in developing today's marine resource management programs. Unfortunately, the ethnographic literature dealing with indigenous marine environmental knowledge of the I-Kiribati is unreliable. Grimble's descriptions of fishing and fishing lore are difficult to interpret because they are interspersed with fantasies such as a description of how Gilbertese fishers (and Grimble himself) used themselves, while tied to a rope, as bait to catch giant octopuses (Grimble 1952). Luomala, the only other ethnographer to devote significant space to

Gilbertese fishing lore, was under the impression that sharks and rays have lungs, porpoises attack canoes (Luomala 1974, pp. 1,212, 1,219, 1,234), crabs have tails, and groupers are toothless (Luomala 1980, pp. 544, 549).

Results of Interviews

Spawning Migrations and Other Movements

Among the most useful local knowledge for purposes of marine resource management in many Pacific islands is that concerning the spawning migrations and aggregations of reef and lagoon fishes. A large variety of such species migrate along a highly regular route at a predictable season, moon phase, and tidal stage. They aggregate at the terminus of this migration to spawn and then return to their prespawning areas (e.g., Johannes 1981; Thresher 1984).

The spawning migrations of certain reef and lagoon fishes traditionally have been the focus of much of the fishing activity in Tarawa because these migrations have provided regular opportunities for catching large numbers of fish. Accordingly, fishers were able to provide us with considerable information concerning some of these migrations.

Fish engaging in such behavior are not only more accessible to fishers but also offer biologists exceptional opportunities for monitoring stocks. Just as populations of salmon returning to their rivers to spawn are far easier to monitor than at other times, so also are many reef fish easiest to census when they are concentrated in spawning runs. In addition, these runs provide a useful focus for the regulation of fishing pressure (Johannes 1980; Sadovy in press). In Tarawa, fishers have taken advantage of such spawning runs for centuries. So far, fisheries researchers and managers have not.

Bonefish (*Albula glossodonta, Te ikari*). Bonefish is not only the most popular food fish in Tarawa (Phillips, this volume), but catch statistics show that it has also been the single most important species in the shallow water catch and in commercial sales. Sabatier (1977, p. 121) observed in the 1930s that on some islands in the Gilberts bonefish accounted "for perhaps half the fish consumed."

Research elsewhere has shown that after an oceanic larval stage, bonefish move into shallow water where they feed on invertebrates found on sand or mud bottoms. Bonefish are found throughout Tarawa Lagoon wherever sand and mud bottom predominate.

Although bonefish are found throughout the nearshore tropics and are a highly valued game fish in some regions, little has been published concerning their reproduction. The descriptions of bonefish reproductive behavior given to us by Tarawa fishers were highly consistent with one another and contained considerable information not found in the scientific literature.

Every lunar month, according to Tarawa fishers, bonefish formed large schools 1 to 3 days before the full moon. These aggregations (which we will refer to here as prespawning aggregations) formed

in the lagoon near the spot where the fish would subsequently leave the lagoon on the spawning migrations. All but one of their reported migration routes involved passes between islands. The most important passes for bonefish migrations were Buota, Abatao, Taborio, Tabonibara, the passes now blocked by the Stewart and Anderson causeways, and the Betio-Bairiki pass, which has been almost completely blocked by a causeway since 1987. At low tide, bonefish entered the inner mouth of the main pass found in interisland channels and waited to migrate to the ocean. When the tide rose and the water currents became strong in the channel, the fish moved laterally up into shallow, slower flowing water and moved seaward. An important bonefish run that did not use an interisland pass was near Buariki, where the fish migrated across the reef southeast of the village.

We were able to obtain the most information on prespawning aggregations and the response of the I-Kiribati to them for an area in the lagoon near Buariki, called *Te tao*. Traditionally, an elder from Buariki was responsible for directing where and when people could place their nets during the bonefish spawning period. Great care was taken not to disturb prespawning aggregations, and no one was allowed to fish, sail on the lagoon in their vicinity, or make loud noises in the village. The reason given for this great care was that disturbing the fish at this time tended to break them up and scatter them, making fishing for them subsequently much less successful. (As discussed below, bonefish are well known to be exceptionally wary and easily put to flight by extraneous sounds.) Similar village rules prohibiting any activities that might disturb the fish during their prespawning aggregations were said to have been in force in other Tarawa villages. Fishing was allowed to start only after the aggregation began its spawning migration across the sand flats and outer reef flat toward the outer reef slope. When the government declared lagoon resources public property (discussed above), however, the people of Buariki lost the ability to control these activities. As a result, people began fishing on prespawning aggregations before they began to move out.

Between about 4:00 and 10:00 P.M. (the period of the high spring tide), the schools at *Te tao* and at least seven other locations around Tarawa migrated seaward on or near the day of the full moon. At this time, their gonads filled their body cavities. Fishers reported that to avoid sharks, schools of bonefish would hug the outer reef edge as they reached the ocean and move up into shallow water on the outer reef flat when the tide permitted. When the fish returned to the lagoon by the same route, they were invariably spent, according to fishers. For the next few days, schools of bonefish were said to be unusually easy to find in the lagoon because they stirred up clouds of mud to a degree not seen at other times. (Bonefish feed by grubbing in the sediment; perhaps they feed particularly heavily after spawning because their energy reserves have been depleted.)

None of the informants, including divers who frequent the outer reef slope, had ever seen bonefish spawn. Fishers surmised, however, that bonefish throughout Tarawa converged on the seaward side of the reef dropoff at the eastern tip of Tarawa Atoll near Temaiku to spawn. Consistent with this theory is the fact that bonefish leaving the lagoon to spawn at Abatao, near Temaiku, typically returned after only 1 day, whereas fish migrating from the lagoon at more distant locations, such as Betio and Buariki, typically returned after 3 days, according to fishers.

Additional evidence suggests that bonefish mass in this area during their spawning migration. The pass at Temaiku, which was open to the ocean until about 30 years ago when it was closed by local landowners, never had bonefish runs, according to fishers. Nevertheless, the highest concentration of bonefish trap remains (discussed below) on Tarawa are on the ocean reef flat here (Figure 1). Because no bonefish migrated through the adjacent channel, the bonefish that these traps were built to catch must have migrated from elsewhere. Spawning is the only reason bonefish are known to migrate outside the lagoon. Adding further plausibility to fishers' hypothesis concerning where Tarawa bonefish spawn is the fact that spawning aggregations of a wide variety of tropical nearshore fishes are known to occur at outer reef promontories, such as the one near Temaiku (e.g., Randall and Randall 1963; Johannes 1978).

For centuries on Tarawa, bonefish returning from spawning were captured in rock fish traps built specifically for that purpose at strategic spots on the outer reef flats. We were told that it was not uncommon for catches to be so large that people could not harvest all the fish, with as many as 2,000 fish being gathered from a trap in a morning and the trap being full again by evening. One thousand fish in a trap was said to be a typical catch and as few as 400 were caught in "poor months." Some of the excess was salted. During their return from spawning, the fish would sometimes be so abundant and crowded on the reef that many would strand at low tide.

Although fishers throughout the world have a reputation for exaggeration, fishers from all over Tarawa volunteered similar quantitative information. A passage from a report by the Pacific Island ecologist, Dr. Catala (1957, p. 132), lends further credibility to their statements. He describes bonefish fishing on Tarawa in 1951:

> It is indeed exactly at the moment of the full moon that they approach the shore and that a great number of them get caught inside the traps without being incited to escape by the ebbing tide. Unlike mullet caught in this way, they do not jump over the walls; or when they try to do so it is too late. The fishermen are around the trap spearing them. The women carry them to the shore where the sharing is done in the shade of the coconut trees between the owner (of the trap) and the close relations and friends, a portion being left for the people who helped catch or carry the fish . . . The haul will vary in importance each month. We were fortunate enough to attend one of these distributions at the full moon of August. While not a record, the catch was nevertheless one of the best for the year, totalling over two thousand fish for one trap only. Only four hundred had been caught the preceding month (in that one trap presumably - REJ), which was considered a very low figure. The weights we recorded gave a total of 45 pounds for twenty fish, taken at random. The largest weighed 4.5 lbs.

