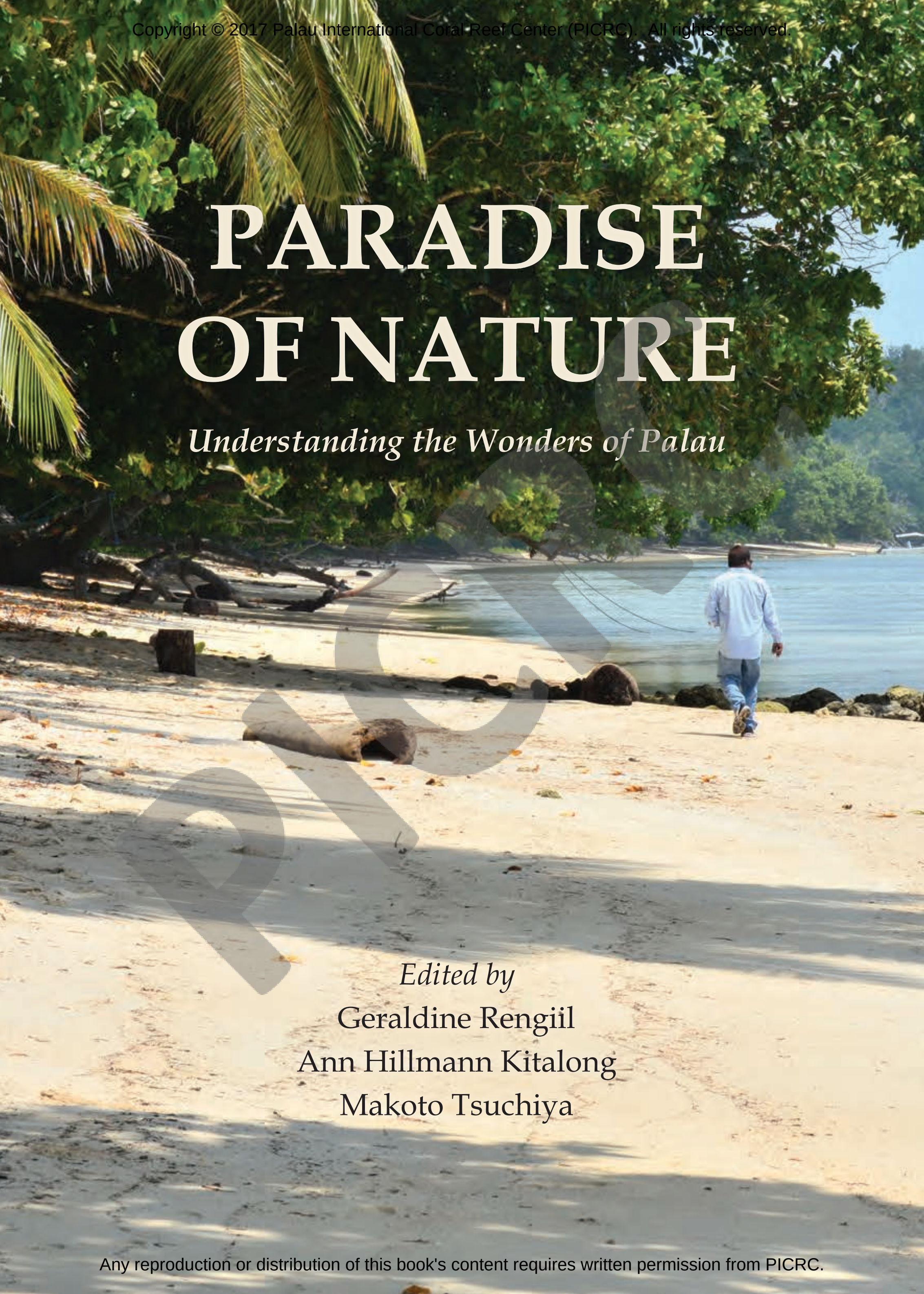

PARADISE OF NATURE

Understanding the Wonders of Palau

Edited by
Geraldine Rengiil
Ann Hillmann Kitalong
Makoto Tsuchiya

PARADISE OF NATURE

Understanding the Wonders of Palau

In partnership with the

Palau International Coral Reef Center (PICRC)

Japan International Cooperation Agency (JICA)

Japan Science and Technology Agency (JST)

and the

Palau Coral Reef Island Ecosystem Project (P-CoRIE)

Edited by
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Published by:

Palau International Coral Reef Center (PICRC)
P.O. Box 7086
Koror, Republic of Palau 96940
URL: http://www.picrc.org

Through the
Palau Coral Reef Island Ecosystem Project (P-CoRIE)

ISBN: 978-982-9079-04-6

First Printing, October 2017

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Printing:
P.I.E Printing
P.O. Box 796
Koror, Republic of Palau 96940

Publication of this book was funded by:

Japan International Cooperation Agency (JICA)
Nibancho Center Building
5-25, Niban-cho, Chiyoda-ku, Tokyo 102-8012, JAPAN

Japan Science and Technology Agency (JST)
K's Gobancho,
7, Gobancho, Chiyoda-ku, Tokyo, 102-0076, JAPAN

Front photo provided by PICRC. Back photo by Mark Priest.

Photo by Mark Priest.

Palau's abundant and beautiful nature is our treasure.

To share the treasure with our descendants,
it is important that young people be interested in nature.

PREFACE

Palau has so much to offer the world in terms of its unique beauty and available, but fragile, resources. With lush tropical forests and high terrestrial diversity, diverse coral reefs with thousands of fish species, and an expansive National Marine Sanctuary, Palau is considered a haven for sojourners, tourists, and researchers.

In this book, the editors have worked with local and international experts to put together a publication that helps people from all walks of life—and especially our youth—better understand the wonders that Palau has to offer. It provides a glimpse of what is edible from the bounties of our seas and lush tropical forests—from the hilltops all the way down to the mangroves. It describes mangrove forests, tidal flats, and seagrass beds and the specific roles they play in the maintenance of populations and as habitats for juvenile fishes and other creatures.

It describes Palau's beaches, rocky shores, and coral reefs and how each habitat is significant to the thousands of organisms that are so vital to the life cycle of our healthy and prosperous environment.

Photo by Ian Shive.

While this research-based publication is not exhaustive, it does provide a significant step in the right direction to understanding and appreciating the diversity for which this place is known.

The book concludes with thoughts on natural and human interactions with nature and how they can be destructive if we don't pay enough attention to our activities. The forces of economic development and their impact on this pristine environment are discussed and potential mitigation is offered.

The publication also covers the inevitable natural disasters that are now being exacerbated by the global forces of climate change, and which can only be mitigated through clearer understanding and proactive actions by all of us, stewards of this environment.

Patrick U. Tellei, EdD
President, Palau Community College
Former Chairman, PICRC

Noah Idechong
Chairman, PICRC Board of Directors
Former Speaker, House of Delegates

CONTENTS

Part 5: Rocky Shores and Coral Reefs

Part 6: Nature and Humans

INTRODUCTION

Takashi Nakamura, Yimnang Golbuu, and Makoto Tsuchiya

When we were children, nearly four decades ago, most of our tropical island ecosystems were intact and filled with numerous organisms living in a variety of seascapes and landscapes that showcased the beauty of nature. Of all the various forms of life on this planet, nearly half can be found in its transparent reef waters, including major groups of corals, fishes, and plants. While covering only a small fraction of the Earth's surface, coral reef and island ecosystems are home to a hugely diverse number of marine and terrestrial species. Coral reef and island ecosystems offer us an opportunity to discover the most incredible wildlife and habitats on the planet. For instance, if you observe the coral reefs surrounding the island, you realize that reefs are the largest living structures on the planet, created over thousands of years by numerous tiny organisms such as coral polyps or foraminifera.

Palau is a **Pristine Paradise**. The beauty and the dazzling variety of animal and plant life in its ecosystems have been preserved by a delicate balance with human activities for centuries. Today, however, some of Palau's marine and terrestrial habitats are in decline. Globally, more than half of the coral reef ecosystems world-wide are in serious decline. Some reefs have been altered or have disappeared as a result of human actions like global climate change. As elsewhere, global and local stresses like **overexploitation, unsustainable use, pollution,** and **unplanned development** occur and arise out of a lack of awareness of what is threatening our environment every day.

In 2013 researchers from Palau and Japan jointly undertook the "Palau Coral Reef Island Ecosystem Project" (P-CoRIE) under the Science and Technology Research Partnership for Sustainable Development Program (SATREPS) of the Japan Science and Technology Agency (JST), also in collaboration with the Japan International Collaboration Agency (JICA). The main objectives of this joint project is to apply scientific knowledge to improving sustainable conservation practices in Palau. Through P-CoRIE, researchers collaborating with the Palau International Coral Reef Center (PICRC) and Palau Community College (PCC) have found new marine species, revealed eutrophication around sewage output, and discovered that some of Palau's coral communities are highly resilient to ocean acidification.

As tourists and as scientists, we have had the opportunity to visit regions and countries all over the world. After seeing many coral reefs, we believe that Palau has the most pristinely conserved human-inhabited coral reef ecosystem on the planet. In fact, P-CoRIE research revealed that Palau's coral reef and island ecosystems

The endemic *Dendrobium palawense* orchid. Photo by Makoto Uesugi.

are still in good shape even after several reefs were heavily damaged by Super Typhoon Bopha in 2012 and Super Typhoon Haiyan in 2013. Most surveyed sites had surprisingly high coverage and diversity of coral and fish species. Despite their resilience, however, we do expect Palau's ecosystems will continue to be negatively impacted by global climate change in the near future.

Over several decades, we have observed reefs in Japan and other countries lose their pristine coral reef communities due to global climate change. We also know that these reefs had already been negatively impacted by local stresses like overfishing. Reducing local stresses is key for these pristine ecosystems to survive into the next century even under global threats. Negative impacts from global stresses will be minimized in the long-term only if local stresses to the ecosystem are reduced. This book covers many of the local and global stresses impacting Palau.

As researchers, we recognize the need to help people understand the unique ecosystems of Palau, its stresses, and the actions needed to protect these systems. This book, "Paradise of Nature," depicts an outstanding portrait of the astonishing organisms and environments surrounding you each day in Palau. From your backyard plants to turtles on the reef, this book takes you on an adventure into an extraordinary ecological realm, revealing the diversity and fragile nature of these remarkable worlds.

Witness the full spectrum of organisms in the rivers, mangroves, beaches, coasts, and between trees growing along your shortcut to school. Trace the intricate, interdependent relationships that exist between diverse species, and observe the dynamics of their daily life from the coral reefs and mangrove swamps to the forests. After reading this book, we hope you realize how precious, but increasingly threatened, the natural beauty of the Palau is.

We have an opportunity to reverse the troubling trends of environmental loss and decline. Conserving island ecosystems is a global challenge with many local solutions. But no one person, organization, or state can do it alone. We all need to take our knowledge and come together, as communities living at the front lines of threats facing island ecosystems, to jointly act to protect Palau's environment.

"Paradise of Nature" is not simply a nature book about species or the environment. It is designed to provide you with new questions to tackle, surprising insights into the organisms and seascapes and landscapes of your daily life, and inspiration towards sustainable action. This book provides scientific knowledge, cultural ideas, and even new concepts. The images in this book will provide you with a chance to explore some of the finest nature on the planet. We encourage you to join the journey with thousands of other people who care about the beautiful and exciting natural world of Palau. We hope this book will make an enduring difference to your life and to the future of natural ecosystems in Palau.

Photo by Geraldine Rengiil.

Photo by Ines Kintoki.

PART 1
On A Dining Table

Chapter 1

ON A DINING TABLE

Geraldine Rengiil, Ann Hillmann Kitalong, and Makoto Tsuchiya

Critical Thinking:

Is there nature on your dinner table?

Imagine you are dining with the family pictured here, enjoying a lively conversation during a delightful meal.

The son asks his father a question: "A lemon has small sacs. Why doesn't an avocado?"

His sister also wonders, "Why are strawberry seeds on the outside? Don't the fruits in our backyard have seeds on the inside?"

Deep in thought, she asks her mother another rapid-fire question: "Where are the seeds in pineapples and bananas?"

The parents look troubled. These questions are too difficult for them to answer. Where can they find the answers?

In this book, we extract interesting stories from the observation of common animal and plant species in Palau, like the ones we see daily at the dinner table. Often, we look at animals, plants, and habitats without a specific reason in mind, just to observe their wonders. At other times we examine species—even those we dislike—in order to formulate actions.

Do you have any orchid flowers at your house? Go outside and take a look. You might realize that the structure of orchid flowers is quite strange. Which is a stamen or pistil? Compare the structure with a *Hibiscus* flower. In Palau, you will find different and interesting structures of *Hibiscus* flowers (***see Chapter* 2**).

Palau is a beautiful island nation rich in biodiversity. This "Paradise of Nature" provides food for our tables and sustains jobs and livelihoods, making it a treasure worth conserving for future generations. We hope that we can observe Palau's natural beauty forever. For this reason, we have a responsibility to teach and learn about the importance of Palau's unique nature and biodiversity.

This book includes many observations about common species. We hope young Palauans will find many interesting phenomena in nature and will have fruitful ideas and discussions with friends, family, and teachers. Our hope is that this book will encourage more interactions between our youth and the natural environment.

Photos provided by the authors.

Chapter 2

STRUCTURE OF FLOWERS

Makoto Tsuchiya

Critical Thinking:
How many petals do orchids have?

A flower is the reproductive part of a plant. Many parts—or structures—of a flower can be seen easily using species found in gardens at home or at school. While many structures are visible by eye, a hand lens or microscope can assist with detailed observation.

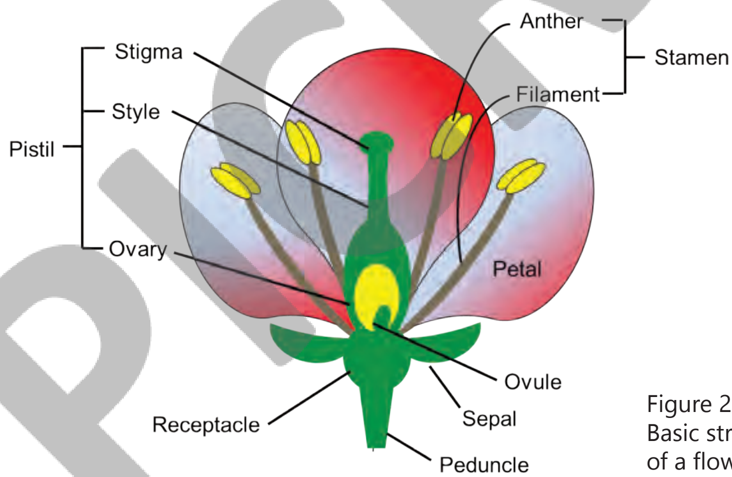

Figure 2-1. Basic structure of a flower.

There are four main parts of a flower: pistil, stamen, petal, and sepal (or calyx). These structures are usually arranged from the center of a flower to the outside in this order (***Figure 2-1***). Their morphology and pattern of arrangement differs in different species. The tip of the pistil is called a stigma; it has a sticky surface for the attachment of pollen. Sometimes the stigma branches out. A stigma is supported by a tube called a style.

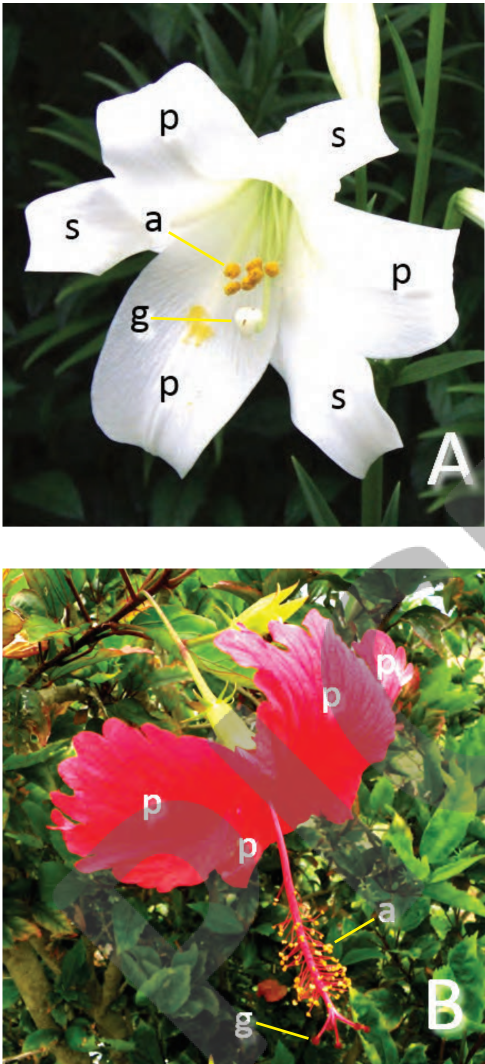

Figure 2-2. Structures of a lily (A) and *Hibiscus* (B) flowers. p: petal, s: sepal, g: pistil, and a: stamen.

Look at a lily (***Figure 2-2A***). The buds are also shown in this photograph. How many petals does the lily have? When we ask this question to children, many of them will answer six, but that answer is incorrect. In a lily's bud, petals are completely covered with sepals that have a similar morphology to the petal. The correct answer is that the six white structures include three petals and three sepals.

Next, compare the structure of the lily with the *Hibiscus* (***Figure 2-2B***), which is a very common flower in Palau. It has five beautiful petals with a variety of colors including white, pink, red, orange, purple, and yellow. The *Hibiscus* has a long style and a branched stigma growing in the center. In the upper part of the style there are many stamens. There are significant differences in structure, particularly in the position of stamens between the lily and *Hibiscus*, even though you may think that these flowers look similar.

However, different types of *Hibiscus* are common in Palau (***Figure 2-3***). Sometimes, you may find the *Hibiscus* with many petals, or with a double-layered petal structure. *Hibiscus* has five petals, with a petal-like structure in some types that is considered a modified stamen.

Figure 2-3. Unusual structure of *Hibiscus* flowers.

Next, we observe orchid flowers in which the structure is quite different. How many petals does an orchid have? Like lilies, orchids are monocotyledons (meaning their three sepals are arranged outside of petals). However, the number of petals may be counted as two. In ***Figure 2-4***, two big petals are seen.

Figure 2-4. Structure of orchid flower of *Spathoglottis carolinensis*. Source: Photograph taken by Kitalong and Uesugi, 2017.

The structure of one of the three petals is very different from the other two petals and is called the lip or labellum. In *Spathoglottis carolinensis*, a common orchid in the grasslands of Palau (***Figure 2-4 right***), the tip of the lip looks like a heart.

In the center of the flower, a column surrounded by an anther (the tip of a stamen) the stigmatic surface is located. The column is an agglutinated structure of pistils and stamen. Only one stamen is recognized and the pollen is not scattered but is a mass called the pollinium. Usually, the tip of the pollinium is sticky.

The structure of a flower is related to its pollination pattern. Pollen is carried to pistils of different flowers in various ways, such as by insects (entomophilous flowers), wind (anemophilous), and water currents (hydrophilous). Orchids are entomophilous and have adapted different strategies for attracting specific insect species for pollination. Structures have evolved for their successful pollination.

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Photos and graphics provided by the author.

CHAPTER 3

STRUCTURE OF FRUITS

Makoto Tsuchiya

Critical Thinking:
Why are the seeds of a strawberry outside the fruit?

In Palau, we can enjoy a variety of fruits. Fruits are fascinating scientifically, even if not a common topic for conversation. Remember the conversation about a strawberry, an avocado, and so on in ***Chapter 1***? In this chapter, we will answer those questions and learn about the structure of different fruits.

Fruits or seeds are the ovary or ovule of a plant. When we eat fruit we are eating part of a flower. In order to understand fruits, review flower structure (***Chapter 2***), and then consider the positional relationships between the ovary and the receptacle (***Figure 3-1***).

A hypogynous flower (***Figure 3-1A***) shows the most basic flower structure, in which the ovary is located on its receptacle (***see Figure 2-1***). In a perigynous flower the lower part of the ovary is covered by the receptacle and the upper part is exposed (***Figure 3-1B***). The ovary of an epigynous flower is completely covered with a receptacle (***Figure 3-1C***).

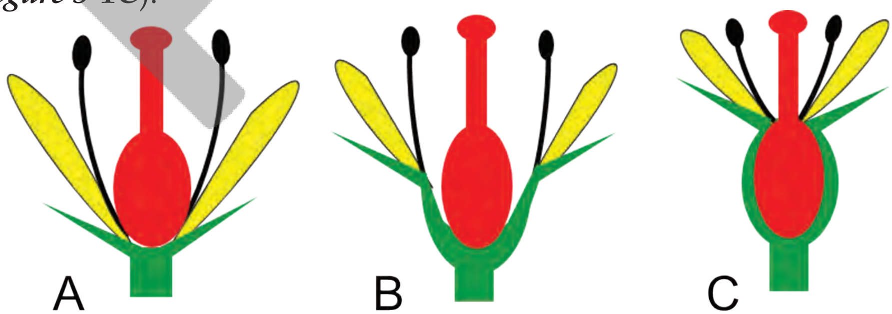

Figure 3-1. Three different positions of the receptacle in different flowers. A: Hypogynous flower, B: Perigynous flower, and C: Epigynous flower.

One of the typical examples of a hypogynous flower is the flower of a plum, apricot, or peach, belonging to the Family Rosaceae. The fruit and seeds of this group are growing ovary and ovules, respectively, and the fruit will appear on its receptacle (***Figure 3-2***).

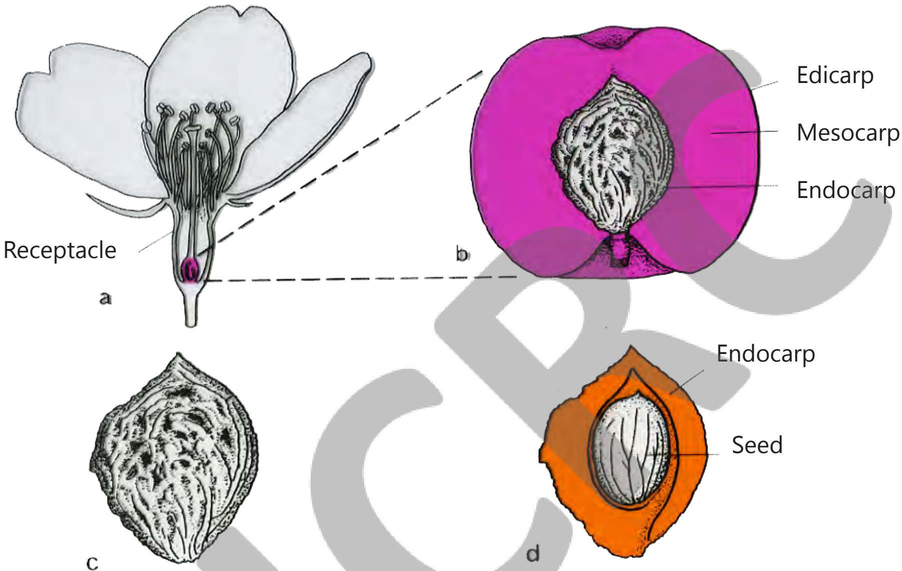

Figure 3-2. The hypogynous fruit of an apricot.

The apple is an epigynous flower with the ovary covered with its receptacle. When growing, the size of its receptacle enlarges to become the sweet fruit we enjoy eating. The core of apple is a growing ovary in which we can observe seeds (***Figure 3-3***).

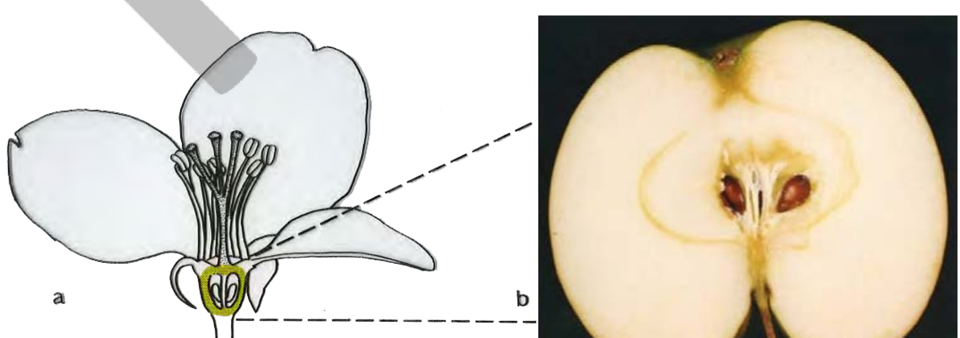

Figure 3-3 The epigynous flower of apple.

The strawberry is a hypogynous flower. The most important difference between a strawberry and other species is that it has many pistils and seeds on the growing receptacle (***Figure 3-4***). We eat the growing receptacle of a strawberry (***Figure 3-5***).

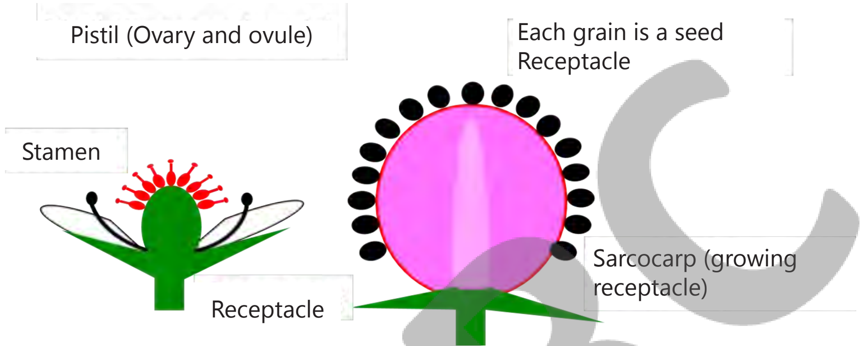

Figure 3-4. The hypogynous flower of strawberry.

Figure 3-5. The growth stages of a strawberry fruit.

Have you seen the flowers of a pineapple (***Figure 3-6***)? When the plant is ready to bloom, the stem grows longer and the tip enlarges. Flowers with red or purple petals grow from the stem's apex, accompanied by yellow, red, or green bracts (scale-like modified leaves). A cluster of smaller leaves also develops on a top flower cluster. When the flowers produce seeds, they must be fertilized by pollinators. Self-fertilization does not occur in pineapples. Most pineapples in the market have undeveloped seeds or lack them. Flowers usually remain on the plant for about two weeks.

After flowering, it takes an additional six months for the fruit to fully develop, and only one fruit is produced per year. A pineapple fruit has more than 100 developed ovaries fused together, each one originating from a separate flower. The oval-shaped fruit may grow to a foot in length and weigh ten pounds or more at maturity. The sweet, juicy interior of the fruit is edible and ranges in color from white to yellow. The stem of the plant becomes the core of the fruit and is much tougher and more fibrous than the rest of the fruit. The syncarp also has a thick, waxy rind made up of hexagon-shaped eyes that turn dark green, yellow, yellow-orange, or red when the fruit ripens. Each eye is located on a separate ovary in the fused compound fruit. To replant pineapple, take the top and replant it like a taro.

Figure 3-6. Flowers and fruits of pineapple.

Photos and graphics provided by the author.

CHAPTER 4

BIODIVERSITY IN PALAU

Makoto Tsuchiya and James D. Reimer

Critical Thinking:
What is biodiversity?
Why is biodiversity important?

There are many different plants and animals that live on Earth. Biodiversity is the word we use when we talk about all the different species of plants and animals.

Biodiversity or biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems (Convention on Biological Diversity, CBD)

Even within the same species different individuals may have phenotypic intra-species variation, different shapes, or different colors. This diversity within species is also called genetic diversity. If there are many different species in one place, we can say that species diversity is high. Coral reefs, mangrove forests, and beaches are different types of ecosystems that are common in Palau. These different ecosystems have different scenery, and we call this landscape diversity. There are many biological functions that occur in different species on an ecosystem—we call this functional diversity.


Photo by Rod Salm.

Genetic diversity or diversity within species

Why do the shells of these clams and colors of starfishes each look different (***Figure 4-1***)? It's the same reason each person has a different face: unique DNA. DNA helps decide the color and shape of the clam shells, and each clam has different DNA.

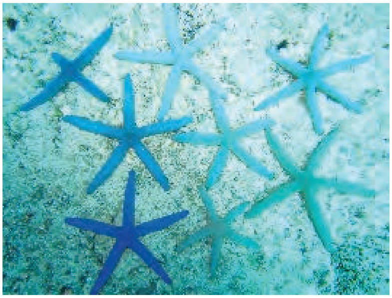


Figure 4-1. Left: Different coloration of the starfish *Linckia laevigata*. Right: Manila clam *Ruditapes philippinarum* showing a variety of shell markings.

Species diversity

Look at all the different species in ***Figure 4-2***! How many species are in Palau?

On Earth, we know there are at least 2 million species, but it is thought there are 5 to 10 times more than this! For Palau, no one knows how many species live here, although the islands are recognized as having a high number of species, many of which are endemic (found only here). How can all of these different species live together?

Which of these species could disappear without impacting the ecosystem? How do these different species interact with each other?

Ecosystem diversity

Some examples of ecosystems are coral reefs, mangroves, swamps, forests, and seagrass beds (***Figure 4-3***). There are many different ecosystems on Earth.

"Ecosystem" is a word we use to talk about all the animals, plants, and non-living features in one habitat or environment. All the different ecosystems on Earth are connected in some way.

Figure 4-2 (next page). A variety of plant and animal species in Palau.

Figure 4-3. Various ecosystems are shown clockwise from left to right such as terrestrial forest, tidal flat, mangrove forest, seagrass bed, coral reef and rocky shore in Palau.

Landscape diversity

Palau has many different types of landscapes and seascapes, which we may call scenery (***Figure 4-4***). This is one reason why Palau is so beautiful and popular with tourists. How are these places and ecosystems connected to each other?

Figure 4-4. Different types of landscapes in Palau.

What are those small white mounds of sand?

If we took a walk on a tidal flat in Palau, we would see scenery such as in the pictures below. The white mounds of sand are made by ghost shrimp, which carry sand to the surface as they make their homes. In other lagoons, there are also crabs called fiddler crabs (***Figure 4-5, right***) that do the same thing. Even though they are different species, they have similar functions.

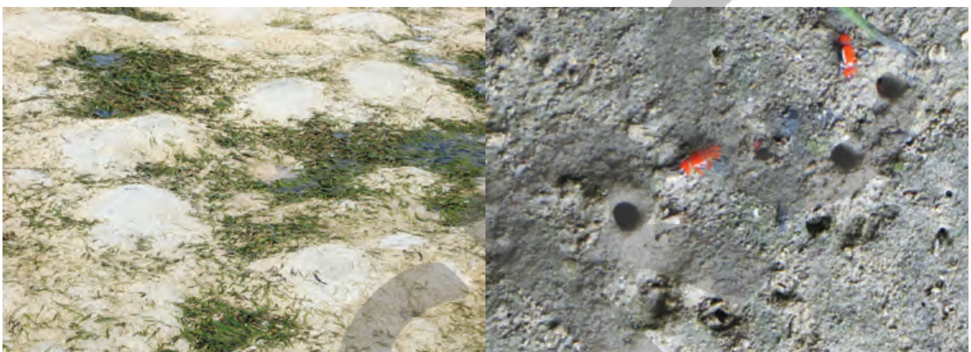

Figure 4-5. Left: Numerous sand mounds made by ghost shrimps in the tidal flat. Right: Fiddler crabs excavating sediment. Do these activities show a similar function or different?

Why do we need to protect high diversity?

We refer to ecosystems as having different functions, such as being a habitat, providing food, or providing water. These functions benefit humans as well as species in nature. Different ecosystems have different functions based on their connections. For example, many birds can be found on tidal flats eating the numerous animals that live there, and then assisting with pollination of their nesting plants. Another example is a seagrass bed, with high plant and animal diversity that provides food for dugongs and shelter for the fish we harvest. Ecosystems only function well when biodiversity is intact.

We depend on nature's different functional services, species richness, and connections. We enjoy various leisure activities in different ecosystems. We are healthy and happy because of the different foods and materials we get from different ecosystems.

Except where sourced, photos provided by the authors.

Photo by Ines Kintoki.

PART 2

Taking a walk:

Threats to terrestrial ecosystems

Chapter 5

TARO FIELD AS A NATURAL FILTER OF FINE PARTICLES

Shirley Koshiba, Meked Besebes, Kiblas Soaladaob, Adelle L. Isechal, Steven Victor, and Yimnang Golbuu

Critical Thinking:

Does a taro field accumulate terrestrial sediments?

Taro cultivation in Palau probably developed after A.D. 1200 to 1300. Accelerated erosion in the island's interior probably occurred during extensive clearing of the vegetation on the slopes for cultivation of taro. Sediment analyses, radiocarbon dating, and archaeological investigations indicate substantial inland land disturbance starting around 2,400 years ago. The focus of this article examines the capability of taro fields and farming methods in Palau as an effective sediment filter.