Catala (pp. 122, 129) also refers to "massive concentrations of *te ikari* (*Albula vulpes*) along the shore outside Tarawa Atoll" and "huge concentrations of *Albula*" at Tarawa. Sabatier (1977, p. 121) states that from rock fish traps "you can on occasion pick up as many as two thousand of them (bonefish)."

Because Catala was a trained biologist, we assume that his sample was indeed random and that his estimated mean weight of 2.5 lb (1.02 kg) was reasonably accurate. We can therefore make a rough

estimate of the harvest from these runs. Catala's and fishers' statements both suggest that an average monthly catch per trap was about 1,000 fish weighing 2.5 lb (1.02 kg) each, or a total of about 1 tonne, which amounts to 12 tonnes of fish per year per trap (there are, in fact, 12.3 lunar months in a solar year). The remains of well over 150 bonefish traps are clearly visible today from the air on Tarawa's outer reef flat.

This calculation does not include the bonefish caught by net fishers during the spawning migration. One fisher said that occasionally the migration would start as late as 1 day after the full moon. Although the rock traps were privately owned, as were their catches, bonefish on spawning runs were also easily caught with nets by non-trap-owners, according to fishers.

In the 1850s, Tarawa's population was estimated at about 3,500 (Maude and Doran 1966). If the more than 150 bonefish traps were all in existence and operating simultaneously at this time, their catches alone would have provided about 1.5 kg of whole fish per capita per day, a catch far in excess of their needs. Many of these traps, therefore, were likely built more recently as Tarawa's population boomed.

Conditions have changed greatly in recent decades. Detailed interviews with expert fishers throughout Tarawa revealed that by 1990 only one spawning run of bonefish remained–the one near the village of Buariki–and it was declining fast. In addition, only five bonefish rock traps were still maintained on Tarawa, all of them at Buariki. Even these have now ceased to catch bonefish.

Some bonefish spawning runs began to dwindle in the late 1960s. Some were blocked by causeways (e.g., Tabonibara, Anderson, Stewart, Taborio). More recently, the Betio-Bairiki causeway, completed in 1987, destroyed what is said to have been the largest spawning run in Tarawa, apparently because the fish refused to go through the tiny pass (10 m wide) built into the 3-km-long causeway. There were no suggestions from informants that blocked spawning aggregations sought egress elsewhere.

Fishers say that the runs through the Abatao and Buota passes dwindled and disappeared, apparently as a result of localized overfishing. In the old days, bonefish would arrive at these passes in a few large schools described as "thick as baitfish." Imported gill nets began to be used intensively in and near these passes in the late 1950s to exploit the spawning runs. By the late 1960s, the fishers noticed that the numbers of bonefish moving through these two passes were decreasing. In addition, instead of arriving in a few large schools, the fish began to come in numbers of smaller schools. Eventually the runs began to miss 1 month, then 2 months, and then several months would go by without a run. Finally, about 12 years ago, the runs stopped completely. A decline in the numbers of migrating bonefish, presumed by fishers to be caused by overfishing, was also observed at the Betio-Bairiki pass before this run was eliminated by the causeway in 1987.

Buariki is the furthest village from the district center of South Tarawa. It is in one of the least populated portions of the atoll and is one of the villages least involved in commercial fishing. Perhaps for these reasons its bonefish run was the last to dwindle on Tarawa. Changes in the

bonefish runs were not noted by Buariki fishers until the early 1980s, when the fish began to migrate in many small schools rather than in a few large ones as they once did. This change in behavior is the same as that described independently by other fishers regarding the other Tarawa spawning runs beginning in the

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1960s, before these runs ceased. In addition, the migratory pathway of the Buariki bonefish moved further offshore into deeper water, out of reach of the five rock traps of Buariki. These traps are the last intact bonefish traps remaining in Tarawa and, since about 1990, none of these traps has caught any bonefish.

Since April 1992, the Buariki spawning run–the last known bonefish run on Tarawa–has failed to appear, according to fishers. Small prespawning schools of bonefish have formed occasionally at *Te tao*, but these have been so small and the fishing pressure on them so great that no fish have escaped to complete the spawning run. These developments are of great concern to Buariki villagers who say that bonefish, along with goatfish (discussed below), have always overwhelmingly dominated their catch. They blame the decline mainly on splash gill netting (described below).

Large bonefish were once caught on the lagoon side of Tarawa close to the shore throughout the lunar month. Now, we are told, even small ones are rarely found there. Bonefish can still be caught in significant numbers in deeper lagoon waters, however, and in late 1993 were still frequently available from roadside fish sellers in South Tarawa.

Goatfish (*Upeneus* **sp.**, *te maebo*). Fishers describe this species of goatfish as making spawning migrations from the lagoon onto the reef flat on rising tides and into the ocean as the tide drops. This pattern occurs for 3 days around the new moon throughout the year. *Upeneus* sp. do not migrate through interisland passes, but move around the tips of the southernmost and westernmost islands on the atoll, Betio and Buariki. No one was able to tell us exactly where these fish spawn.

Low rock traps were used on the reef flat near the southern end of Betio specifically to trap this species during its spawning migrations. The traps are rarely used now because the migrations have dwindled to insignificance in recent years according to fishers. Overfishing, including the use of the splash gill netting method is presumed to be the cause. For a few years before the catches diminished noticeably, many net fishers moved into the area during the spawning run, placing their nets between the traps so that the fish had little chance of running the gauntlet.

Rock fish traps built specifically for *Upeneus* sp. are still used by the Buariki people on the reef flat to the west of the area where their bonefish traps are located. About 30 such traps exist and all of them remain in use. They are repaired periodically just before the new moon spawning runs.

The Buariki runs have also declined significantly in recent years, according to fishers. In contrast to the bonefish near Buariki, *Upeneus* sp. now tend to run closer to shore during their migrations than they did in the past. Ten years ago, a good catch would be up to 1,000 fish per night per trap. Now trap owners are lucky, we were told, to get 100 in a night. The size of the *Upeneus* sp. caught in the traps at Buariki has not changed noticeably over the years, according to fishers.

Goatfish (*Mulloidichthys* **sp.**, *te tewe*). According to fishers, *Mulloidichthys* sp. made seaward spawning migrations through several channels in the early morning on a rising tide, often returning the same evening on the following rising tide. On their return, they were described as traveling in

small compact schools consisting of about 100 individuals. The biggest runs were said to be at the Buota and Abatao passes. Both runs occur rarely now and consist of small schools. Informants believe that overfishing with gill nets has caused the depletion. Runs were also destroyed by causeways at Tabonibara and Nuatabu, and, according to fishers interviewed by Johannes in 1979, by the Anderson and Stewart causeways. A minor run reportedly still occurs at Kainaba. Information concerning the moon phases associated with these runs was inconsistent, although "around the full moon" was the most frequent description of their lunar timing.

Large numbers of this species once returned from spawning through at least two channels not used by the species for outward migrations: Tabiteuea and Nuatabu. Until the 1960s, *Mulloidichthys* sp. could be caught in traps and with nets on the ocean reef at Nuatabu (a village near the pass of that name, now blocked by a causeway, at the western end of Buariki Island), during which time they were full of eggs. A few days later, small schools would move from the ocean side through the channel in the evening as the tide rose. These movements continued until high tide each evening for 3 to 5 days.

We were unable to determine the importance of these runs as a source of food for Tarawa. They do not appear to have been as significant as bonefish *Upeneus* sp. spawning runs, but are important enough, nevertheless, to have prompted the building of specially designed rock traps along the migration routes at Nuatabu and Tabonibara, and possibly elsewhere on the atoll.

Silverbiddy or Moharra (*Gerres* spp., *te ninimai*). *Gerres* spp. are said to come into shallower water to form large schools in the lagoon over or around the edges of certain sand banks and islands during the period of the full moon. The island of Bikenamori (meaning "island of the large silverbiddies"), in the lagoon south of Tabonibara in South Tarawa, was often mentioned as the most important of such sites. A fish trap designed specifically to catch this species was said to have been located there once. A legend says that Bikenamori belongs to a ghost called Bukamarawa who materializes as a light. *Te ninimai* are "pets" of this ghost and are attracted by this light. The full moon aggregation at Bikenamori has become irregular now.