There are two kinds of taro fields called *mesei*: dryland and swamp fields. This chapter is related to the latter found in the lowlands, usually just upstream of the mangrove zone. Taro cultivation is a traditional agricultural method in Palau. Coastal wetlands are known to be effective sediment filters.

Palau taro field structure, regulation of water flow, and water management have persisted for many generations and have proven to be an integral part of Palauan life.

In a typical taro field in Palau, water is diverted from a stream to the field. This type of irrigation system allows water to enter from the top and side of the soil as well as the bottom. The field is further

Figure 5-1. Taro Roots. Photo by Faustina Rehuher-Marugg.

protected by embankments to keep the water within the field. An outflow is located at the downstream end of the taro field to allow excess water to flow back into the stream. This structure ensures a steady flow of water that neither dries up or floods the taro field. Maintaining the water flow of the taro field requires constant cleaning of the divides to prevent blockage from debris and weeds as well as avoiding water stagnancy. Skilled women regulate and manage water flow into the taro field based on weather and cultivation cycles. The management of taro fields in Palau has continued for many generations and is a critical part of Palauan life.

Sediment trapping efficiency of taro fields was estimated for three sites. While sediment accumulation rates varied between the taro fields because of different sediment loads from their catchments, the sediment trapping efficiency was similar: at 90% on average. The high sediment trapping efficiency of taro fields is the result of water flow management in the field. All taro fields are designed so that water enters from the stream and exits back into the stream at an outflow that is overgrown with grasses. The taro plants themselves and the plant leaves, i.e. banana leaves that are used for managing grass growth, also impede water flow. This essentially restricts the outflow of water-carrying sediment and increases the residence time.

In Palau, anthropogenic disturbances include increased resource use and resource extraction, land-use change and higher intensity of use have increased sedimentation, resulting in damage to reefs near the coast. Similar negative impacts of sedimentation on coral reefs result from increased soil runoff caused by poor land-use practices. Runoff from land affects coral reefs in several ways: it increases the nutrient levels on reefs (both inorganic and particulate organic matter), it decreases light levels due to increased turbidity, and increases rates of sedimentation in coral reef areas.

As stated earlier, the use of water runoff in irrigation of taro fields and the traditional practices of managing taro fields decrease the export of terrestrial fine sediment to coastal waters and coral reefs. Even if the taro field continually accumulated sediment, it remained viable without eventually drying up because the taro cultivators often let the taro field and the associated irrigation system get overgrown with grass to maintain the water level in the taro field as well as the water in the irrigation channels. During rainfall events, the grass helped reduce water flow, allowing sediment to settle. Taro cultivators often cleared the irrigation system and the taro field as sediment accumulated; the accumulated sediment was often piled on the sides of the taro field creating an embankment that divided taro fields, essentially creating a barrier that prevented further runoff from entering into the taro field. This allowed for control of water and sediment in the taro field. This practice helped maintain a fine balance between water and sediment that kept the taro field from becoming stagnant while continuing to be productive. Most importantly, it kept the soil on the land and kept the taro field productive. Thus, the practice of agroforestry and water management in the

Figure 5-2. Taro Fields. Photos by Faustina Rehuher-Marugg.

taro field helped reduce degradation of coastal areas from increased sedimentation.

The results of this study showed that taro fields are able to trap sediments, similar to the sediment trapping capacity of mangroves. Additional studies to quantify the amount of soil runoff into the taro fields and the extent of taro farming throughout Palau, together with the known sediment trapping capacity of mangroves, would allow us to quantify the sediment budget of Palau both historically and at present.

Because of the Palauan traditional management of water flow into and out of the taro field, continued taro field cultivation is encouraged to trap sediment, among other reasons. Not only are taro fields vital in providing crops that have been a major source of starch for the people of Palau, but this study has shown that for centuries, taro fields have been effective as an additional buffer for marine environments. While the use of taro as a food staple is decreasing because of the import of rice, it is still widely eaten, especially during customary and cultural events. The promotion of the continued use of taro farming has the dual benefit of providing for food security as well as buffering coral reefs from land-based impacts. With this study shedding light on the function of taro fields in providing environmental benefits, it is hoped that taro farming will remain a constant practice in Palau.

There are a number of plant species found within and around the boundaries of an individual taro field. Plants around the boundaries are usually those that women use to cultivate or use as medicinal herbs, among many other uses. Bananas, betelnut, and the coconut are the most common. Within a taro field, there are various herbs planted for hygiene or for treatment of the fields (***see also Chapter 41 by A. Iida***).

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CHAPTER 6.

TARO IN PALAU

Aurora G. Del Rosario

Critical Thinking:

How is Taro produced in Palau?

Introduction

Taro, *Colocasia esculenta* (sweet taro/*dait*/*kukau*), is an important staple food in Palau and in the Pacific Islands. It is used in many customary practices and social events. Taro is very important for food security and family pride.

Originally, taro production in Palau was principally done on a subsistence level for family use, for traditional customs, and for the local market. It is grown in all the states of Palau in the main island of Babeldaob. With the current increase in population and demand for taro, 61% of the production is now designated for the market, while 26% is for households and 17% is for traditional customs. A survey in 1996 showed that 695 farmers produced 924,366 lbs of taro valued at $600,838 (Del Rosario and Esguerra, 2003). Due to its cultural and social significance, taro increased in price from $0.65/lb in 1996 to $0.75/lb in 1998 and $1.00/lb in 2001. However, there was a decline of taro production by 3.5% per year from 2002 to 2012 (PACC Technical Report 2, 2013). The current price for uncooked taro is $1.75 per pound while cooked taro is $1.75 to $2.00 per pound (Rehuher and Tellei, Personal Communication, 2015).

The taro plant

Taro is a perennial herbaceous plant that grows up to 2 meters in height. The leaves are peltate with the petiole attached to the leaf near the center with pointed leaf tips and rounded basal lobes. The petiole extends up to 2 meters in length rising up in whorls from the apex of the corm and varies in color from light greenish yellow to dark red depending on the variety.

The inflorescence is a spadix surrounded by a bract-like spathe consisting of two unequal parts and the flowers are unisexual. The lower green pistillate flowers are found at the base of the spadix usually up to 5 cm high with sterile aborted flowers located above. This is followed by staminate flowers toward the end of the spadix. The fruits are small ellipsoid berries. However, not all taro plants flower naturally.

The roots are mainly on the soil surface, fibrous and adventitious. The corm is a large underground starchy stem, oblong to globular in shape with diameters up to 20 cm and weighing up to 1 kg. Colors vary from white to purple, red, or yellow.

All parts of the plant contain calcium oxalate raphides responsible for the itchy characteristic which can be destroyed by cooking to render them edible.

Taro is a rich source of carbohydrates, fiber, calcium, and phosphorus. The leaves also contain high amounts of B carotene, total vitamin A, and ascorbic acid. On the other hand, the petioles also have appreciable amounts of B-carotene, total Vitamin A, calcium, and phosphorus (FNRI, 1997). In addition taro contains Vitamin E (3.9 mg), folate (25 ug), magnesium (36.9 mg); potassium (639 mg); and selenium (1.2 ug) (USDA).

Taro production systems in Palau

Taro is planted continuously throughout the year. In Palau, there are three principal systems of growing taro, namely the wetland *mesei*, *dechel,* and upland *sers*.

1. Mesei

Most taro in Palau are grown in mesei, a wetland taro production system, where the taro is grown in a paddy-like system with channels and dikes for water control. The taro patches are arranged very skillfully and thoughtfully near mangrove swamps which surround the island. The taro patch is a main source of staple food (*ongraol*) for families. The mesei is inherited through maternal and parental lineage and sometimes through marriage.

Mesei are found in valley bottoms near sea level where water cannot drain freely into streams or the ocean. The various fields are irrigated by running water from a nearby elevated area and resemble rice terraces wherein one is always slightly higher than the next. The planting areas are usually long and narrow or could be irregular in shape. They are separated from each other by small embankments with paths. Narrow water channels are found next to these paths and sometimes on them. The fields have been laid out a long time ago by fore parents, probably designed and constructed by men from the whole village.

Taro is planted in very deep soil which has poor drainage. It was formed by organic material derived from decomposed and partially decomposed fresh water marsh vegetation and overlying alluvium washed from upland soils. The surface layer is dark brown or a very dark grayish brown muck about 86 cm deep. It has a high water table from 30 cm above the surface to 14 cm below the surface year round. Various plants and trees are grown on the dikes.

Weeds are first removed from the taro patch and the weeds are placed in a pile. The top 15 cm of the soil is turned over by hand and placed in another pile. The weeds are then placed in the hole followed by bundles of green manure. Then the top 15 cm of the soil is placed back in the hole and smoothed out. This is done in several sections of *bluu,* a subsection of the mesei meant for daily use measuring approximatley 4x4 m. Other sections of the mesei such as *uars*, *ulecharo*, *uleboil,* and *orak* are reserved for customary and ceremonial use. In the mesei, planting materials are set out at a spacing of 60x60 cm and then mulch usually consisting of banana leaves or other leafy materials is put on top to prevent growth of weeds and conserve moisture and nutrients.

Figure 6-1. Sers, or upland taro farms. Photo by Geraldine Rengiil.

2. Dechel

Dechel is normally used for planting giant swamp taro (*brak*) and taro (*dait*) is planted in between but may differ from place to place. The dechel system of planting is practiced in places adjacent to upland areas, near streams or the shorelines. The soil is very deep and poorly drained and formed from alluvium washed from upland soils formed from volcanic rock. The surface is covered with a mat of undecomposed and partially decomposed grasses and sedges 10 cm thick. The surface layer is a dark grey mucky silt loam and the underlying material is olive and grey to greenish grey silty clay loam. Permeability of dechel soil is moderately slow. In dechel, the soil is damp or wet but there is much less water than the mesei.

The land is usually cleared of weeds first. A long narrow shovel or stick is used to make holes 60x60 cm apart. The taro planting material is placed inside the hole, and the surrounding loose soil is stepped on.

3. Sers

Another production system where taro can be grown profitably in upland areas is known as sers. There are many upland areas suitable for taro production on Palau. These ensure the availability of taro corms as food even when the mesei becomes unfit for production due to climate change and salt water intrusion.

The sers plantings are grown on higher and drier ground. The soil is deep and well drained. The surface layer is a dark brown silt loam. The upper 10 cm of the subsoil is brown silty clay loam and the next 56 cm is yellowish red to a strong brown silty clay.

Land preparation

The land is initially cleared of weeds and bushes by slashing and burning. The taro is planted in holes which are prepared using a stick, pick ax, or rotavator. In areas that have been previously grown with other crops, the soil is cultivated manually or plowed with a tiller as rows or mounds are made.

Newly established areas for planting taro upland are cleared of shrubs and vegetation. Since most of the soils in Palau are acidic, lime is applied by broadcasting at 750 kg/ha before rototilling. This allows the lime to be mixed into the soil. Rows are made 1 m apart.

Planting materials

Planting materials of taro are *setts* (top of corm and base of stems), suckers, and stolons. The roots and fiber are scraped off the corm with the use of a crescent shaped knife (*ngark*) and the leaf blades are cut, leaving 30 cm of the petiole above the corm. The cut surfaces of the planting materials are allowed to dry or may be replanted immediately. In Palau, planting materials are dipped in 10% Clorox solution or salt/ocean water prior to planting to kill disease-causing microorganisms and insect pests.

Figure 6-2. Preparing planting materials.

Tissue-cultured planting materials

Taro planting materials can also be obtained from tissue cultures which have been propagated in the laboratory. Tissue culture plants are small plantlets grown in artificial medium in sterile containers. It is a rapid way of mass propagating taro plants. The plants obtained are uniform and disease-free. Plantlets are acclimatized in the greenhouse prior to planting them in the field.

Distance of planting

A plant is inserted into the ground at a depth of 10 to 15 cm. The distance between planting holes is about 60 cm. The base of the planting material is covered with soil then pressed around the base of the seedlings to keep the plant upright.

Weed control

Manual weeding is done using a hoe or scythe. The weeds are removed between plants and between rows. Weeds near the base of the plants are hand pulled. Once the leaf canopy closes, weeding is no longer done.

Fertilization

One month after planting, a handful of compost or manure and a handful of inorganic fertilizer (10-30-10) are placed about 7 cm around the base of each plant and then covered with soil.

Figure 6-3. Cluster Caterpillars, a taro pest.

Insect pests of taro

There are four major insect pests attacking taro in Palau:

1. Cluster caterpillar, *Spodoptera litura*
2. Taro hornworm, *Hippotion celerio*
3. Melon aphid, *Aphis gossypii*
4. Taro leafhopper, *Tarophagus colocasiae*


Figure 6-4. Leaf Lesions from Taro Leaf Blight.

Diseases of taro

There are two important taro diseases in Palau:
1. Taro Corm Rot, *Pythium* spp.
2. Taro Leaf Blight, *Phytophthora colocasiae*

Harvesting

Taro is harvested usually from 7 to 9 months after planting when the leaves shrink to only 2 to 3 leaves per plant. The soil around the plant is loosened using a hoe or knife. Once loose, the plants are pulled from the soil. The corm is cleaned by scraping off the soil and roots using a crescent-shaped knife (*ngark*). The shoot, which is used as planting material, is removed and leaf blades are cut leaving 30 cm of the petiole above the corm. The corms are collected and placed in a harvest basket for home consumption or for sale.

Taro Varieties in Palau

Local Taro Varieties			
1. Dilisor	9. Esuuch	17. Ngemekeang	25. Okelang Becheleleu
2. Dirraousch	10. Homusted	18. Ngertmau	26. Renged
3. Dirratengadik	11. Kerdeu	19. Ngeruuch	27. Terebkul
4. Dirrubong	12. Kirang	20. Ngesuas	28. Terrekakl
5. Dois	13. Meltalt	21. Ngetmadei	29. Thomas
6. Dungersuul	14. Merii	22. Ochab	30. Ungil Dil
7. Dung Ra Terrekakl	15. Miuako Ngkeklau	23. Ochelochel	31. Urungel
8. Erderid	16. Miuako Ouberburs	24. Ordiil	32. Ulechem

Introduced Taro Varieties		
1. Hawaii 12 / BC 99-6	6. Samoa 44	11. Samoa 128 / Nu'utele 2
2. Hawaii 26 / BC 99-11	7. Samoa 111	12. Samoa 151
3. Hawaii 37 / Paakala	8. Samoa 114 / Salelologa	13. Indonesia 14
4. Samoa 10	9. Samoa 115 / Malaela	14. PNG 3
5. Samoa 12	10. Samoa 116 / Manu	15. Malaysia 12
		16. Malaysia 14

PALAU ADAPTATION TO CLIMATE CHANGE

Sea level rise and salt water intrusion

Pacific island countries are among the most vulnerable places in the world to the impacts of extreme weather events. One of the most adverse effects of climate change is increased air and ocean temperatures which impact precipitation, sea level, winds, tides, and other key climatic conditions. As ocean temperatures rise, thermal expansion of ocean waters combined with melting glaciers elsewhere leads to rise in sea levels causing loss of land, coastal erosion, and increased salt water intrusion (Solomon et al., 2007). In the Pacific Islands, the impact of climate change is likely to be more severe and likely to include food insecurity resulting from reduced food production due to salt water intrusion and increasing soil salinity, excessive rainfall, increased flooding, and soil erosion. The mean sea level trends at Malakal in Palau since 1969 have been about 0.2 + 1.8 cm/decade, or a total change of 0.6 + 5.8 cm (Shea, 2001).

OERC (2007) identified the main threats to be: drought, more frequent storms and intense rainfall, and sea level rise. El Niño brings drought-like conditions to Palau and La Niña brings higher than average rainfall with more intense and frequent storms. In 1998, 236 taro patches in 19 states were assessed by the PCAA, IESL, and NEMO Office. In these cases crops were seriously affected and consequently, livelihoods were hurt (Bishop, 2001). Furthermore, as a result of sea level rise, salt water inundation is plaguing taro farmers who use

Figure 6-5. Sea level rise is a climate change threat.

the lowlands close to coastal areas, especially during high tide. Even though agriculture in Palau is relatively small in scale, contributing only 6.2% of the GDP, there are hundreds of vulnerable small taro farms dispersed around the islands (Bells and Daniels, 2002).

Upland and lowland farm areas in Palau cover 255 hectares. Of these, 76 hectares are lowland (mesei) areas. A survey conducted by PALARIS showed that 21% (equivalent to 16.4 hectares) of the total lowland (mesei) areas experienced salt water intrusion. This greatly affects food security since these lowland areas are devoted principally to taro production.

Impacts of salt water intrusion

Salt water in taro patches is detrimental to the growth of taro. In 1998, salt water intrusion associated with abnormally high tides caused extensive damage to taro patches and traditional food supply throughout Palau (Bishop, 2001). The highest tides in Palau normally occur from September through October, and every few years some low lying patches will experience some damage due to salt water intrusion. But as early as August 1998, large areas of low lying and inadequately maintained taro patches were inundated with salt water (Bells and Daniels, 2002), resulting in crop losses as high as 75 to 100%. After 1998, and even continuing to today, many farmers have abandoned their taro patches because of constant losses, thus losing farming areas and reducing total production of taro.

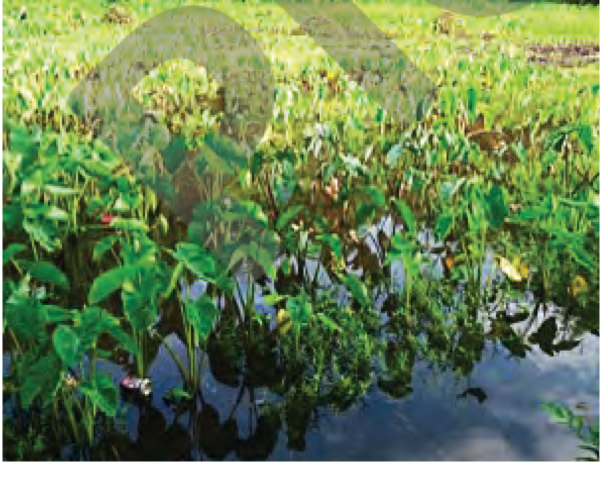

Figure 6-6. Salt water intrusion into a mesei.

Figure 6-7. Rehabilitated dikes can protect mesei from salt water intrusion.

Prevention of saltwater intrusion with dikes

Research determined that existing dikes were insufficient to prevent salt water from coming into the taro planting area under a regime of more frequent high tides. Thus, there is a need to rehabilitate and improve the dikes in these areas. A pilot project identified sites with salt water intrusion in Ngimis, Ngatpang and in Ollei, Ngarchelong. Through the project, the height of the main dike was increased to prevent salt water from coming in during the high tide. A strong secondary dike was also constructed inside the taro patch to further protect the taro growing area.

With these remedial measures, the pilot project found that:

- Salt water was coming into the taro patch through holes made by small crabs.
- There was a need to increase the height of the dike based on water level monitoring.

- The use of pipes is not recommended for drainage of water from the taro patch due to clogging with debris and dried leaves.
- Waterways and ditches should be regularly weeded and cleaned to ensure steady flow of water.

Recommendations for preventing intrusion using dikes include:
- Increase the total height of main ditches to at least 1.5 m and cover the main dike with rubber sheet lining held in place by sand bags.
- Increase depth of the water ditch inside and outside the main dike by at least 60 cm.
- Install a gate valve on the northern corner of the taro patch to prevent salt water from coming into the parch during high tides.
- Construction of secondary dikes inside the taro patch is an essential adaptation measure to prevent salt water from coming in.

Other adaptation measures

Evaluation and the search for salt tolerant taro varieties continues. On low elevation atolls, rainfall maintains a precarious fresh water lens, which is subject to salt water intrusion during drought or storms. Salinity has been shown to affect early growth and nutrient accumulation in taro (Hill et al., 1998). Diffuculty in farming, due to the lack of plant tolerance to salinity, may be a factor for declining interest in taro production in favor of imported food and for cultivation of swamp taro (*Cyrtosperma* spp.), which appears to have some salinity tolerance (Manner, 1993). This is seen in the predominance of *Cyrtosperma* in atoll or low islands such as Kayangel and Peleliu.

Some variability in tolerance among genera (Manner, 1993) and within the genus *Colocasia* (Chang et al., 1984) has been observed. There are about 70 taro varieties being cultivated in Palau. Likewise, varieties of taro hybrid have been introduced from the Secretariat of the Pacific Community (Del Rosario, 2012).

Thirteen local varieties and 6 introduced varieties were evaluated for tolerance/susceptibility and performance in salt-water-intruded taro patches in Ngimis and Ollei. Based on survival and yield, the varieties *Kirang*, *Dirrubong*, and *Dungersuul* were found to be salt tolerant (Del Rosario et al., 2014).

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Except where sourced, photos provided by the author.

Chapter 7

WHY ARE FORESTS IMPORTANT?

Ann Hillmann Kitalong

Critical Thinking:

What is Palau without its forests?
Are forests and climate change connected?

We cannot survive without the forests. Our health and the planet's health depend upon the forest. In 2007 about 82% of Palau's total land was covered with healthy and diverse forests (Donnegan 2007). Palau has a highly diverse terrestrial ecosystem with over 1,300 plants including over 700 native plants of which over 130 are

endemic to Palau. (Endemic means that these plants are only found in Palau). The forests are an important source of food, medicine, building materials, and a critical habitat for birds and wildlife. Forests are a great place to walk and enjoy nature's wonder.

The forests provide ecosystem services that help maintain the health and ecological integrity of both terrestrial and marine ecosystems. The roots and stems stabilize the soil and reduce soil erosion and sedimentation into aquatic and marine ecosystems. Trees release water and oxygen into the atmosphere and recycle nutrients that increase soil fertility. Forests serve as effective buffers from storms, protecting our homes and infrastructure.

Tropical rainforests provide about 70% of the earth's biological productivity. One single large tree can release 760 liters of water as vapor into the atmosphere daily. One hectare (10,000 square meters) of tropical forest releases 187,000 liters of water into the atmosphere daily for cloud formation. Forests produce rain clouds partly as a result of the evapotranspiration process. In the evapotranspiration process, water is transferred from the soil and plant surfaces into the atmosphere in the form of water vapor. Plants absorb water through their roots and release it as water vapor through their leaves. In the photosynthesis-respiration cycle, plants use carbon dioxide (CO_2) and give off oxygen (O_2). An average tree uses about 325 kilograms of CO_2 each year. About 30 metric tons of CO_2 are produced each year from the average household in the U.S. Therefore, about 100 trees are needed to absorb the annual amount of CO_2 produced per household (Kitalong et al. 2013).

Globally, there was a net forest loss of 7 million hectares annually in tropical countries from 2000 to 2010 and a net gain in agricultural land of 6 million hectares (FAO, 2016). The major cause of forest loss is conversion to other land uses. In Palau, there is an extensive intact forest, however the quality of forest habitat is declining because of forest fires and invasive plants. In 2015, 40% (19.7 km^2) of Palau's mangroves were protected and 20% (90 km^2) of terrestrial habitats (excluding mangroves) were protected (NEPC 2017). It is critical to effectively protect more forests from the upper watersheds to the mangroves for long term sustainability and resilience to climate change.

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Photos provided by the author.

CHAPTER 8

KEYSTONE CULTURAL SPECIES OF PALM TREES IN PALAU

Ann Hillmann Kitalong

Critical Thinking:

What are two palm trees that are keystone cultural species in Palau because of their many uses in daily life?

List some of the uses for keystone species.

Areca catechu or *buuch*

Areca catechu or *buuch* (betelnut) is a small palm tree that is a keystone cultural species in Palau. A keystone cultural species means that the species plays a critical role in the way of life of Palauans. *Buuch* is commonly found around the homes and village landscapes in Palau. The green seed is cut in half, lime added, wrapped with leaves of *kebui* (*Piper betle*), and chewed as a **stimulant**. The *keai* (base of the frond) is used as a **food wrap** for starch and fish (Marciana Telmetang pers. comm. 2016) and a **rain hat** or **rain coat** (Eriko Singeo pers. comm., 2007). The *keai* is used as a *tet* (**small basket**). The lower portion of the trunk was used to make **spears**, **dancing paddles,** and **sticks** (Eriko Singeo, Maria Kim, Nona Luii; and Hinako Takeo, pers. comm., 2008). The sheath can be used as a **sled** to slide down hills. **Tip of spears** were made with *buuch* stems (Albert Naito Soaladaob pers. comm., 2015). The trunk is used for **flooring** for local houses and for **outdoor benches** (Eriko Singeo pers. comm., 2007).

The trunk is used to make **roof beams** in the construction of a *bai*. The *keai* is used to **wrap babies** while they sleep (Eriko Singeo pers. comm., 2008).

Betelnut is used as **medicine**. The juice of the very ripe big nut is an **astringent medicine** used to heal the navel (belly button) once the umbilical cord detaches (The Palau Society of Historians, 1998a). The very ripe and fully developed endocarp was heated to make it soft; it was then squeezed to extract the liquid of the seed, cooled a bit, and a drop or two of the liquid was put on the baby's navel to help it heal faster. This medicine was usually applied after the umbilical cord had fallen off, which took two to four weeks. Thus, this traditional medicine application was better categorized as a preventive measure or natural antiseptic (Eriko Singeo, Maria Kim, Nona Luii; and Hinako Takeo, pers. comm., 2008). To stop a **toothache**, the roots can be pounded and the juice applied to a tooth to stop the pain (Eriko Singeo, Maria Kim, Nona Luii; and Hinako Takeo,

Figure 8-1. *Areca catechu* or *buuch* sheath.

Figure 8-2. *Areca catechu* or *buuch* tree trunks.

Figure 8-3. Betelnut.

pers. comm., 2008). The base of the betelnut with its "brushy" texture can be used as a **teeth cleanser** (Demei Otobed pers. comm., 2008). It is combined with *sengall* (*Leea guineensis*) to **relieve menstrual cramps** (Eriko Singeo, Maria Kim, Nona Luii; and Hinako Takeo, pers. comm., 2008).

During 1941 to 1943, Okabe (translated by DeFilipps et al., 1988) documented four uses for *buuch* as follows: (1) To treat a **cold**, the seed of *buuch* is wrapped in the leaf of *kebui* and chewed; the cold is cured after sweating. (2) To cure **stomachache**, eight roots of *buuch* are crushed together with young leaves (about 6 cm long) of *chertochet* (*Pandanus macrojeanneretia*[1]), and eight leaves of *kesuk* (*Codiaeum variegatum*); mixed with a cup of water, and then strained through the fibrous network of a *lius* (*Cocos nucifera*) petiole-base; finally copra (dried coconut meat) is added, and again the mix is strained before drinking. (3) To **stop bed-wetting**, the unripe fruit is pressed, diluted with water, and juice is drunk. (4) To use an emmenagogue (**promotes menstrual flow**), new roots of *buuch* are crushed together with new leaves of *chertochet* (*P. macrojeanneretia*), eight leaves of *kesuk* (*C. variegatum*), and shaved copra; the mixture is strained through the fibrous network of a *lius* petiole-base before drinking.

Culturally, the betelnut is often chewed as part of the **process of decision making** about important matters. It gives the decision maker more time to think (Obakradebkar pers. comm., 2016). The betelnut is part of a **famous Oikull legend** involving the gods, *chesisebangiau* and *buuch*. The Palauan gods decided that the god who

[1] This may also be *Pandanus aimiriikensis* which is also called *chertochet*.

threw his betelnut the furthest would own Ngerduais Island in Oikull Hamlet, Airai State. The god, *Medechii Belau*, hid a *chesisebangiau* (honeyeater, *Myzomela rubratra*) in his palm in place of a betelnut. Once thrown, the honeyeater flew to *Ngerduais* and *Medechii Belau* won the island (Pratt and Etpison, 2008).

Cocos nucifera or *lius*

Cocos nucifera or *lius* (coconut) is a large palm tree that is a keystone species in Palau.

The clear liquid from young fruit is consumed as a **beverage**. The endosperm is edible **food**, either when young or mature. The unopened inflorescence can be tapped; the sweet sap drips from the cut end and is a very nutritious, high calorie beverage (*chemadech*). The sap can also be collected and boiled down into sweet coconut syrup or "honey" (*ilaot*). The sap is considered essential for the good health of young children on the island of Sonsorol where it is called *hasi* (Joel Miles, pers. comm., 2017). The flowers are boiled and made into a honey (Tomomi Watanabe, pers. comm., 2007). The dried fruit is used to make **oil** for **cooking**.

Figure 8-4. *Cocos nucifera* or *lius*.

Coconut oil is an important and basic ingredient in many **medicines** (Eriko Singeo, pers. comm., 2007). The oil is used for **earaches** (Flora Wasisang, pers. comm., 2008) and to remove a **boil** (Rideph Emesiochel, pers. comm., 2008). Coconut oil is mixed with the leaves of *Piriqueta racemosato* to treat

itchy skin, (Elin Rebluud, pers. comm., 2008). During 1941 to 1943, Okabe (translated by DeFilipps et al., 1988) described the following medicinal uses for coconut: (1) To treat a **cold**, coconut oil is rubbed on the head. (2) To treat a **wound**, sliced copra (dried coconut meat) is applied. (3) To treat a **burn**, the oil is applied to the affected area; a burn can also be treated by squeezing out the juice of the rotten leaves and applying it to the affected area. (4) To treat an **abscess** (collection of pus), coconut oil is spread over affected area. (5) To treat **insect bites**, hot oil is dripped onto the affected area. (6) To treat **arthritis**, the affected area is covered with coconut oil two to three times per day. (7) To treat **amoebic dysentery**, apply the sap of young, red pericarp. (8) To use as an antiemetic (prevent or relieve **nausea and vomit**), the pericarp of a young, unripe coconut is shaved and pulverized, and taken together with coconut milk. (9) To use as a febrifuge (to **lower fever**), the oil is spread over the head and body. (10) to stop **bed-wetting**, drink juice pressed out of the exocarp of an unripe coconut. (11) For seasickness, the young pericarp of coconut is chewed. (12) To **clean the hair and body**, use grated copra wrapped in coconut fiber.

The *meolt* (young leaflet) is used to make the ***dui*** (the bundle used for transferring a traditional title) (Eriko Singeo, Maria Kim, Nona Luii; and Hinako Takeo, pers. comm., 2008). Fibers from the coconut husk are used to make **rope** for tying or lashing wooden beams together for buildings and to tie the outrigger of canoes (Albert Naito Soaladaob, pers. comm., 2016; Ananias Bultedaob, pers. comm., 2016). To make a **broom**, the softer more flexible part of midribs of the pinnae are bunched together and tied at the base (Eriko Singeo, pers. comm., 2008). The *meolt* is used as a **food wrap** to prepare *bilum* (ground tapioca), and *ulechem* (fish). The fronds are used to make a variety of **baskets**.

In 2007, *Obakradebkar* Clarence Kitalong described the following uses of coconut: The trunk is used to make **tool handles** and **stirring utensils** and **taro pounders**. The base of the frond is used to make **toy canoes** or toy boats using a stick to push it around. The rib of the frond is used to make a **shrimp trap**. The pinnae or leaflets are used to make **pin-wheels** or **toy balls**. The trunk is used for making **spears**. The husk is used as kindling to make a **fire**. The hard exocarp can be used to make a **cup** or **bowl** for drinks and food. The hard exocarp can be used as a **bra for ceremonial dances** and activities and to make **jewelry and buttons**. The *techiir* (outer fiber) can be used to make a **sieve**.

The exocarp can be used for a **lime container** (Eriko Singeo, pers. comm., 2007). The frond can be used to weave **hats** and **belts**. The hard exocarp of the fruit can be used to make a **hair pick**, and **dipper** (Tomomi Watanabe, pers. comm., 2007). The *keai* can be used to make a **small basket**. The coconut fiber is used to make *derau*, a hand held **fish net** (Subediang Ubedei, pers. comm., 2008).

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Photos provided by the author.

CHAPTER 9

WHAT ARE "INVASIVE ALIEN SPECIES" (IAS), AND WHY ARE THEY A PROBLEM?

Joel E. Miles

Critical Thinking:

What can we do to minimize impacts?
How can future invasions be prevented?
How can you help?

Monkeys, rhinoceros beetles, cockatoos, smothering vines, snails, agricultural pests, and disease-causing microorganisms: all of these and more have invaded Palau, and all are having impacts on the environment, the economy, human health, and even the traditional Palauan way of life.

What is an invasive species?

Invasive species are living organisms, which, for various reasons, begin to grow and reproduce out of control and cause harm to the other living things around them. In some cases, invasive species have caused major alterations in ecosystems, and have even caused the extinction of other living species. In most cases, invasive species become invasive when they are introduced into a new environment where they have no natural enemies. These are often referred to as Invasive Alien Species, or IAS. The United Nations Convention on Biological Diversity (CBD) defines an Invasive Alien Species as "A species that has been introduced into an environment in which it did not evolve, and whose introduction causes, or is likely to cause, economic or environmental harm, or harm to human health."