At this time the gonads fill the body cavity and the fish were easy to catch with gill nets. The fishers we spoke with throughout Tarawa were unanimous in their assertion that although numbers of these fish are still comparatively high their average size has dropped dramatically and spawning aggregations have virtually disappeared. These fish do not show up significantly in government catch statistics, but appear to form an important element of Tarawa villagers' subsistence catch.

Snappers (Lethrinids and Lutjanids). Despite the fact that the spangled emperor, *Lethrinus nebulosus* (*te morikoi*), is the second most important species in shallow water catches according to Fisheries Division data, we were unable to learn much about this fish from fishers. The same is true of other popular, drop-line-caught lethrinids and lutjanids, including *Luthanus gibbus* (*te ikanibong*) and *Lethrinus ramak* (*te rou*). All three species are said to have well-developed roe around the time of the full moon but are not believed to school up to spawn or leave the lagoon.

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Many lethrinids and lutjanids are reported to migrate to outer passes or reef edges to spawn on lunar cycles in other tropical areas. Fishers do not think they do so in Tarawa. In fact, the fishers we interviewed did not seem to know about these species' specific movements, finding them mainly around rocky or coral outcrops in the lagoon. They said that getting good catches is increasingly difficult, although such catches occur occasionally. The mean sizes of *Lethrinus nebulosus* and *Luthanus gibbus* are dropping noticeably, fishers said, and some of the fishers' favorite fishing spots do not produce anymore.

Mullets (Mullidae). Several species of mullet seem to be fairly important in catches in some parts of Tarawa today, according to fishers. These species were said to constitute the main replacement for depleted bonefish and *Mulloidichthys* sp. runs in areas of North Tarawa (e.g., Abatao) where they are caught in deeper lagoon waters using a recently developed gill netting technique.

Some informants told us that they had seen mullet in spawning aggregations around the time of the full moon off the point near Temaiku, where bonefish are also believed to spawn (discussed above). Fishers interviewed by Johannes in 1979 stated that the mullets *Liza macrolepis (te bauamaran)* and *Valamugil seheli (te bauataba)* migrated from the lagoon to the ocean to spawn around the time of the full moon. According to these fishers, such runs were restricted largely to channels along the eastern reef of Tarawa. Today, all such channels are blocked or nearly blocked by causeways.

One informant said that mullet spawned in the lagoon near Temaiku before extensive dredging and filling disturbed the area. Another said he had sometimes seen large, compact schools of mullet at the surface 6 to 7 mi (10 to 11 km) at sea off Tarawa. Mullet were once seen in abundance during high tides on both the ocean reef near shore and in the lagoon near shore, but they are no longer found in either location in significant numbers, according to fishers.

Leatherskin (*Scomberoides lysan*, *te nari*). In 1979 interviews, fishers said that the leatherskin migrated through the Betio-Bairiki channels to spawn 5 to 7 days after the full moon. Similar migrations reportedly occurred near Buariki.

Sharks (Chondrichthys). Although the I-Kiribati like to eat shark meat, fishers did not provide much information on shark movements or aggregations, and sharks are not a common constituent of fishers' catches. Grimble (1952, p. 134) claimed that "there is a four-fathom bank off Tarawa Lagoon where the tiger shark muster in hundreds for a day or two every month." Their numbers were clearly visible from canoes, he said, and a few of them reached lengths of 18 ft. None of the fishers we interviewed had heard of such a phenomenon, possibly because this shark aggregation was fished out as Tarawa's population grew. Because of their low fecundity, shark populations are especially vulnerable to overfishing. Another possible explanation is that this story is another instance of the fantasies that Grimble interspersed throughout his writings.

Whales and Dolphins. Whales and schools of porpoises once commonly entered Tarawa Lagoon through the boat passage, according to fishers. They often swam right into the Temaiku Bight area to a spot called Whale's Pillow in I-Kiribati. Fishers presumed that they did so because they could

sense the fresh seawater coming into the lagoon and, therefore, thought they could get to the sea by swimming in this direction. This occurrence may account for some younger I-Kiribati's belief that whales entered the lagoon through the pass connecting Temaiku Bight and the ocean. The pass was filled by adjacent landowners several decades ago. Before being filled, however, the pass was never big enough for whales to enter, according to an older informant. Inspection of the area and of aerial photographs from 1944 support this recollection.

Damaging Fishing Methods

Tarawa appears to be free of the two scourges of many tropical reef fisheries, dynamite and chlorine. A technique introduced in the early 1980s is of considerable concern to many fishers, however. Called *te ororo*, it consists of driving fish into gill nets by splashing 2-m crowbars into the water. According to fishers, the sound of these heavy bars penetrating a few inches into the water scares bonefish more effectively than do wooden rods that hit only the surface.

The technique enables fishers to scare fish from deeper water than that in which fish can easily be gill netted and to move the fish into shallower water where the nets are placed. As mentioned above, fishers believe that this method is responsible for important changes in the behavior of bonefish and *Upeneus* sp. Feelings against the method were strong among fishers we interviewed in some parts of North Tarawa. In South Tarawa, even some fishers who used the method told us they thought it should be banned.

Discussion

Customary Marine Tenure

When asked if it was reasonable to conclude that the government's position on CMT was confused, one government official replied "chaotic would be a better word." Teiwaki (1992) has expressed the need for a "remodeled" CMT system, which, he says, "depends on an overall review of some government policies, particularly those related to the disruption of the marine environment or those policies that help to facilitate or accelerate the extinction of the traditional marine tenure system" (see also Teiwaki 1988). We further suggest that such an effort would require a more detailed study of the local traditional systems of fishing rights and how they operated throughout Tarawa than was possible during the present study. Such an effort would also require a detailed examination of the legal dimensions of the subject.

The Kiribati government has long endorsed a policy of decentralization. CMT is the keystone to decentralization of reef and lagoon resource management. I-Kiribati villagers have long demonstrated a desire to manage their fisheries. But today, when pressure on these resources by outsiders is significant and villagers have no authority to exclude them, little incentive or ability to manage resources exists.

The resurrection of CMT, even in a remodelled form, probably would generate or reactivate disputes as to who has what traditional rights within bounded areas and exactly where these traditional boundaries lie. The potential seriousness of such problems should not be underestimated; some kind of government-mediated education process might be desirable to resolve disputes. We believe, however, that these negative effects would be outweighed by the very substantial conservation benefits of reinstating CMT, at least in North Tarawa.

This need not necessarily preclude the use of North Tarawa waters by people from South Tarawa. In many Pacific island countries where CMT operates, outsiders are often given permission by CMT owners to fish for subsistence purposes, and sometimes to fish commercially for a fee.

Reestablishment of CMT in South Tarawa may not be feasible because so many of the residents are from elsewhere and would have no claim to local fishing rights. For this reason CMT-based management is often impractical near district centers. For example, although CMT operates in outlying areas in Fiji, the Solomon Islands, Western Samoa, and Palau, it does not function effectively in the vicinity of the district centers in these countries (Johannes, personal observations). In these areas the responsibility for fisheries management must fall on the government. Government management is somewhat less difficult near the enforcement agency's headquarters because logistics are simpler.

Local Knowledge

As with many Pacific Islanders, the I-Kiribati of Tarawa possess valuable information about the spawning migrations of important food fishes, including changes in their behavior and abundance as apparent consequences of human actions. Important information obtained during the interviews proved to be unknown to fisheries scientists and managers. Our study clearly demonstrates the value of appropriate interviews with selected fishers as a means of obtaining practical information on the prior history of local fisheries where scientifically derived information is sparse. The most valuable information for management purposes was that concerning changes in bonefish behavior and distribution and the cessation of all known bonefish spawning runs.