Organisms which become invasive usually have one or more of the following characteristics:

- Exploit disturbed areas more quickly than native species
- Lack of natural enemies (i.e. pathogens, diseases, predators, or competitors)
- High reproductive rate and dispersal
- Rapid growth and maturity
- Highly adaptable (diet/habitat).



Figure 9-1. Top to bottom: Crab-eating Macaque, Coconut Rhinoceros Beetle, and Sulfur-Crested Cockatoo.

What effects do invasive species have on biodiversity?

Invasive species cause harm by eating animals or their eggs (monkeys, for example, eat bird eggs and nestlings), by eating plants (coconut rhinoceros beetles eat the hearts of coconut trees, while parrots and cockatoos eat the hearts of two palm trees found only in Palau's rock islands, killing the trees), by growing over plants (several invasive vines), by increasing the likelihood of wildfires (several plants, most notably *Imperata cylindrica* and *Chromolaena odorata*) or by being more likely to survive fires, by carrying disease organisms (sparrows, rats, mosqui-

Figure 9-2. Two invasive plants. Top: *Kebeas* or *Merremia peltata*. Bottom: Mile-a-minute weed or *Mikania* smothering taro leaves.

toes), by causing diseases of humans, animals, and plants (microorganisms), by making noise (coqui tree frog, cockatoo, and parrot), and in many other ways.

Invasive Alien Species are one of the greatest threats to biological diversity worldwide, and on islands they are often the number one threat to biodiversity. Palau is no exception: invasive species in Palau pose a serious threat to the islands' wildlife and ecosystems. Additionally, invasive species threaten Palau's economy, human health, agriculture, and even the unique Palauan way of life.

How do invasive species invade new places?

Many living things have adaptations which help them to move from place to place naturally. Most biological invasions, however, are the result of human activities. Humans move, or introduce, living things like ornamental and crop plants, and pet and livestock animals from place to place intentionally. Many introductions, however, are unintentional: ants, plant seeds, disease organisms, snail eggs, and many others can be hidden in cargo, attach to clothing, and find other ways to move in the things that people move. The brown tree snake, which has devastated the bird populations of Guam and which costs Guam's economy millions of dollars every year, is notorious for its ability to hide in very small places.

In some cases, a naturally occurring species can become invasive when conditions change. A good example of this is the plant known in Palau as *kebeas* (scientific name *Merremia peltata*). This is a very vigorous and fast-growing vine which naturally grows in clearings in forests. As recently as 20 years ago, kebeas was common in Palau, but it was not generally a problem. Now, land-clearing, road-building, and other human activities have created more opportunities for kebeas, while there are fewer human activities to control its growth. Now kebeas is threatening forests and communities all over the islands of Koror and Babeldaob. Some communities are now taking action to control kebeas, and the results are very promising; kebeas can be brought back under control when communities are involved.

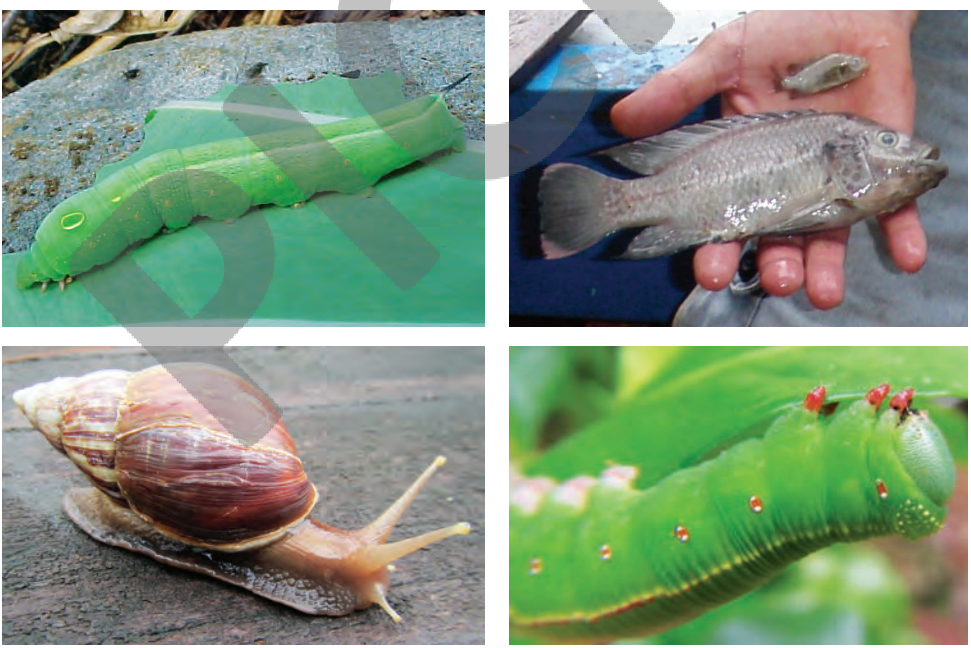

Figure 9-3. Clockwise: Taro hornworm, Tilapia Fish, Gardenia Hornworm, Giant African Snail.

Figure 9-4. Croton Caterpillar (*Achaea janata*).

How can we prevent the harm caused by invasive species?

The most important thing we can do to prevent invasive species is to strengthen our biosecurity. Biosecurity means all the things a country or island can do to prevent introduction or spread of new invasive species. The most important part of biosecurity is inspection of everything that enters the country or island. For example, cars, boxes, refrigerators, and many other items which are imported to Palau from Guam must be thoroughly inspected to ensure that brown tree snakes do not enter our islands. Another example is the coqui, a tiny tree frog with a very loud voice. Hawai'i's tourist industry is now suffering because the loud call of the coqui disturbs the peace and quiet which many tourists are seeking. The coqui lays its eggs on vegetation, so every plant imported into Palau from Hawai'i, including cut flowers and nursery stock, must be thoroughly inspected for the tiny coqui eggs. Seeds of invasive weeds can be caught in radiators and other crevices of automobiles, trucks, and heavy equipment. Any mechanical equipment which has been used or driven overseas should be steam cleaned prior to entry into Palau, and even steam cleaning is not a guarantee that no seeds will survive. Weed seeds can even survive being eaten by livestock, so any livestock that will be imported should be fed only weed-free feed for several days before importation into Palau.

Another important part of biosecurity is the ability to detect invasions early and to respond rapidly. If invasions are detected early, they often can be eradicated, but it is essential to respond quickly. Late detection or slow response can allow an invader to spread to the point where eradication is either impossible or prohibitively expensive. An example is the introduction of the Philippine Fruit Fly to Palau: when the infestation was discovered in 1996, Palau was not prepared to respond. Now, in 2017, Philippine Fruit Flies are found throughout Palau, and it is estimated that eradication of the fruit flies will cost over $2 million. However, if the Philippine Fruit Fly is not eradicated Palau will continue to be unable to produce enough fresh fruit for local consumption, or to export many fresh fruits and vegetables to neighboring countries. This affects the health of everyone in Palau, and also prevents the development of an agricultural export industry that could contribute greatly to the national economy.

In Palau, biosecurity is the responsibility of the Biosecurity Division in the Bureau of Agriculture, but they cannot do everything: every person in Palau is needed to prevent the harm caused by invasive species.

Invasive species are everybody's responsibility

How can Palau deal with these biological invasions? Can some of the invaders be eradicated? If not, what actions can we take to minimize their impacts? How can future invasions be prevented? There are numerous plants, animals, and other organisms causing problems in other Pacific Islands, which have not yet been found in Palau. How can we keep them out?

How can you help? These are very important questions that you can help to answer.

Photos provided by the author.

Figure 9-5. Fruit fly larvae in guava.

Chapter 10

THE MACAQUE MONKEY PROBLEM IN PALAU

Joel E. Miles

Critical Thinking:
How do monkeys affect our lives?

The long-tailed macaque monkey, *Macaca fascicularis*, was introduced to the island of Angaur in the early 1900s. This species, also known as the crab-eating macaque, is native to Southeast Asia, and is very common and widespread there. Its natural habitat is tropical forests, including mangrove forests. The long-tailed macaque is known throughout its native range as a "crop raider," with severe impacts on a wide range of agricultural crops, including several types of fruit and root crops (Cawthon Lang, 2006; Hambali et al., 2012; Kemp and Burnett, 2003).

Figure 10-1. Native range of long-tailed macaque. Source: Wikipedia.

Although their impacts have not been well documented in Palau, it is common knowledge here that macaque monkeys have caused severe socio-economic and environmental damage to the people and island of Angaur. Many women in Angaur have given up farming due to monkey damage, thus losing an important source of income, as well as a key part of their cultural identity as Palauan women. Most of the few studies on the macaques on Angaur have not paid much attention to their impacts, but in 2011 a study funded by the German government found that macaques are the most important constraint to agriculture and food production on the island of Angaur. The authors (McGregor et al., 2011) concluded that: "The first step in removing this overwhelming binding constraint to food security and agriculture on Angaur is an unambiguous national government priority to eradicate/control the macaque monkey population." The authors went on to say that an appropriate project to eradicate the macaques needs to be designed, and that adequate long-term funding to achieve the desired eradication objectives will be required. As of 2017, such a project has not yet been initiated.

Figure 10-2. Captive macaque, chained due to aggressive behavior.

In addition to the socio-economic impacts on agriculture, macaque monkeys may be having detrimental effects on biodiversity. A 2005 survey of forest birds (VanderWerf, 2007) showed that Angaur has the lowest bird population and species richness of any island in

Figure 10-3. Crop damage by macaques on Angaur. Left to right: betelnut, breadfruit, coconut.

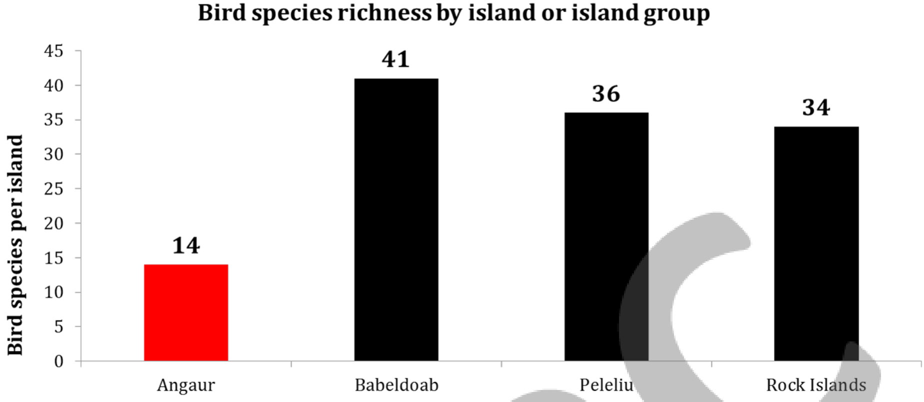

Figure 10-4. Negative impacts on biodiversity. Source: A. Wegmann, Pers. Comm. based on VanderWerf, 2005.

Palau, while the nearby island of Peleliu, with a similar environment, has the highest populations and a much higher species diversity. Possible impacts on other wildlife, such as native forest lizards, have never been assessed. Similarly, possible impacts on forest plant biodiversity have also never been assessed.

An additional threat, of which many people, including many in the medical professions, are unaware, is the serious threat to human health associated with macaques. It is part of macaque behavior to bite and scratch, and it is not uncommon for macaque owners to be bitten and scratched. In addition to the physical injury, there is a risk of secondary infection following bites and/or scratches. Perhaps even more important, macaques can spread several serious human diseases. Palau's macaques have been found to carry B-virus (*Cercopithecine herpesvirus 1*) (Matthews et al. 2010); although the risk of transmission to humans is low, this disease is usually fatal in humans if the infection is not treated immediately (Cohen et al., 2002; Huff et al., 2003; Ostrowski et al., 1998).

All the islands and communities of Palau are at risk of the same damage that is already happening to Angaur, on a larger scale. It will only take one breeding pair of escaped macaques on any of the other islands in the Palau archipelago to result in an ecological and socio-economic disaster. There are known to be several pet macaques outside of Angaur (Matthews et al. 2010), despite the existence of a national law prohibiting their transport out of Angaur, and pets have escaped in the past. It is therefore urgently necessary to take steps to control the macaques on Angaur, and to prevent their spread to the rest of Palau.

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Except where sourced, photos and graphics provided by the author.

Chapter 11

MONITORING THE BIRDS OF PALAU

Alan R. Olsen and Milang Eberdong

Critical Thinking:

What do birds tell us about the health of our ecosystems?

Palau is home to 158 species of birds, the richest bird diversity in Micronesia. Birds perform important services for Palauans and the Palau environment including: (a) controlling insect pests, (b) spreading seeds and other plant propagules throughout the forest, (c) transporting nutrients between habitats through their excrement, (d) maintaining the balance of nature as dominant herbivores and carnivores, (e) attracting bird-watching tourists to Palau, and (f) contributing to the quality of life in Palau with their colorful plumage and cheerful songs. Birds are also valuable indicators of the health of our forest and coastal ecosystems. A change in bird abundance is often the first sign of an ecosystem stressor such as climate change, drought, invasive species, or over development. The Belau National Museum's **National Program for Monitoring Forest and Coastal Birds** is responsible for monitoring our birds in order to detect changes that are early warnings that something is happening to the health of our forests and coastal wetlands.

Scientists of the national program use a variety of methods to monitor our birds. One method is to take repeated counts of the birds at a site in order to develop an inventory of the bird diversity (number of species) (**species richness**) of the site. The repetition is necessary because not all the species at a site are active on any particular day. It takes many repeat visits to find them all. After many counts, the scientists statistically analyze the accumulated results to verify whether they have compiled a complete inventory of the species richness of the site. In 2008, for example, scientists for the national program surveyed the species richness of a bird sanctuary by counting the species that they saw or heard along the same trail every two weeks for a full year. The survey found that the sanctuary is home to 38 bird species of which 30 were residents of the sanctuary and 8 were migratory visitors. The chart below (***Figure 11-1***) shows the accumulation of the different resident species that were observed by the scientists over the one-year series of biweekly counts (solid line) along with two statistical estimators of species diversity (broken lines). The convergence of the three lines near the end of the year (right side of the chart) means that it is statistically safe to conclude that the accumulated total of 30 species represents a complete inventory of the species that live in the sanctuary. Following the survey, the sanctuary published a list of the names of the 30 species as an official checklist for the site. Checklists are important reference documents for future research and are popular with bird eco-tourists.

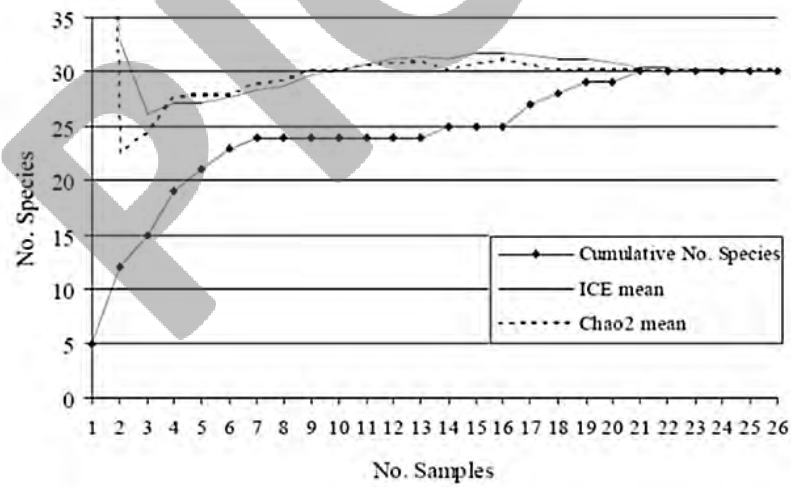

Figure 11-1. Accumulation of the different resident species . Source: A. Olsen and M. Eberdong, 2009. *Micronesica* 41: 59-69.

Another method is to monitor trends using databases such as the eBird website (www.ebird.org), a citizen-scientist crowdsourcing project of the Cornell University Ornithology Laboratory. For example, the eBird database for the Micronesian Imperial-Pigeon (*Belochel* or *ieb*) showed a decline in the average numbers of pigeons reported by Palau's citizen scientists for the years 2014 and 2015. The following graph (***Figure 11-2***) shows the declining trend (red line) in pigeon counts based on eBird data. The declining trend was caused by a combination of deforestation and poaching (illegal hunting).