Causeways have been responsible for the destruction of some spawning runs, and overfishing seems to have played an important role in eliminating other runs. If village authorities had not lost their traditional right to exclude outsiders from their fishing grounds, some would have likely prohibited practices such as splash fishing and blocking passes with nets during spawning runs. As mentioned earlier, fishers said that while splash fishing catches more bonefish in the short run, in the long run it spooks the fish, causing migrating schools to break up, and, in the case of Buariki, caused the fish to shift their migration path to deeper water.

Tests carried out by Tavolga (1974) on a single specimen of *Albula vulpes* revealed unusually acute hearing at low frequencies (between 100 and 300 Hz). He also pointed out that bonefish are notorious among sport fishing guides for taking flight in response to minute noises. In the field,

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Tavolga determined that by hitting an oar lightly against the gunwale of a boat or by dropping a lead sinker into the water, the resulting noise had most energy around or below 300 Hz (i.e., where the bonefish had its greatest sensitivity). The resulting noise level was above the animal's hearing threshold at 10 m from the source. He also noted that bonefish are often more spooked at depths of over 3 m than at 1 m or less. Tarawa fishers appear to take advantage of this by targeting bonefish in deeper lagoon waters using the splash fishing method. Bonefish also produce a "startle type" sound when disturbed (Myrberg 1981) that may function to spread the alarm caused by splash fishing to fish beyond the direct reach of the sound of the splashing.

Observations and measurements made elsewhere thus support Tarawa fishers' contention that splash fishing spooks bonefish. Regarding their contention that the Buariki bonefish have altered their spawning migration pathway, now using deeper water in an apparent response to heavy splash fishing pressure, such behavior would entail learning, both to avoid the noxious stimuli of splash fishing along the old pathway and to adopt, as a group, an alternate migration pathway. The ability of bonefish, like many other fish, to learn to respond negatively to sounds is demonstrated by Tavolga's experiments; his hearing tests on bonefish were based on a type of learning known as conditioned response.

New recruits would learn the new migration path in the same way they probably learned the old migration pathway: from experienced adults. No relevant research has been done on bonefish, but such learning of migration routes by novice fish from experience has been confirmed for another tropical nearshore species, the Caribbean grunt (*Haemulon flavolineatus*) (Helfman and Schultz 1984). In short, what we know about the behavior of fish, including bonefish, is consistent with the fishers' assertion that splash fishing has altered bonefish spawning migration pathways and behavior.

As mentioned earlier, Buariki fishers said that bonefish in their area no longer make spawning migrations, even in deeper waters, because their small and increasingly rare prespawning aggregations are eliminated by fishing before they can migrate. If bonefish can learn to alter their migration pathways, however, the possibility remains that some have developed one or more alternative migration routes in Tarawa that are unknown to fishers. That this could occur in such a heavily fished lagoon seems unlikely, but the possibility cannot be dismissed. It is prudent to assume that such a change has not occurred, however, and that if the Buariki spawning run cannot be reestablished, Tarawa may lose its bonefish within 10 years.

Large bonefish were once readily caught in shallow lagoon waters close to shore, according to fishers, but even small bonefish are uncommon there now. Large bonefish are still caught in sizeable numbers in deeper waters in the lagoon, however (Beets, this volume), which tends to reduce some I-Kiribati's concern over the fate of their bonefish stocks. The observation is not as reassuring as it might appear, however. First, the sex ratio of these fish is extremely biased toward males (Beets, this volume). In addition, if Tarawa bonefish live for up to 12 years as do their Caribbean counterparts (Bruger 1974), some bonefish will be in the lagoon, even in the absence of spawning (barring their complete removal by fishers), for at least 12 years after the last known spawning (i.e.,

until about 2004). We would, however, expect them to become increasingly uncommon before then due to natural and fishing mortality.

Some bonefish larvae may be recruited to Tarawa Lagoon from spawnings at nearby atolls. We cannot assume that such recruitment occurs, however, nor can we assume that if it does occur, it would suffice to maintain adequate stocks. In addition, bonefish spawning runs are said to be seriously threatened on at least some of the nearby atolls, for example at Abemama (Tebano 1991; Tiwau Awira, pers. comm.).

Tarawa's single most important species of lagoon food fish, the bonefish, may suffer local extinction within the next decade unless concerted, immediate action is taken to protect and rebuild the Buariki spawning run. Scientific proof of the seriousness of this situation is lacking, but obtaining such proof would be expensive and time consuming and waiting for such proof is a risk that the I-Kiribati cannot afford.

The total protection of all prespawning aggregations of bonefish that form near Buariki is critical. Banning splash fishing seems desirable, despite the absence of proof that it is as harmful as Tarawa fishers believe it to be. In addition to the possible benefits of such an action (discussed above), the banning of this method would result in the de facto creation of a reserve in the deeper waters of the lagoon, where bonefish would be out of the reach of net fishers. Such a ban could also, as suggested by fishers, help rebuild spawning runs of *Upeneus* sp. and perhaps other species. The reopening of causeways would not guarantee the restoration of spawning runs; no relevant research in the tropics exists to help in making useful predictions on this subject.

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A Survey of Tarawa Residents and Their Perceptions of Tarawa Lagoon

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A Survey of Tarawa Residents and Their Perceptions of Tarawa Lagoon

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Abstract

A public opinion survey was conducted to obtain the opinions and determine the expectations of residents in South and North Tarawa regarding present and past conditions in the lagoon. Residents were interviewed in their homes in the Kiribati language regarding the values that they place on the lagoon, the lagoon's most common uses, the types of gear used in the lagoon, the characteristics of the finfish and shellfish caught, the problems they perceive regarding the lagoon, and the ways in which they or the government might aid in remedying these problems.

A stratified survey sample was designed to ensure random, individual participation and resulted in a survey sample that included all villages of Tarawa, traditional leaders (*unimwane*) from each village, people who live on the shore of the lagoon, and people who live away from the shore. A total sample size of 132 households (4% of the total population) was surveyed in South Tarawa, and 37 households (6% of the total population) were surveyed in North Tarawa.

The survey results indicate that the residents have a low level of understanding regarding the lagoon's depleted condition and are even less familiar with the human impact on the lagoon. Also, little is known about past and present governmental efforts to manage the lagoon, and almost no one is aware that local or national government has the authority to adopt regulations regarding the use of the lagoon. Those who are familiar with individual governmental fisheries projects believe, in general, that such projects have been unsuccessful. Tarawa Lagoon's current management seems to be the result of thousands of individual decisions made on a daily basis, unguided by an overall vision for the lagoon. People seem to make these decisions with little awareness of the lagoon's condition or of efforts to improve it.

Most of the people interviewed believed that the causeways between islands have affected the fishery, but they do not seem to know in what ways. Even so, the majority of residents in both South and North Tarawa support the construction of more causeways.

The results indicate that technologies designed to catch more fish and smaller fish, with more speed and less effort than historical methods, have been widely adopted. Respondents believed that people should reduce their take from the lagoon, but were generally unwilling to do so themselves. This

viewpoint may reflect the "free rider" syndrome, a fear that if one were to reduce his or her catch, others would take that catch instead. The majority of respondents in South and North Tarawa do not support new governmental regulations or fees to manage the lagoon.

The majority of respondents, however, indicated that they were willing to assist, on an individual or community basis, with projects intended to improve the conditions in the lagoon. The respondents also indicated a high level of support for and willingness to assist in public education, awareness, and training projects.

Introduction

This report presents the results of a survey conducted on Tarawa Atoll in 1992-1993. The purpose of the household survey was to obtain socioeconomic and attitudinal information from the residents that would be useful in connection with the preparation of the Tarawa Lagoon Management Plan.

South and North Tarawa consist of several small villages spread out over the atoll. Each village has its own council, composed of elderly men (*unimwane*). South Tarawa, constituting about one-third of the populated islands, has 17 villages. North Tarawa has 14 villages.

Population changes and new technologies affect the amount of pressure put on the lagoon and the rate at which the lagoon's characteristics change. With the introduction of today's technologies, a few people can cause a large change in the lagoon, and an increased population can bring about large changes rapidly. For example, the causeways have linked most of the village populations of South Tarawa to the population center on Betio. The causeways may have had an adverse effect, however, on water circulation patterns in the lagoon and may have had a major adverse effect on the lagoon fishery.

Thus, the numbers of people, and the attitudes of these people, are important to lagoon management for three principal reasons:

(1) An increased population is likely to put increased harvest pressure on the finfish and shellfish resources. If the population adopts technologies that increase the extraction rate of resources from the lagoon, both per capita and total population pressure on the lagoon can be expected to increase.

(2) Lagoon habitat is affected by the following: a) increased disposal of human waste and garbage into the lagoon, b) modification of the shoreline because of dredging, filling, and sand mining activities, and c) construction of causeways, which link the islands and act as new land masses between the islands.

(3) New residents on Tarawa (including immigrants and the younger generations) may have different attitudes from those of long-time residents regarding the lagoon,

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traditional fishing rights and lagoon uses, and the use of technology to harvest marine resources.

Opinion surveys are a commonly accepted means of obtaining critical information for the development of a management plan and process. When planners combine survey results with observations of behavior, they can acquire a good sense of the stakeholders' preferences. The Fisheries Division of the Ministry of Environment and Natural Resources Development has conducted numerous surveys of the opinions of the public and fishers over the years (e.g., Tearo 1993).

Methods of the Public Opinion Survey

The public opinion survey (Appendix A) was designed to obtain information from residents regarding their activities affecting Tarawa Lagoon; their opinions on changes in activities associated with the lagoon and conditions in the lagoon; present and future problems or issues involving the lagoon; and their willingness to assist with future management efforts through self-regulation, volunteer activities, or financial support.

A stratified sampling technique was designed to ensure that the selection of individual families and households to be surveyed was random, that every village in South and North Tarawa was surveyed, and that at least one traditional leader was interviewed from each village. Also, in each village an attempt was made to survey one household each from the lagoon shoreline, away from the lagoon shoreline, and from the ocean shoreline. This sampling method resulted in a sample size of 132 households in South Tarawa (4% of the total population) and 37 households in North Tarawa (6% of the total population).

The survey was conducted by three enumerators, all of whom live on Tarawa, from April 1992 to March 1993. The enumerators were trained in the purpose and structure of the survey instrument. Each question was reviewed in detail in English to determine its meaning in Kiribati. Specific wording was refined to improve the questions' clarity for the enumerators and to ensure that respondents would understand the questions.

The survey was pretested in April 1992. The enumerators conducted interviews, which were tape recorded, as a group. The written responses and the tape recordings were then reviewed (with the enumerators' translations). The questionnaire was then further refined.

Topographic maps showing structures were used to aid in effectively selecting houses and to maintain a record of the houses surveyed. The surveyors began in the villages of Betio in South Tarawa and worked north until all the villages of South and North Tarawa had been surveyed.

All surveys were conducted in the Kiribati language. At the beginning of each survey, the respondent was provided with a detailed, standardized explanation of the purpose of the survey. Each respondent

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was also assured that his or her responses would be kept confidential. Surveys were tape recorded to assist with subsequent translation by someone other than the enumerator who conducted the interview to avoid subsequent reinterpretation of the results. Each tape was erased after it was translated to protect the confidentiality of the respondent. The senior enumerator interviewed the traditional leader in each village to avoid conflict regarding social rank and to provide a consistent approach among the enumerators.

Appendix B contains the survey enumerator field checklist. The survey sample design and size is shown in Appendix C. Appendices D and E contain samples of the survey record systems.

Results and Discussion

Characteristics of the Respondents

The survey results for households in South and North Tarawa were analyzed separately for comparison. Most of the respondents were men (94% in South Tarawa and 97% in North Tarawa), although other family members were present for most of the surveys (79%). Traditional community leaders provided 27% of the responses in South Tarawa and 35% in North Tarawa.

Respondents in South Tarawa had been living there for an average of 21 years (N = 129). In North Tarawa the average tenure was 32 years. Respondents had also been fishing and collecting shellfish for many years, usually since childhood (mean 16 years on South Tarawa and 25 years on North Tarawa).

Respondents in South Tarawa had been collecting shellfish for an average of 11.6 years. In North Tarawa, respondents had been collecting shellfish for an average of 18.1 years.

The average number of people living in each household surveyed was "more than 4" in South and North Tarawa, and most respondents lived less than 100 m from the lagoon.

In South Tarawa, 62% of the respondents believed that the causeways affect the movement of the fish (N = 122); yet only 14% believed that the causeways affect their family (N = 121). Sixty-one percent reported that they support the building of more causeways. In North Tarawa, more than 80% of the respondents believed that the causeways affect the movement of the fish (N = 36); yet only 30% felt that the causeways affect their family (N = 36). Forty-eight percent supported the building of more causeways (N = 37).

South and North Tarawa respondents did seem to think that boating on the lagoon is changing. They reported that more motor-driven boats and fewer canoes were being used than were 3 years ago.

Health-Related Matters Pertaining to the Lagoon

Some members of the public and government officials have suggested that the residents of Tarawa may be exposed to health risks associated with their practice of using the lagoon as a toilet. This risk may be particularly relevant in areas where shellfish are gathered for eating. Several questions in the survey were intended to collect information related to such a possibility.

In South Tarawa, 66% of the respondents reported they had some kind of toilet (i.e., indoor toilet, outdoor privy) (N = 131). This figure suggests that 34% still use the lagoon or the ocean for their toilet. These results are fairly consistent with the 1990 census (Introduction to the Study, this volume). In North Tarawa, only 24% reported having a toilet.

Approximately 92% of the respondents in South Tarawa reported that their family had diarrhea problems (N = 131). The families seemed to experience these problems with a frequency of about once per week. Only 27% of the respondents, however, indicated they had ever heard of anyone getting sick from eating shellfish. In North Tarawa, 83% of the respondents' families experienced diarrhea problems (N = 36). The frequency appeared to be about every 1-2 weeks. Only 5% reported ever hearing of anyone getting sick from eating shellfish.

Diarrhea and related health issues seem to be a common part of life on Tarawa. If the problems are associated with eating shellfish, the people do not realize it. If an association exists, people apparently find diarrhea so common that they do not associate it with sickness.

Respondents were also asked if they boiled their shellfish before eating them. Although eating shellfish while they are being gathered is common, most people reported that sometimes they eat the shellfish raw and sometimes they boil them. None of the people surveyed always eat shellfish raw. In South Tarawa, 56% reported that sometimes they boil their shellfish, and sometimes they eat them raw. About 44% reported they always boil shellfish (N = 113). In North Tarawa, people sometimes boil their shellfish and sometimes eat them raw. The length of boiling time reported varied widely, from 5 min to 45 min (N = 34).

Respondents in South Tarawa seemed to think that the lagoon is getting dirtier. The average response to the question "Do you think the lagoon is dirtier today than it was 3 years ago" was .75, where 0 is "no not dirtier" and 1 is "some dirtier" (N = 130). Yet, in North Tarawa only two respondents thought the lagoon is "some dirtier" today than it was 3 years ago; the rest of the respondents either did not believe that the lagoon is dirtier or did not know (N = 37).

Respondents' Use of and Value Associated with Tarawa Lagoon

Not surprisingly, the lagoon is important to residents. On a scale of 1 to 10 (10 being the highest value), the average rating of the lagoon by South Tarawa respondents was 8.6 (N = 126). The average ratings for North Tarawa respondents was 9.2 (N = 37).

All respondents cited fishing, gathering, and bathing as the three most common uses of the lagoon. When these three uses were analyzed together, fishing was one of the three most common uses for 87% and 97%, respectively, of the South and North Tarawa respondents. Gathering was one of the three most common uses for 90% and 95%, respectively, of the South and North Tarawa respondents. Bathing was one of the three most common uses for 61% of the South Tarawa respondents and 59% of the North Tarawa respondents. In contrast, toileting was cited as one of the three most common uses of the lagoon by only 6% of the South Tarawa respondents, even though 34% had no toilets.