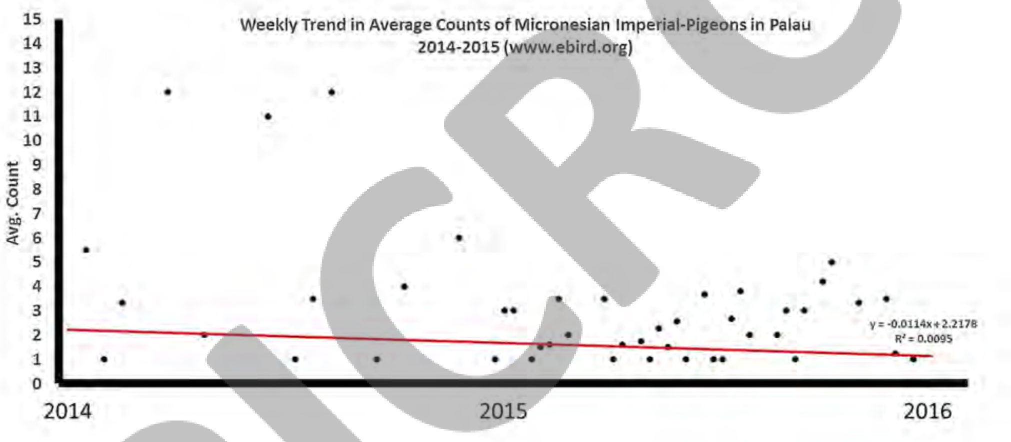

Figure 11-2. Decline in Micronesian Pigeons based on citizen scientist reports.

A useful method for estimating the total population of a species is to count as many as possible in as short a period of time as possible. In 2014, the scientists of the national program used this method to estimate the number of Rufous Night Herons (*melebaob*) in Palau. This species is an important indicator of the health of coastal wetlands with mangrove habitats. The herons are easy to count at low tide, when they emerge from their roosts in the mangroves to search the exposed tidal flats for prey. Local scientists counted these birds in as many coastal localities as possible during a low-tide cycle from June

4-7, 2014. The counts covered over half of the heron's coastal wetland habitat in Palau. The next table shows the results of the counts, a cumulative total of 552 birds.

Rufous Night-Heron Counts			
Locality	**No. Adults**	**No. Immatures**	**Total**
Eastern Babeldaob	109	6	115
Western Babeldaob	174	0	174
Northern Babeldaob	162	13	175
Southern Babeldaob/Koror Complex	66	19	85
Inland Sites	3	0	3
Total	**514**	**38**	**552**

Source: A. Olsen and M. Eberdong, 2014. *Western Birds* 45:231-235.

Scientists reasoned that if half of the herons' habitat was covered during the counts then the total population of Rufous Night Herons in Palau is approximately twice the number counted. That value, roughly 1,100 to 1,200 birds, became the baseline for measuring future changes in the abundance of the Rufous Night Heron as an indicator of the health of coastal wetlands.

Figure 11-3. A Rufous Night Heron catching fish on the tidal flats.

An "area search" is a method used by scientists to monitor a particular species of birds. For this method, the scientists conduct a comprehensive search for signs of the target species including birds seen or heard, nests, tracks in the dirt, or other evidence of bird activity. This method was used by scientists from the national program to survey Palau for nests of the endangered Palau Megapode (*bekai*) over a three-year period (2011-2013). Megapode nests consist of mounds of soils and forest litter that can be up to 3 ft. high and 6 ft. in diameter. The nests are located in permanent nesting grounds, usually near a beach. The scientists searched 122 uninhabited beaches and found 173 active nest mounds distributed among 53 of the beach sites. The largest numbers of nesting mounds were found in the Rock Islands Southern Lagoon UNESCO World Heritage Site and on Kayangel Atoll. Based on their searches and the number of nesting mounds, the scientists estimated the megapode population of Palau to be approximately 350 birds. The survey also found that most of the nesting grounds are low-lying coastal localities that are vulnerable to inundation from typhoons and "king" tides that are a consequence of climate change.

Figure 11-4. Palau Megapode – Bekai.
Source: A. Olsen and M. Eberdong, 2016. *Western Birds* 47:27-37.

The Micronesian Imperial-Pigeon, Rufous Night Heron, and Palau Megapode are resident species that spend their entire life in Palau. Palau is where they build their nests, lay their eggs, and raise their young. Over half of the bird species that are found in Palau are migratory birds, not full-time residents. The migratory species of Palau do not nest here. Instead, they build their nests and raise their young in northeast Asia and the Arctic Circle. Every year when summer ends and weather in the north becomes too cold to survive, migratory birds fly long distances to spend the winter months in warmer places. Many of these travelers, called **passage migrants**, come through Palau on their way to and from Australia or New Zealand. Many others, called **overwintering migrants**, stay in Palau until the weather becomes warm again in the north and they can safely return to their nesting grounds to resume the cycle of life. The migratory season in Palau begins every September with the arrival of migratory birds from the north and lasts to the next April or May when they depart on the return flight to their nesting grounds.

Although migratory birds can be found throughout Palau there is an Important Bird Area (IBA) in Peleliu, named the **Northern Peleliu Lkes IBA**, that attracts large numbers of the group of migratory birds known as the shorebirds (plovers, sandpipers, and related species). Every September, thousands of shorebirds arrive at the IBA because the intertidal sand flats (*lkes*) of Lkes IBA are a rich source of the small fish and marine invertebrates that are their primary food. In 2015 BirdLife International, an influential international organization for the conservation of birds, designated the Northern Peleliu Lkes IBA the "most important site for migratory shorebirds in Micronesia and Oceania" in recognition of the diversity and large numbers of shorebirds that gather there during migratory season.

Monitoring the flocks of shorebirds at the IBA is challenging because of the large numbers of birds and their tendency to move about while scientists are trying to count them. One solution is to photograph the flocks and count the birds from a picture (***below, Figure 11-5***) with their movements frozen in time.

Figure 11-5. Flock of 190 shorebirds at the Northern Peleliu Lkes IBA. Photo by Glenn McKinlay.

Palau's scientists are part of a global network of concerned scientists who monitor and study migratory shorebirds and who use their knowledge to protect the birds and their coastal wetland habitats. Monitoring migratory shorebirds is important because the shorebirds of eastern Asia are in danger of extinction due to overdevelopment and the resulting loss of coastal habitats along their migratory route. The Northern Peleliu Lkes IBA is one of the few shorebird resting places that remains unspoiled.

For Palauans, the most important shorebird to visit the IBA is the Far Eastern Curlew, better known as *Delerrok*, the Palau Money Bird (***Figures 11-6 and 11-7***). This iconic species is endangered and could become extinct if Palau and the other countries where it stops during the migratory season fail to protect its habitat. Palau is party to the United Nations Convention on the Conservation of Migratory Species of Wild Animals which mandates the protection of the habitats of migratory shorebirds such as Delerrok; yet the IBA in Peleliu where the species is usually found is not protected by Palauan law.

Figure 11-6. Far Eastern Curlew, *Delerrok*.

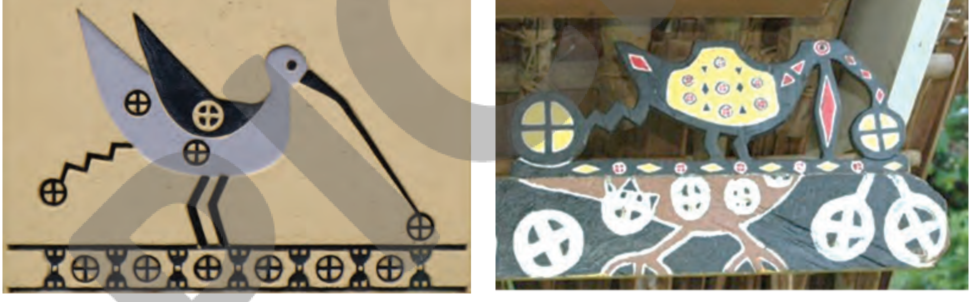

Figure 11-7. Above: Depictions of the Palau Money Bird, *Delerrok* (Far Eastern Curlew), from the Palau Capitol (left) and the traditional *abai* at Belau National Museum (right).

The Far Eastern Curlew is often confused with a similar shorebird, the Whimbrel (*okak*), which also migrates to Palau. The Far Eastern Curlew is distinguished by its large size. It is the largest migratory shorebird in the world. The Far Eastern Curlew also has a much longer beak than the whimbrel. The Far Eastern Curlew is endangered while the Whimbrel is not. The pictures below compare the physical differences between the Far Eastern Curlew (left) and the Whimbrel (right).

Figure 11-8. Far Eastern Curlew, *Delerrok*.

Figure 11-9. Whimbrel, *Okak*.

Scientists of the National Program for Monitoring Forest and Coastal Birds regularly post their observations of resident and migratory birds on the eBird website to share the information with the global community of bird conservationists as well as local and visiting bird enthusiasts. Interested students can use the "Explore Data" tab on the website to learn more about our resident birds and to follow the migrations of the Far Eastern Curlew and other shorebirds.

The research described in this report was conducted by the National Program for Monitoring Forest and Coastal Birds and funded by the Global Environment Facility Small Grants Program through UNDP, the Marisla Foundation via the Global Greengrants Fund, and the Royal Forest and Bird Protection Society of New Zealand through BirdLife International.

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Chapter 12

ROLE OF RIVERS

Makoto Tsuchiya

Critical Thinking:

What kinds of materials are rivers transporting?

Millions of people live along rivers, near river mouths, and in riverine regions in the world. The high density of human populations in watersheds draining into rivers and aquatic ecosystems causes this zone to be one of the most vulnerable to anthropogenic impacts. These impacts affect the coastal zone as well, including coral reefs, seagrass beds, and offshore habitats. On a global scale, riverine nutrient and organic matter fluxes within coastal areas have increased dramatically as a consequence of urban development, agriculture, and industrialization.

Organic matter and nutrients support the lives of animals and plants in shallow waters. However, increased organic carbon and nutrient loading contribute to the eutrophication of coastal areas. Eutrophication is the excess input of organic matter and nutrients into water bodies, which causes degradation of water quality, phytoplankton blooms, loss of seagrass beds, and mass mortality of corals.

Figure 12-1. This river is carrying a large number of fallen leaves on the surface. Photo by M. Tsuchiya.

Disturbing any of these processes causes other adverse effects including diminished aesthetic value, decreased human utility, human illnesses, and economic loss.

Biogeochemical processes transform nutrients during transport through river systems, ultimately controlling the distribution, flux, and fate of organic matter. In Palau, these processes are threatened in dense, populated areas. River systems play a critical role on island ecosystems.

Ecosystem services of rivers

Several important ecosystem services are recognized in river systems as follows:

- Self-purification
- Retention of nutrients and sediments in rivers
- Fishing, breeding, and nursery grounds for fish and shellfish
- Climate regulation
- Sites for leisure and recreation
- Protection of native species

Figure 12-2. Rivers in Palau. Photos by M. Tsuchiya.

Many Palauan livelihoods like taro farming and fishing are linked to rivers and their health. Rivers provide benefits such as being a source of drinking water and irrigation, and being sites for recreation and tourism.

Large amounts of terrigenous (originating from land) fine particles are carried by rivers to the coral reef during heavy rains. Fish and shellfish are impacted by these turbid conditions. Golbuu et al. (2011a, b) studied the effect of river discharge on coral reef ecosystems in Palau and reported that earth-moving during land development is significantly correlated to an increase in river runoff and suspended solids concentrations and that coral cover and coral diversity are significantly lower on nearshore reefs versus offshore reefs. More scientific research is needed to understand what management systems are needed to ensure sustainable land use along rivers.

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Photo by Geraldine Rengiil.


Photo by Mark Priest.

PART 3

Mangrove Forests

Chapter 13

UNIQUE CHARACTERISTICS OF MANGROVES

Makoto Tsuchiya

Critical Thinking:

What are mangroves?

Mangroves are forests that consist of trees, shrubs, herbs, vines, and ferns growing in coastal regions such as the inner part of a bay or a brackish zone with freshwater and saline environments. Mangroves occur in the tropical and subtropical regions. The broad definition of a mangrove ecosystem is all plant and animal assemblages living in such an environment and their habitats. Mangrove forests are sometimes called mangal.

Mangroves have these characteristics:

1. Their habitats are usually restricted to coasts, river mouths, or the inner part of a bay, and they do not expand their distribution to above the high tide mark.
2. They have specialized root systems.
3. Some tree species produce viviparous seeds.
4. Taxonomically, mangrove trees are isolated from other terrestrial species.

Viviparity

Bruguiera, *Ceriops*, *Kandelia*, and *Rhizophora* are mangrove tree species that produce viviparous fruits, which germinate while still attached to their parental tree. Propagules or seedlings start their growth on their mother trees.

Figure 13-1. Examples of mangroves in Palau. Photos by M. Tsuchiya.

Why are many mangrove species viviparous? Viviparity is only found on mangrove tree in Palau. This is probably a reproductive strategy of species inhabiting brackish waters where big fluctuations of salinity occur. What kind of scientific information should we gather to confirm this speculation?

Dispersal of propagules by currents

Once the propagule drops from the parent tree, there is an obligate dispersal period in which each propagule must remain in the water column. During this period, embryonic development continues. This is an important process to maintain the species and for expanding their distribution area.

For the red mangrove in Florida (USA), *Rhizophora mangle*, this dispersal period is reported to be 40 days. The propagules of the black mangrove, *Avicennia germinans* must drift for at least 14 days. The dispersal period of propagules of the white mangrove, *Avicennia marina,* is only 5 days for embryonic development and germination.

Figure 13-2. Mangrove propagules stranded on a shore. Photo by M. Tsuchiya.

If the propagule is floating and arrives in a suitable habitat, there is an obligate stranding period before the primary roots and cotyledons (primary leaves) emerge. The red mangrove has the longest obligatory stranding period of 15 days. During this period, the propagule may be either be lying horizontally on the sediment or vertically "standing up" or may be covered by water.

Root system

Mangrove trees have a complex and unique root system to adapt to salt water, wave action, and low oxygen concentrations (anaerobic conditions) within the muddy zone:

1. **Stilt-roots**: The species of *Rhizophora* form branched aerial roots, from the lower branches of the tree. They become shallow stands to support the position of the adult tree (***Figure 13-1***).
2. **Pneumatophores**: *Avicennia* and *Sonneratia* have buried root systems that grow in all directions from the main stem (***Figure 13-3***). A number of short vertical aerial roots erect in various heights. These aerial roots are an adaptation for gas exchange and grow up to 3 m in height in an anoxic environment.

3. **Knee roots**: The root system of *Bruguiera* is characterized by knee-shaped aerial roots. The horizontal underground roots of these species grow upward and loop downwards, resulting in the formation of a knee shaped root structure. The aerial root is used for gas exchange.
4. **Plank roots**: This kind of root is found in *Xylocarpus* growing outward and upward from the horizontal root. This type of root can help anchor the tree in an unstable environment and the exposed root enables gas exchange.

Figure 13-3. Top and Bottom: Pneumatophores. Photos by M. Tsuchiya.

Chapter 14

DISTRIBUTION OF MANGROVE SPECIES

Makoto Tsuchiya

Critical Thinking:

How are mangroves distributed in different regions?

Mangroves are very abundant around river mouths and the inner part of bays on Babeldaob and Koror (***Figure 14-1***). In 2009, mangroves were found along an estimated 80% of the coastline of Babeldaob, with the remaining 20% comprised of tidal flats, sandy beaches, and coral reefs (Colin, 2009). In 2014 there were approximately 50 km^2 of mangroves in Palau, with 90% in Babeldaob, 10% around Koror and the Rock Islands, and 10% around Peleliu. Mangroves do not occur naturally in Angaur (Cole et al, 1999).

On Babeldaob, mangrove forests are distributed over several hundred meters from the river banks to inland areas extending one km upstream from estuaries. Exploring the mangrove forest from the river mouth to an upstream area, we can observe the distribution pattern of mangrove species. Along the seafront, *Sonneratia alba* and *Rhizophora mucronata* are common, whereas *R. apiculata* dominates the river mouth regions. *Xylocarpus granatum* and *Nypa fruticans* can be observed upstream.

Some of Palau's mangrove species

Sonneratia alba

The mangrove apple, *Sonneratia alba*, is widely distributed along the coasts of the tropical Indian Ocean and Southeast Asian countries as well as northern Australia and the Pacific Islands.