Finfishing and Shellfishing in Tarawa Lagoon

Finfish

Fishers reported average catches of 16-20 fish per fishing trip. Respondents in South Tarawa reported that they must travel farther and spend more time to catch fish than 3 years ago (50 min longer on average) and that the catches are shifting away from the preferred species. North Tarawa respondents reported catching fewer fish today than 3 years ago, and about 85% reported that it took longer to catch fewer fish. The North Tarawa fishers did not think they had to travel farther than they did 3 years ago, but they reported that the type of fish they caught was changing.

Shellfish

About 57% of the South Tarawa respondents reported that they had to travel farther to collect the same number of shellfish they caught 3 years ago, and 81% indicated that shellfish are smaller than they were 3 years ago. Only 37% of the North Tarawa respondents reported they spent more time collecting the same number of shellfish than they spent 3 years ago, and 30% said the shellfish were smaller.

In South Tarawa, about one-half of the respondents indicated they collect shellfish from the shore; the other half collected shellfish by diving. In North Tarawa, 97% said that they collect shellfish from the shore.

Fishing Techniques

Gill netting is the most common fishing method. A total of 151 gill nets were reported by the 92 people who said they use gill nets in South Tarawa. In North Tarawa, 39 gill nets were used by 33 of the respondents. Many households, therefore, had more than one gill net (the average in South

Tarawa was 1.4 gill nets per household, and the average in North Tarawa was 1.2 gill nets per household). The mesh sizes and average lengths reported are summarized in Table 1.

Table 1 Type, size, and quantity of gill nets owned by survey respondents in South and North Tarawa.

		South Tarawa		North Tarawa	
Net Mesh Size	Target Fish	Quantity Reported	Average Length (fathoms)	Quantity Reported	Average Length (fathoms)
1. ½ in.	half beak (*te kabubu*)	4 (2.6%)	65	1 (3%)	25
2. 1 in.	silverbiddy (*te ninimai*)	41 (27.2%)	37	13 (34%)	37
3. 2 in.	goatfish (*te maebo*)	31 (20.5%)	73	16 (41%)	82
4. 2½ in.	bonefish (*te ikari*)	39 (25.8%)	113	7 (17%)	69
5. N.A.	spangled emperor (*morikoi*)	17 (11.3%)	120	0	
6. 3 in.	mullet (*auataba*)	12 (8.0%)	68	2 (5%)	55
7. N.A.	trevally (*urua*)	1 (<1.0%)	90	0	
8. N.A.	other	6 (4.0%)	N.A.	0	

In South Tarawa, the *te ororo* method of smacking the water with rods to scare fish into gill nets is the second most common fishing method (used by 79% of the respondents); it is less common in North Tarawa (30%). In South Tarawa, fishing with fishlines was the third most common method used. In North Tarawa, fishing with lines was reported by 56% of the respondents. Only 104 people reported using one or more methods other than gill nets (but including fishlines) for fishing.

Use of rock traps to catch fish was reported by 21% of South Tarawa respondents (N = 129) and 43% of North Tarawa respondents. Table 2 summarizes fishing methods reported in South and North Tarawa. Only 14% of the respondents in South Tarawa reported that they refrigerate their fish (N = 126), and 51% reported that they refrigerate their shellfish (N = 101). None of the respondents in North Tarawa refrigerate or put their fish on ice (N = 36), and none refrigerate their shellfish (N = 35).

Table 2 Fishing methods reported used by survey respondents in South and North Tarawa.

	South Tarawa (N = 104)		North Tarawa (N = 34)	
Method	Number Reported	Percentage Using Method	Number Reported	Percentage Using Method
te ororo gill net	82	79.0	9	26.5
fishlines	79	76.0	19	56.0
spears	16	15.4	3	8.8
use bait	71	68.0	12	35.3

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fish from a boat	64	61.5	10	29.4
fish from shoreline	40	39.0	15	59.0
traps	—	—	7	20.5

Catch Characteristics

People believe that they are catching fewer fish than they used to. The survey revealed that the types of fish caught by North Tarawa fishers are similar to the types caught in South Tarawa (Table 3). Bonefish, goatfish (*te maebo*), silverbiddy, and paddletail snapper are the most commonly caught fish.

Table 3 Comparison of the number of fish reported caught per trip today and 3 years ago by survey respondents in South and North Tarawa.

	South Tarawa			North Tarawa		
Type of Fish	3 Years Ago	Today	Percentage Change	3 Years Ago	Today	Percentage Change
bonefish (*te ikari*)	45	17	-62	11	0	-100
goatfish (*te maebo*)	18	3	-83	2	0	-100
goatfish (*te tewe*)	6	1	-83	1	0	-100
silverbiddy (*te ninimai*)	15	12	-20	2	3	+50
mullet (*auataba*)	27	4	-85	4	3	-25
spangled emperor (*morikoi*)	18	8	-56	0	0	0
paddletail snapper (*te ikanibong*)	5	11	120	0	1	+100
other	44	48	9	15	8	-47

About 36% of the South Tarawa respondents indicated that they catch "somewhat" fewer fish today than they did 3 years ago, and 58% of the respondents believed that they catch "a lot" fewer fish than they did 3 years ago (N = 96). Only 6% of the respondents thought they caught the same or more fish 3 years ago.

The number of South Tarawa fishers reporting a catch of fish types 1 through 6 (Table 3) decreased in the last 3 years and the number catching paddletail snapper, trevally, and "other" fish increased. The reported frequency of catch of bonefish, the fishers' favorite catch, has decreased the most in the last 3 years (Table 4). The next most popular fish, paddletail snapper, seems to be the only popular fish for which fishers report an increase in catch.

North Tarawa fishers report catching fewer bonefish and goatfish than they did 3 years ago but more silverbiddy and paddletail snapper. All the North Tarawa respondents reported catching fewer fish

than they did 3 years ago; 91% reported catching "a lot less" than 3 years ago (N = 32). About 85% also reported that it took longer to catch fewer fish (N = 35).

Table 4 Favorite fish in order of preference as reported by survey respondents in South and North Tarawa.

Type of Fish	South Tarawa			North Tarawa		
	Most Favored	Second Favorite	Third Favorite	Most Favored	Second Favorite	Third Favorite
bonefish (*te ikari*)	39	18	1	11	3	0
goatfish (*te maebo*)	2	5	2	1	3	1
goatfish (*te tewe*)	0	0	1	0	0	2
silverbiddy (*te ninimai*)	1	9	5	4	1	2
mullet (*auataba*)	2	5	6	2	4	0
spangled emperor (*morikoi*)	6	6	5	0	0	0
paddletail snapper (*te ikanibong*)	11	7	4	1	3	2
other	38	33	52	13	3	3

Table 5 summarizes the distribution of fish types and sizes reported to be caught by South Tarawa respondents. A size scale of 1 to 5 was used, where 5 is the biggest and 1 is the smallest (using local size indicators, 5 is about the length of a typical man's arm and 1 is the length of a finger). In South Tarawa, fishers reported catching paddletail snapper in all sizes. In North Tarawa, paddletail snapper is not only less popular, but it is also reported to be caught only as small fish. Instead, the silverbiddy is reported to be more popular and is caught in most sizes. Whether preference for certain types of fish is affected by the mesh size of gill nets used is unclear.

Table 5 Comparison of types and sizes of fish typically caught today by survey respondents in South and North Tarawa.[1]

Type of Fish	Size in South Tarawa					Size in North Tarawa				
	1	2	3	4	5	1	2	3	4	5
bonefish (*te ikari*)	0	6	17	20	1	0	2	9	7	0
goatfish (*te maebo*)	2	7	5	0	0	0	8	6	0	0
goatfish (*te tewe*)	0	2	2	1	0	0	1	1	0	0
silverbiddy (*te ninimai*)	16	5	5	0	0	5	3	2	1	0
mullet (*auataba*)	0	4	7	1	1	2	6	4	0	0
spangled emperor (*morikoi*)	0	1	9	9	5	0	0	1	1	0
paddletail snapper	10	3	10	10	0	4	0	0	3	0

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(*te ikanibong*) other	18	17	10	3	7	4	0	2	6	0

[1]The numbers 1 through 5 are a size scale where 5 is the biggest and 1 the smallest; 5 being the length of a man's arm, 1 the size of a finger.

Seventy-two percent of South Tarawa respondents eat what they catch. Twenty-seven percent indicated that they sell their fish, and the remainder of respondents give fish to family or friends. The respondents who sell their fish sell them to "anyone."

Ninety-two percent of the South Tarawa respondents also buy fish for their families (N = 121). They reported that they have been buying fish for an average of 12.4 years (N = 107), and indicated that they buy fish about twice each week (N = 125). The respondents reported that they usually buy their fish from the market (some of the respondents reported that the market is the only legal place to buy and sell fish). About 85% of the respondents indicated that they buy fish from stores or the market. They buy few fish from family or friends.

People give away or sell some of their fish catch. Respondents indicated that, of their total catch, they typically eat about 51%. Of the remainder, about 6% are given away, and they sell about 43% (Table 6).

Table 6 Buyers of fish from South Tarawa respondents.

Buyer	Most Often Buying	Next Most Often	Third Most Often
Extended family	4	1	0
Friends	3	0	1
Restaurants	1	1	1
Stores/market	31	6	0
Anyone else	24	14	3

Shellfish Gathering

A total of 108 South Tarawa respondents (82%) and 34 North Tarawa respondents (90%) indicated that they gather shellfish in the lagoon and have done so for an average of 12 years (South Tarawa) and 18 years (North Tarawa). South Tarawa respondents seemed to be equally divided between collecting on the shoreline and collecting by shallow-water free diving (N = 108). Only one respondent from North Tarawa reported collecting shellfish by diving.

Today, shellfish gathering takes longer and smaller shellfish are collected than 3 years ago. Approximately 57% of the South Tarawa respondents and 37% of the North Tarawa respondents indicated that they have to travel further today to collect shellfish than they did 3 years ago. By a large margin (81%), the South Tarawa respondents believed that the shellfish they gathered today

are smaller than they were 3 years ago. About 17% thought that they were about the same size, and only 2% thought that they were larger. More than 60% of the North Tarawa respondents indicated that the sizes of shellfish collected are the same size as 3 years ago, and about 30% said that they are smaller.

Approximately 87% of all respondents indicated that their families gather shellfish. The responses suggest that the entire family participates in gathering, not just the women and children. In fact, about 25% of the male respondents indicated that they were the principal gatherer.

Table 7 summarizes the types and quantities of shellfish reported taken by the respondents. *Te bun* (*Anadara* sp.) and *te nouo* (*Strombus luhuanus*) are taken in large quantities, by the basinful and sackful in both South and North Tarawa. *Te koikoi* (*Asaphis violascens*) is reportedly a popular shellfish, but the quantities taken seem to be relatively small.

Table 7 Types and quantities of shellfish typically gathered by survey respondents in South and North Tarawa.

	South Tarawa				North Tarawa			
Type of Shellfish	One Basinful	¼ Rice Sack	One Sack	Two Sacks	One Basinful	¼ Rice Sack	One Sack	Two Sacks
1- *te bun* (*Anadara* sp.)	2	16	30	12	3	10	19	1
2- *te koikoi* (*Asaphis violascens*)	11	3	1	0	10	1	1	0
3- *te koumara* (*Gafrarium pectinatum*)	5	4	5	0	6	0	0	0
4- *te nouo* (*Strombus luhuanus*)	1	11	68	11	2	3	13	4
5- *te katura* (*Atactodea striata*)	4	0	1	0	0	0	0	0
6- *te ibo* (*?Sipunculus indicus*)	5	0	0	0	1	0	0	0

Rule Making and Management of the Lagoon

Awareness of government lagoon management efforts and activities is minimal in both South and North Tarawa (Table 8). In South Tarawa, the average response to questions regarding awareness of government programs and their possible successes and failures was close to zero. In North Tarawa, only four of the respondents indicated having knowledge of government programs.

Table 8 Summary or Responses to Question 45, "Do You Know of Any Government Programs That Have Been Able to Improve the Fishing in the Lagoon?"

Responses	South Tarawa	North Tarawa
Tried and succeeded	1	1
Tried and failed	5	3
Don't know of any	119	32

When asked questions regarding who makes the rules that govern the use of the lagoon, only 15% of the South Tarawa respondents indicated awareness that the government could make rules regarding the lagoon (Table 9). Eight percent thought that the island councils made rules regarding the lagoon, and 5% thought that the village leaders had a role in making rules for use of the lagoon. All 15% of those who indicated awareness of a governmental role also listed fishing as one of their top three uses of the lagoon. Forty-seven percent of the North Tarawa respondents were unaware of rule-making authority. Only 3% were aware of government rules, 17% thought that village councils made rules, and 33% thought village leaders established rules (N = 36).

Table 9 Summary of responses to Question 6, "Who Makes the Rules Governing the Lagoon?"

	Number of Respondents			
	South Tarawa		North Tarawa	
	Yes	No	Yes	No
Does the government make rules governing the lagoon?	19	106	1	35
Does the island council make rules governing the lagoon?	10	115	6	30
Do the village leaders make rules governing the lagoon?	7	118	12	24

Over the years, the government has actually undertaken a wide range of programs and projects intended either to assist the fishers in the lagoon or to improve the fishery. Several possible reasons could explain the lack of public familiarity with these programs:

- The government may not be doing enough to disseminate information about its policies, programs, and activities to the public.
- Individuals and their families may see government activities as not part of their own family and, therefore, as activities outside their interests (Introduction to the Study, this volume).
- People may not relate to government projects unless they are personally involved or are personally the beneficiary of the project (Introduction to the Study, this volume).

Most residents were willing to help maintain or improve the lagoon through a wide range of voluntary programs and assistance with enforcing rules, but they were not as willing to pay for government programs or reduce their own harvests from the lagoon (Table 10).

Paying for government programs and limiting one's own take from the lagoon were the least popular actions. Fewer than 50% of those interviewed in South Tarawa were willing to pay for programs or reduce their take from the lagoon (N = 131). Only one respondent in North Tarawa was willing to pay for government projects (3%). All other actions were given a majority of support in South Tarawa. North Tarawa respondents were less willing to help with programs, and only 30% were willing to limit their own take of fish or shellfish voluntarily. These North Tarawa views probably reflect a combination of a) a higher level of dependence on the lagoon, b) a predisposition to rely on the family or the *maneaba* to solve problems, and c) a lack of confidence that spending money on government projects would produce results to directly benefit the family or the *maneaba*. All other actions were given a majority of support. Respondents indicated that they were most willing to assist with educational programs and help with enforcement of rules.

Management Implications of the Survey Results

Tarawa Lagoon is a highly valued resource for the residents of Tarawa Atoll, who view the lagoon as a significant source of food. Those interviewed revealed that they use the lagoon extensively and intensively. The entire lagoon appears to be utilized, and large numbers of many species of fish and shellfish are taken. Responses to the survey questions that were intended to elicit information on the aesthetic or recreational value of the lagoon revealed that respondents do not place much value on these qualities when compared to the importance placed on the three primary uses of the lagoon: fishing, gathering shellfish, and toileting or bathing.

The respondents indicated some awareness of the lagoon's declining output, because respondents reported having to work harder to catch fewer and smaller fish. The survey, however, revealed the respondents' general lack of understanding regarding the effects of human activities on the resource. People seemed to believe that they were only having bad luck or needed better equipment (e.g., a motor boat) so that they could reach the fish. Even as the level of effort required to catch ever smaller fish increases, fishers may feel that they have few options other than to continue to fish in the lagoon. In this sense, fishers may perceive that they can do little to change their practices, even when faced with the potential loss of fish species if they continue to fish as they now do.

Because the fish that are caught are smaller, they are not living long, sometimes not long enough to reproduce. For example, the sizes of bonefish that people are reportedly catching are smaller than the species' reproductive size (Beets, this volume). The fishery is therefore declining because people are catching fish that need to, but do no have the opportunity to, reproduce.