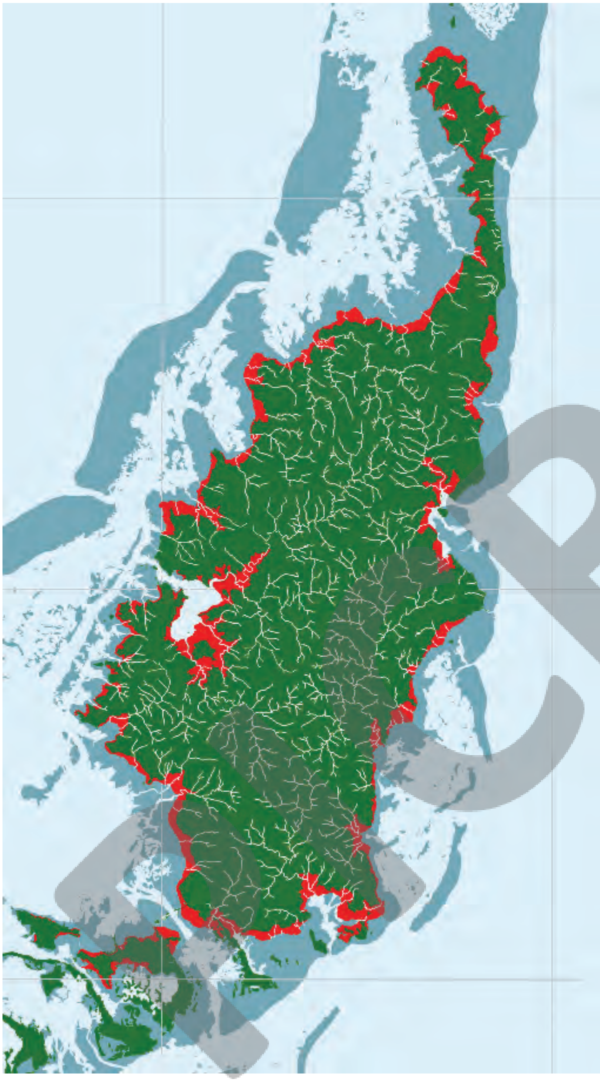
Figure 14-1. Mangrove area in Babeldaob Island (red zone). Source: Colin, 2009.

In Palau, this species occurs around the seaward edge of the mangrove forest. However, the edge is sometimes occupied by other species such as *Rhizophora mucronata*.

Sonneratia alba can grow up to 15 m tall and has large numbers of specialized roots called pneumatophores which are cone-shaped. The leaves are round, leathery, opposite, and have a similar upper- and under-side. The flowers are white and pom-pom-like and open only at night. The fruit are large (4 cm), green, leathery berries with a star-shaped sepal containing 100-150 tiny seeds that are white, flattened, and buoyant.

S. alba can tolerate a wide range of salinity. They may store excess salt in old leaves which they later shed. They are able to sur-

Figure 14-2. *Sonneratia alba* tree. Cone shaped pneumatophores (left) and fruit (right). Photos by M. Tsuchiya.

vive inundation by salt water twice a day, and exist in unstable soil under harsh environmental conditions.

Rhizophora mucronata

This species is a small to medium size evergreen tree growing to a height of about 20 to 25 m along the sea front. On the fringes of the mangrove forest in channel mouths it is smaller, only 10 or 15 m. The tallest trees are near the seaward edge of the forest and the shorter trees are closest to land. The tree has a large number of aerial stilt roots that buttress the trunk (***see Figure 13-1***). The stilt root begins to elongate and may reach a length of 1 m or more.

Propagules detach from the branch when sufficiently developed, being carried by water currents until they take root in the mud.

Rhizophora apiculata

This tree is 20-30 m tall. The bark is dark grey and checkered. It has conspicuous arching stilt roots that can extend 5 m up the stem. Many aerial roots emerge from the branches so that the tree appears to have a skirt of roots under the leaves. The leaves are eye-shaped (8-15 cm long), glossy green and stiff, with tiny evenly distributed black spots on the underside. The stipule is usually red.

The flowers (1-2 cm) grow in pairs on very short stalks so they appear to be stuck directly onto the branch. The calyx is globular, hard, thick, and brown on the outside and yellow on the inside. The petals are yellow to white, flat, membranous, and hairless, and fall off soon after blossoming. The fruit looks like a brown, upside down pear (about 2 cm) and is crowned by short persistent sepals. The cylindrical hypocotyl can be up to 38 cm long, somewhat smooth, and green then ripening into purple.

Xylocarpus granatum

This tree is 3-8 to 20 m tall. The bark is smooth, reddish or orange, and flakes off in patches, revealing greenish new bark. The overall appearance is blotchy and resembles the camouflaged uniforms of soldiers. The trunk base of older trees is usually enlarged with well-developed buttresses forming narrow ribbon-like undulations extending away from the trunk.

The thick and leathery compound leaf is comprised of 2-4 pairs of leaflets (3.5-12 cm long) that are oval or oblong (with a rounded rather than sharp tip) in shape. The leaves are arranged in a spiral and wither to an orange red.

The flowers are tiny (0.5 cm), white to pinkish in color, and grow in clusters. The flower has a “strong but pleasant” scent. Some insects can be seen on the flowers as visitors. The shape of the flower

Figure 14-3. *Xylocarpus granatum*. Photos by M. Tsuchiya.

suggests it is pollinated by short-tongued insects. It appears to bloom seasonally. *X. granatum* trees on various shores in Singapore bloom at the same time.

The fruit is globular and large (10-25 cm in diameter) and has a cannon-ball or bowling-ball shape with brown corky seeds, sometimes used as a game similar to a 3-D puzzle by children in Palau. "*Granatum*" means "full of seeds." The angular seeds fit perfectly inside the round fruit. But once spilled from the fruit, the seeds are hard to fit back together. So the tree is sometimes called the "Puzzle nut" mangrove or "Monkey puzzle" tree. There are usually 8-10 seeds in a single fruit, although up to 20 seeds have been recorded. The fruits develop rapidly, with usually only one fruit per inflorescence. The ripe fruit can weigh 2-3 kgs.

When ripe, the fruit splits open and/or drops off the tree and shatters, releasing bouyant seeds that float away with currents. The seeds may start to germinate as they float.

Nypa fruticans

This mangrove palm tree is tall, with leaves that are very long (5-9 m). The base of the frond is filled with air so it can remain upright even when submerged. The "stem" of this palm is mostly horizontal and even underground, thus called a **rhizome**. It is very stout (up to 70 cm in diameter), creeping in mud, with diagonal leaf scars. The portion of the stem that is vertical is very short. Shoots emerge along the stem, each bearing the long leaves. Pure stands of these palms often appear because of their habit of growing from underground stems. The massive, dense underground stem and root system can resist swift running water better than most other mangrove species.

Flowers appear on a long stalk (1 m), as an inflorescence. Female flowers are encased in bracts and resemble a cone. Male flowers appear as a long spike and when ripe are golden yellow with sticky pollen. *Drosophila* flies appear to be the agent of pollination. Bees may not be important pollinators as they only visit the male flowers and not the female flowers. The small flies, however, visit both kinds of flowers and appear to complete their life cycle in the branches of the male inflorescence.

Fruits are chestnut brown in a cluster, forming a globular shape (20-25 cm). Each fruit bears one seed which starts to germinate while still on the parent palm and just when the fruits drop off, the seedling is ready to pierce through the husk of the fruit. The fruits are fibrous with air cavities in the seed coat and fruit coat that help keep the seedling afloat.

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Figure 14-4. *Nypa fruticans*. Photo by M. Tsuchiya.

CHAPTER 15

FOOD WEBS IN A MANGROVE ECOSYSTEM

Makoto Tsuchiya

Critical Thinking:

What are the feeding relationships in a mangrove forest?

Structure of an ecosystem

Each ecosystem is composed of three basic functional groups: producers, consumers, and decomposers (***Figure 15-1***).

1. **Producers**: Higher plants and algae utilize energy directly from the sun and create their own glucose through photosynthesis. Producers are at the base of the food chain. The sun is the main source of energy that drives the food web in the mangroves.
2. **Consumers**: These are organisms that eat other organisms for nutrients and energy to grow and reproduce. This group is further divided into three subgroups:
    - **Herbivores** are organisms that derive their energy and nutrient requirements from plants.
    - **Omnivores** are organisms that derive their energy and nutrient requirements from both plants and animals.
    - **Carnivores** are organisms that derive their energy and nutrient requirements from animals.
3. **Decomposers** are organisms (e.g. bacteria, worms, centipedes, fungi) that break down organic materials from dead trees or animal carcasses. Decomposers derive nutrients and energy from dead animals and plants, and in the process mineralize or release nutrients that primary producers can then use.

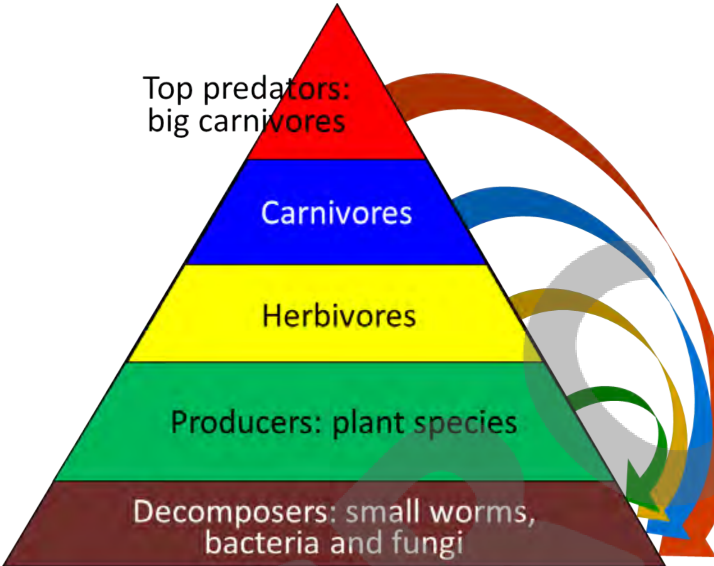

Figure 15-1. Ecological pyramid of an ecosystem. All animal lives are supported by the biomass of producers. Fallen leaves, dead trees, and animal carcasses are decomposed by decomposers, such as bacteria, fungi, and small worms. The number of top predators, such as crocodiles, is thought to be controlled by the abundance of producers.

The microbes and invertebrates that provide decomposition services are often collectively called **sarcophagus**. Examples of decomposers in the mangroves include bacteria and marine worms (***Figure 15-2***).

Role of mangrove detritus

The massive quantities of detritus produced in a mangrove forest form the foundation of the ecosystem's food web, along with nutrients washed in by rivers and tides. They are the litter of twigs, bark, and leaves from the mangroves and the organic waste from animals. A riverine mangrove swamp can produce a large quantity of detritus each year. The physical environment aids the work of decomposers: the rise and fall of tides exposes litter to alternating flooding and exposure to air, which accelerates its breakdown.

Decomposition of mangrove litter

A variety of organisms use the organic detritus in the mangrove ecosystem. Fungi affix to it, sharing space with bacteria and algae; soon crustaceans and other larger organisms join the microscopic community. Crabs, amphipods, small fish, and other creatures may slice apart leaf bits, providing large-scale dismantling that contributes to decomposition.

Food webs in mangrove ecosystems

The cycling of organic matter or nutrients by decomposers supports the growth of algae, plankton, and other tiny organisms as well as mangroves themselves. Vast arrays of fish use mangrove swamps as nurseries and foraging grounds; some of these fish eat

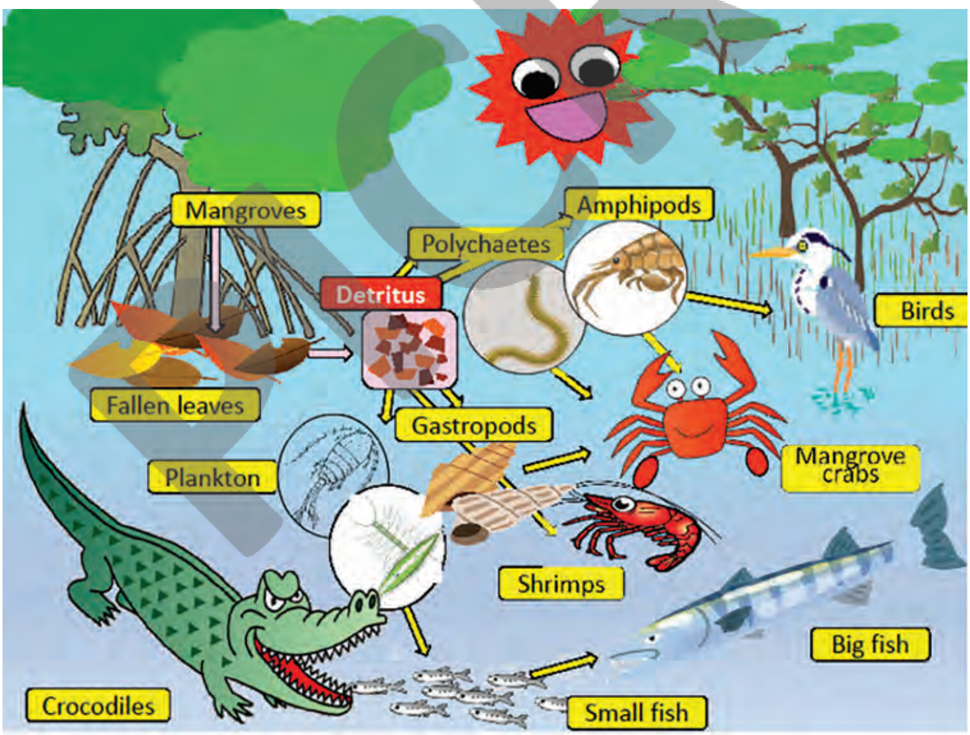

Figure 15-2. A food web in a mangrove ecosystem.

decomposing litter and, in turn, are eaten by predatory fish that ultimately sustain top-level consumers such as herons, ospreys, crocodiles, sharks, and humans. Indeed, the detritus-based food web of mangrove communities is key to fisheries throughout the subtropics and tropics: Florida's mangrove forests, for example, are reckoned to be the direct foundation of 90% of that state's commercial and recreational fishing industries (Whitney et al., 2004).

The mangrove ecosystem is characterized by the highly important detritus food chain. Mangrove litter is consumed by detritus feeders. The strong odor of hydrogen sulphide in the mud is due to the presence of anaerobic sulphur-reducing bacteria which thrive in the low oxygen conditions.

Some of the detritus is consumed by crabs and gastropods but the role of fungi and bacteria as decomposers is most important in making the food available to animals. These micro-organisms produce waste which, along with the even smaller mangrove litter, is eaten by molluscs, small crustaceans, and fish. Dissolved substances are consumed by plankton or, if they are on the mud surface, by animals such as crabs and gastropods (***Figure 15-2***).

Mangrove roots offer a sheltered region for many young organisms. In areas where roots are permanently submerged, the organisms living there include algae, barnacles, oysters, sponges, and bryozoans. Shrimp and mud lobsters use the muddy bottoms as their home. Mangrove crabs mulch the mangrove leaves, adding nutrients to the mud for other bottom feeders.

Crabs are the most abundant and important larger invertebrate in mangroves. When building their burrows, crabs improve the penetration of ground water, water from high tides, and freshwater runoff. This helps to flush out excess salt and reduce soil salinity. The burrows also increase oxygen levels in the mud by creating air spaces. Crab holes also provide a habitat for many organisms, including fish, molluscs, and polychaete worms.

Crabs are vital to the recycling of nutrients, in particular nitrogen. Many crabs eat large amounts of fallen mangrove litter while other species eat algae and detritus. The presence of crabs in these ecosystems has been shown to improve the growth of mangrove plants, and also increases the biomass and diversity of other organisms (Lee, 1998; Smith et al., 2009).

Top predators in mangrove ecosystems are crocodiles, big birds, and humans. The abundance of crocodiles is limited by the abundance of their foods which are controlled by the primary production of mangroves and other plant species.

Mangrove ecosystem services

Mangrove ecosystems are thought to provide the following services to humans:

1. **Storage of high quantities of organic materials and nutrients.** Mangroves grow mainly in river mouth regions, environments that accumulate various types of substances that flow from rivers. Mangroves function as warehouses for the storage of high quantities of organic materials and nutrients.

Figure 15-3. Fallen leaves of mangrove. Fragmented leaves are used by small animals such as crabs and gastropods as food. Photos by M. Tsuchiya.