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Tarawa Lagoon seems to be plagued with what economists call a classic common property resource problem. Although the Ministry of Environment and Natural Resources Development is legally responsible for the natural recovery of the lagoon, no "ownership" of the resource exists. The institutional responsibility for management of the resource is split between the government and ambiguous traditional systems and rights, with no enforcement by either group. Each user of the lagoon's resources perceives his or her actions as having little effect and, therefore, does not perceive a need to take responsibility for the condition of the lagoon.

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Table 10 Willingness of survey respondents in South and North Tarawa to assist with lagoon management.

	South Tarawa		North Tarawa	
Activity	**Respondents Willing**	**Percentage Willing**	**Respondents Willing**	**Percentage Willing**
Volunteer time	74	56.5	11	29.7
Pay for government projects	64	48.9	1	2.7
Help provide rules for allocating marine resources fairly	86	65.6	30	81.0
Help enforce rules	98	74.8	31	83.7
Limit your own take of fish or shellfish	59	45	11	29.7
Write/perform songs, dance, and/or stories to educate people	116	88.5	9	24.3
Help with public education campaign	115	87.8	19	51.4
Other	52	39.7	2	51.4
Not willing to help			3	8.1

Fishing techniques, equipment, and familiarity of the ocean fishery seem to be limited. Access to the ocean also is limited, and lagoon fishers often articulated a perceived need to develop the access to and knowledge about the ocean fishery. At the same time, the high population pressures, new technologies, and ambiguous authority to manage the use of the lagoon seem to create an attitude of "If I don't take all I can get from the lagoon, someone else will." A successful management plan will have to address all these conditions simultaneously.

Because of the slow movement of information between families and an attachment to traditional ways, Tarawa residents maintain the perspective that the lagoon is the same as it has always been. A lack of historical perspective about the lagoon's condition may have blurred the distinction between past conditions and the present condition in the lagoon.

The Tarawa Lagoon Public Participation Program

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Introduction

The design for the Tarawa Lagoon Management project included a general provision that the public be included in the lagoon management planning process. Once the project was underway, it because clear that a major effort would be needed to inform the government and the public about the scientific findings if the plan was to succeed in improving the lives of the people of Tarawa. All those involved in the project wanted their efforts to result in more than just a pretty document sitting on a shelf. Community leaders challenged us to do more than most consultants and to avoid the pitfall of the foreign expert that brings inappropriate ideas and then leaves (Ronoiti Tewika, personal communication). The introduction of dwarf coconut palms and giant European pigs lingers as evidence of useless consultants (van Trees, Atoll Politics, 1993).

As a result of these considerations, the public participation component of the project was begun in late 1993 with the objective of including as many people as possible in the creative process of making a socially-, culturally- and economically-appropriate management plan. Activities focused on encouraging communication between researchers, the government and the public on essential aspects of the research findings. This information was key to determining how the lagoon could be managed to increase production while preserving aesthetic and health-related values.

Methods and Materials

The core of the public participation program was public meetings, one held in October 1993 and the other in July 1994. The remaining elements of the public participation included:

1. Two video documentaries

   1.1 "The Bonefish Commentaries" - in Kiribati and English

   1.2 "My Lagoon, My Life: The Making of a Lagoon Management Plan" - in English

2. A set of 10 bilingual 2- by 4-foot color posters

3. Four issues of a bilingual, four page newsletter, "Voice of My Lagoon"

4. An image contest in which the public was invited to submit drawings symbolizing the lagoon improvement program

5. An economic incentive program

Public Participation Meetings

Both public meetings were held a day or two after presentations to the government, and many of the same government officials attended both sets of meetings. The public meetings were held in a traditional *maneaba* on the campus of the University of the South Pacific near the research laboratory. Each set of public meetings lasted two days. For each meeting, the morning of the first day was devoted to presentations by the consultants. Each scientist spoke for about 15 minutes and highlighted important information with slides and overheads. The afternoon of the first day and the second day were open to public discussions. Participants broke into small working groups each day so that all could have a chance to speak and have their opinions heard. A working group leader consolidated the comments from each session and reported back to the panel of scientist and government officials.

Most of the participants of the first meeting were community leaders such as representative of the Red Cross and churches. The second meeting included more representatives from the commercial fishing community. Approximately half of the invited participants at each meeting were from North Tarawa.

Each participant was paid a small travel allowance at the end of the second day. BioSystems provided refreshments and a traditional lunch. The meetings were open and good natured with frank discussions and calls for action.

Video Documentaries

Two 30-minute documentaries in PAL and NTSC video format were produced. The first documentary, "The Bonefish Commentaries," was released in May of 1994 in English and Kiribati versions. The documentary was created from 13 hours of taped discussions with I-Kiribati citizens from North and South Tarawa about many lagoon-related topics. The bonefish problem is examined through local knowledge, and management alternatives are discussed that could be used to improve the bonefish situation from the perspective of the local people.

The second video documentary, "My Lagoon, My Life," focuses on the development of the management plan and the findings of the research team. Whereas only I-Kiribati citizens appear in the first video, the scientist themselves present their findings in the second video.

Newsletter

The four issues of the bilingual newsletter "The Voice of My Lagoon" were designed to disseminate information about the two public participation meetings. The first newsletter was issued soon after the first public participation program; the second one summarized research findings; the third reviewed topics that would be discussed in the second public participation meeting with an emphasis on bonefish; and the fourth newsletter discussed the outcome of the second public participation meeting. Approximately 70 copies of each newsletter were distributed.

Posters

Ten 2- by 4-foot, bilingual, color posters were developed for the public participation meetings. Mr. Being Yeeting also presented the posters during a short course on coastal management in the Philippines to show what was being done in Tarawa.

Image Contest

A contest was held in late 1993 to select an image to represent issues relating to lagoon management. The intent of the contest was to involve high school students in the public participation process. Notices were posted in schools requesting pictures and slogans and the students with the three best pictures and slogans were given cash prizes.

Economic Incentive Interviews

Dr. Guy Phillips conducted interviews in Tarawa to study the economic driving forces at the *maneaba* and village level. Those interviewed included experts at the Development Bank, the chief economist with the Ministry for Environmental and Natural Resources, and individuals at the public meetings. The objective of the study was to determine what would be needed to induce fishermen to change their behavior in a way that would protect lagoon resources.

Results

Institutional

The results of the first public participation meetings were presented to the minister as the "Report to the Minister," in November 1993. In January 1994, the minister formed a Lagoon Management Committee, consisting of representatives from the Environmental Unit and Fisheries Division. The

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committee discussed ways to protect lagoon resources and to involve other government agencies. The committee was expanded in March 1994 to included other government ministries.

During the second public meetings in July, 1994, it was proposed that a group be created called, "*Bonnano N Tararua*," which translates roughly to "Cooperative Management." The participants of the meeting went back to their communities and nominated village representatives. The *Bonnano N Tarawa* has taken on the form of village-based fishermen organizations. The government is now in the process of preparing a constitution to govern the activities of this organizations.

Information

Although it is difficult to precisely assess the success of the public information programs, we feel we were effective in informing the public about the results of the scientific studies and natural resource issues. The newsletters were widely distributed and read and the videos have been seen by many members of government and the public.

Economics Incentives Programs

The economic incentive analysis led to one of the four cornerstones of the Tarawa Lagoon management plan - jobs and loans. Early in the project it became clear that to reduce pressure on lagoon species, income-generating options must be provided for the commercial fishers. The economic incentive analysis also clarified the role of the development bank in lending money for fishing gear that depletes bonefish resources. The results of the economic incentive analysis are reviewed in Volume III of the management plan.

Discussion

The public participation program achieved the objective of including the lagoon-using community in the management development process. The recent initiatives taken by the government can be seen as the logical consequence of the expressed public interest in alternatives such as cooperative management.

The residents of Tarawa perceive the videos as unique contributions to their understanding of the cultural context of the bonefish situation. "The Bonefish Commentaries" has taken on special significance since the recent death of one of the elderly fishermen that participated in the project.

This public participation effort is unique in many respects; we are unaware of any similar programs in the Pacific Islands. Consequently, we recommend that the public be surveyed in one or two years to evaluate the impact of the program and recommend improvements.

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