2. **Sources of organic matter supply.** Large amounts of leaves, twigs, and flowers from mangrove plants fall to the mangrove forest floor, eventually breaking down and providing organic material to surrounding tidal flats and coastal areas. This material becomes food for small animals and serves as an important food source for coastal organisms.
3. **Environmental purification.** Mangroves and tidal flats are home to immense numbers of crabs and cone snails. When these animals feed, they reduce the amount of organic materials and excess nutrients in tidal flats. Thus they are able to purify their own habitats.
4. **Refuge for young coral reef fish.** During high tides, it is possible to observe small fish swimming in from the sea to forage among the roots of mangroves. Mangroves are an especially important place of shelter for young juvenile fish that live on the coral reefs.
5. **Habitats for birds, insects, and other animal species.**
    - During low tides, a variety of bird species rest and carry out feeding activities on the tidal flats that extend from mangrove forests. Birds deposit organic matter taken from other tidal flats in the form of droppings. Such biological processes cannot be ignored when large populations of birds are present.
    - The diverse types of birds inhabiting tidal flats are also of interest to birdwatchers. The use of tidal flats by birds is not random; some bird species use shorelines and water edges, and others feed with their feet slightly in the water. Although tidal flats may seem uniform, they are comprised of many different environments that are utilized by varying types of living organisms.
6. **Opportunities for food resources.** In Palau, an important resource in mangrove ecosystems is the mangrove crab, *Scylla serrata*. The Cooperative Research and Extension Department at the Palau Community College has successfully

bred mangrove crabs, and crablets are being distributed to aquaculture farms for grow out of mangrove crabs.

7. **Important resources for environmental education.** Mangroves have been widely studied by researchers and fascinating discoveries have been made. Academic studies have advanced our understanding of mangroves and the benefits that mangroves provide for communities. Environmental education programs aim towards better stewardship of our mangrove ecosystems.
8. **Ecotourism**. Ecosystem health is vital to the establishment and maintenance of the tourism industry. Dive shops operate because of the presence of healthy coral reefs and the opportunity to view corals and colorful fish, which as discussed, rely on the mangroves. Many tour companies also organize mangrove forest tours.
    - In recent years, eco-tourism has become increasingly popular, functioning as a source of revenue as well as contributing to the conservation of natural environments. The International Ecotourism Society (TIES) defines ecotourism as "responsible travel to natural areas that conserves the environment, sustains

Figure 15-4. Mangrove crabs (*Scylla* spp.) and land crabs (*Cardisoma* spp.) collected in mangrove forests and surrounding areas are available at restaurants in Palau. Photos by M. Tsuchiya.

the well-being of the local people, and involves interpretation and education." The number of tourists visiting mangroves as part of ecotours is steadily increasing in Palau.

- Tours with insufficient consideration of the environment, and which disrupt the natural balance, can lead to many problems. This kind of unsustainable activity is not categorized as eco-tourism. It is important to consider the nature of different types of eco-tourism as well as their participant capacities.

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Figure 15-5. Kayaking or canoeing is one of the popular recreation activities in mangrove ecosystem. Photo by M.Tsuchiya.

Graphics provided by the author.

CHAPTER 16

SNAILS ON MANGROVES

Makoto Tsuchiya

Critical Thinking:

Why do snails forage on mangrove roots?

Palao Tropical Biological Station

In March 1934, the Japan Society for the Promotion of Science (JSPS) opened a new research station, Palao Tropical Biological Station, near the edge of a mangrove passage near Arabaketsu Village (Present name: Ngerbeched) in Koror, with a great contribution by Professor Sinkishi Hatai of Tohoku University, Japan.

Figure 16-1. Palao Tropical Biological Station established by the Japan Society for the Promotion of Science in 1934.

Scientific research was carried out by a total of 29 young Japanese scientists until the closing of the station in March 1943. Despite its short history, their contribution to coral reef biology as well as to biology in general was significant.

At present only its gate remains, but a monument was placed beside the gate in 2001 (***Figure 16-2***), during a memorial event that coincided with the opening of the Palau International Coral Reef Center.

Figure 16-2. Left: Gate posts of the Palao Tropical Biological Station are now the only things remaining. Right: A monument was placed nearby in 2001.

Migration of small snails on mangrove roots

Although the main priority of research at the station was the biology of coral reef organisms, an interesting study on mangrove fauna was conducted by Professor Noboru Abe.

He observed an interesting behavior of the mangrove periwinkle, *Littoraria scabra*, which was formerly described as *Meralaphe (Littorinopsis) scabra* in his paper, in the mangroves just in front of the station, Iwayama Bay.

This species occurs mainly in mangrove swamps, particularly on their stilt roots and on leaves growing on the lower part of the tree, and also on breakwaters. Synchronized migration with tidal regime was observed mainly at night. Usually the snails are distributed between the mean tide level and 2 meters higher than the high tide level. They are found exposed to air.

When it is rainy or the temperature is higher than normal, they migrate at ebb tides. They stop the migration 10 to 20 cm above the water surface. When waves come, they move upward.

The tendency to move upward or to retrace their paths, which were marked in the downward migration in the ebbing tide, may appear to a higher degree than the tendency to avoid being submerged in water. Some samples of its migration is shown in ***Figure 16-4***.

Recently, similar research was conducted in Fiji (Alfaro, 2007). The migration patterns of *Littoraria scabra* on mangrove trees were investigated during incoming and outgoing tides. Using marked snails, their position was periodically checked during the tidal cycle. Snails were found to move quickly in the upward direction during incoming tides. During the ebbing tide, snails migrated downward, but their speed was slower than the upward movement. The slow movement upward was thought to be due to feeding on microalgae on the mangrove roots. Aggregation behavior during migration, which was not reported in Palau, was also recorded.

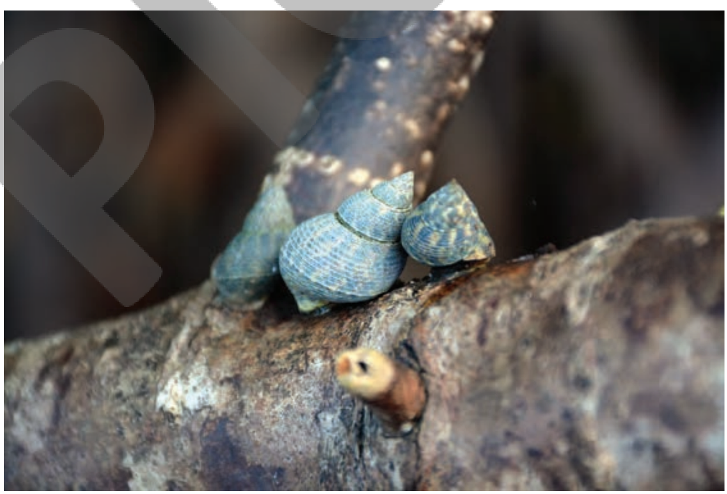

Figure 16-3. *Littoraria scabra*.

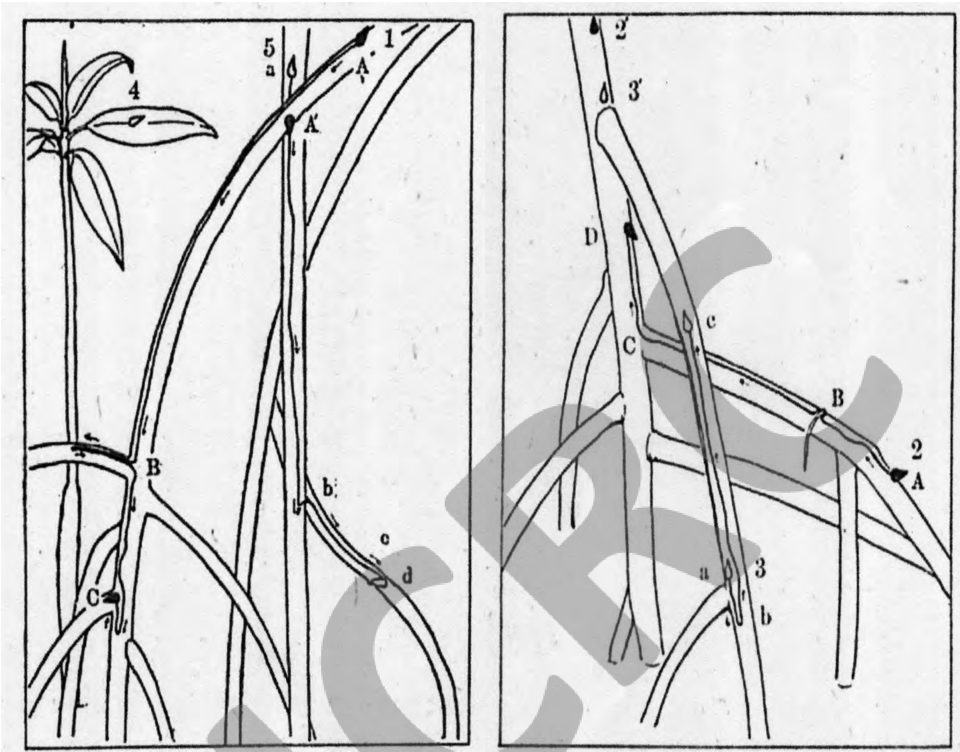

Figure 16-4. Records of migration of *Littoraria scabra* on mangrove roots by N. Abe (1942). They migrate both during rising and ebbing tides. *Left*: migration route at ebbing tide. Specimen 1 was resting at 45 cm from the water level. When the tide started going down, it also started moving downward, reaching C through B. It migrated 156 cm in about 1 hr. When it was staying around C, it sometimes immerged under the water surface. Specimen 5 also showed downward migration. Its total trip distance was 76 cm in 40 min. Specimen 4 on a leaf did not show any movement during the observation. *Right*: migration route at rising tide. Specimen 2 at A (22 cm above water level) started its upward migration 5 minutes after the start of the rising tide, and reached D through B and C. It travelled 69 cm in about 2 hrs. Specimen 3 at A also showed upward migration, but it showed downward movement just in the beginning of its migration.

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Except where sourced, photos provided by the author.

CHAPTER 17
MANGROVE CRABS

Miguel Delos Santos

Critical Thinking:
What are the different species of mangrove crabs in Palau?

Mangrove crabs locally known as "*Chemang*" are indigenous species of crustaceans that are widely caught from the mangrove areas in Palau for local consumption. These crabs are one of the favorite seafood delicacies served in most hotels and restaurants in the country (***Figure 17-1***). They belong to the genus *Scylla* and are also commonly known as swamp, mangrove, or mud crabs (Keenan et al., 1995). The juveniles usually dig and inhabit burrows in mangroves and soft-bottom shallow intertidal waters while the adults usually remain buried at day, emerging at sunset and at night to feed (Keenan, 1999; Shelley and Lovatelli, 2011). They are fished and farmed commercially due to increasing market demand and are considered as an important source of income and fresh food in many coastal communities (Overton et al., 1997; Le Vay, 2001; Shelley, 2008; Colin, 2009; Paterson and Mann, 2011; Meynecke and Richards, 2013; Pandiarajan et al., 2013). Worldwide, mangrove crabs are viewed as a luxury item where they are appreciated for taste and texture (Keenan, 1999; Pandiarajan et al., 2013).

There are many ways of collecting mangrove crabs in the wild. For juveniles and larger crabs, gear used includes: tangle nets, baited traps, lift nets, and trawls (Shelley, 2008; Le Vay et al., 2008); together with hand held hooks, scoop nets, and gillnets (Le Vay et al., 2008). Fine meshed push nets or dragnets can be used for crab larvae and tiny juvenile crabs that are yet to settle (Shelley, 2008).

Figure 17-1. Steamed mangrove crabs.

Mangrove crabs are known as top benthic predators and their diets are based on sessile or slow-moving benthic macro-invertebrates, mainly gastropods, crustaceans, and molluscs (Alberts-Hubatsch et al., 2015). The composition of their foods changes as the mangrove crabs grow. Small crabs are omnivorous, feeding opportunistically on smaller crabs and plants, whereas medium and large-sized crabs are carnivorous, feeding on benthic invertebrates or being opportunistic scavengers (Alberts-Hubatsch et al., 2015).

Recent classification of the mangrove crabs that was revised by Keenan (1999) lists the following species: *Scylla serrata, S. olivacea, S. paramamosain,* and *S. tranquebarica*. Among the four species of mangrove crabs, *S. serrata* is the largest, thus considered a candidate species for aquaculture (Keenan et al., 1998). They are most common in the Indo-West Pacific: from East and South Africa to Southeast and East Asia (from Southeast of China and Sri Lanka), and Northeast Australia. They are also commonly found east around the Marianas, Fiji, and Samoa Islands and were introduced into the Hawaiian archipelago (Alberts-Hubatsch et al., 2015). The rest of the four species of mangrove crabs are commonly found in countries in Southeast

Asia including Indonesia, Thailand, Vietnam, Malaysia, and the Philippines (Sugama and Hutapea, 1999; Keenan, 1999; Quinitio, 2004; and Truong, 2008). In Palau, *S. serrata* is also the most common species caught by fishermen (***Figure 17-2***) although occasionally, *S. olivacea* and *S. paramamosain* are also captured in the mangrove areas of Ngaremeduu Bay (Ewel et al., 2009).

The common diagnostic features of mangrove crabs include the following: 1) Carapace that is smooth, with strong traversal ridges; 2) Gastric zone on the carapace with a deep H-shaped groove; 3) Front with 4 broad lobes, all more or less in line with each other; nine broad teeth on each anterolateral margin, all with similar size and projecting obliquely outwards; 4) Strong chelipeds with well developed spines on the outer surface of the carpus and on the anterior and posterior dorsal parts of the propodus; and 5) The carapace is green to almost black with legs that may be marbled (FAO, 2017).

Figure 17-2. The two species of mangrove crabs caught by a fisherman in Palau: *Scylla serrata* (top left and right) and *S. olivacea* (center below).

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Photos provided by the author.

CHAPTER 18

EFFECTS OF CLIMATE CHANGE ON MANGROVE ECOSYSTEMS

Makoto Tsuchiya

Critical Thinking:

What is the effect of sea level rise on mangrove ecosystems?

One of the important climate change impacts affecting mangrove forests is sea level rise. When relative sea level rise is the predominant force shaping mangrove position, the landscape-level responses of mangroves over long periods can be predicted based upon the reconstruction of the paleo environmental response of mangroves to past sea level fluctuations.

Mangroves are understood to actively move towards a climax community through sediment accumulation and colonization.

There are three general scenarios for mangrove response to relative sea level rise, given a landscape-level scale for time periods of decades or longer (Gilman et al., 2007).

1. If the sea level is rising relative to the mangrove surface, the mangrove's seaward and landward margins retreat landward, and the mangroves species zones migrate inland as they maintain their preferred period, frequency, and depth of inundation, as the seaward margin dies back (***Figure 18-1***). The mangrove may also expand laterally if areas adjacent to the mangrove, which are currently at a higher elevation than the mangrove surface, develop a suitable hydrologic regime. The seaward mangrove margin migrates landward from mangrove tree die back due to stresses caused by rising sea level, such as erosion, that result in weakened

Figure 18-1. Effect of sea level rise on mangroves. When sea level is rising (1), mangroves should move landward (2), where competition with terrestrial plant species may occur (3). Source: Modified from Gilman et al., 2007.

root structures and the falling of trees, increased salinity, and too high a period, frequency, and depth of inundation. As a mitigation measure, people can try to transplant some mangrove trees nearby.

2. When mangroves grow landward and outcompete with other terrestrial plant species, the area of mangrove forest will be sustained.
3. If mangroves are unable to compete successfully with other plant species, the habitat will be reduced. A similar phenomenon will occur in cases where there are obstructions such as houses and breakwaters that limit mangrove migration.

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Figure 18-2. Mangrove trees along the Indonesian coast impacted by strong wave action or sea level rise. Photos by M. Tsuchiya.

Figure 18-3. Transplantation of mangroves in Indonesia. Many young trees were planted in front of the natural mangrove forest. Photos by M. Tsuchiya.

CHAPTER 19

DYNAMICS OF ORGANIC MATTER IN A COASTAL REGION

Makoto Tsuchiya

Critical Thinking:

Does the mangrove zone store organic matter?

As we have learned earlier (***see Chapter 15***), large amounts of leaves, twigs, and flowers from mangrove plants fall to the mangrove forest floors, eventually breaking down and providing organic material to surrounding tidal flats and coastal areas. This material becomes food for small animals and serves as an important food source for coastal organisms.

In order to know the basic information on the dynamic process of organic matter in a coastal region, a preliminary study of the distribution of organic materials was conducted at a river mouth area in Ngiwal (***Figure 19-1, top left***).

The topography of this area along the Ngiwal coast is unique. The national highway loops around Babeldaob Island and crosses the bay, forming a semi-enclosed lagoon. In the center of the road's passage lies a tiny island named Lkes. Two small culverts allow movement of water and passage for small boats.

Waters in the lagoon are characterized by poor visibility and were observed to contain large amounts of suspended matter. Water flow and current velocity were low. Waters on the seaward side of the road was comparatively clearer. This suggested that little water exchange takes place between the lagoon and outer waters. Water surrounding the culverts is constantly exchanged due to tidal movements as well as outflow from the lagoon to the sea.

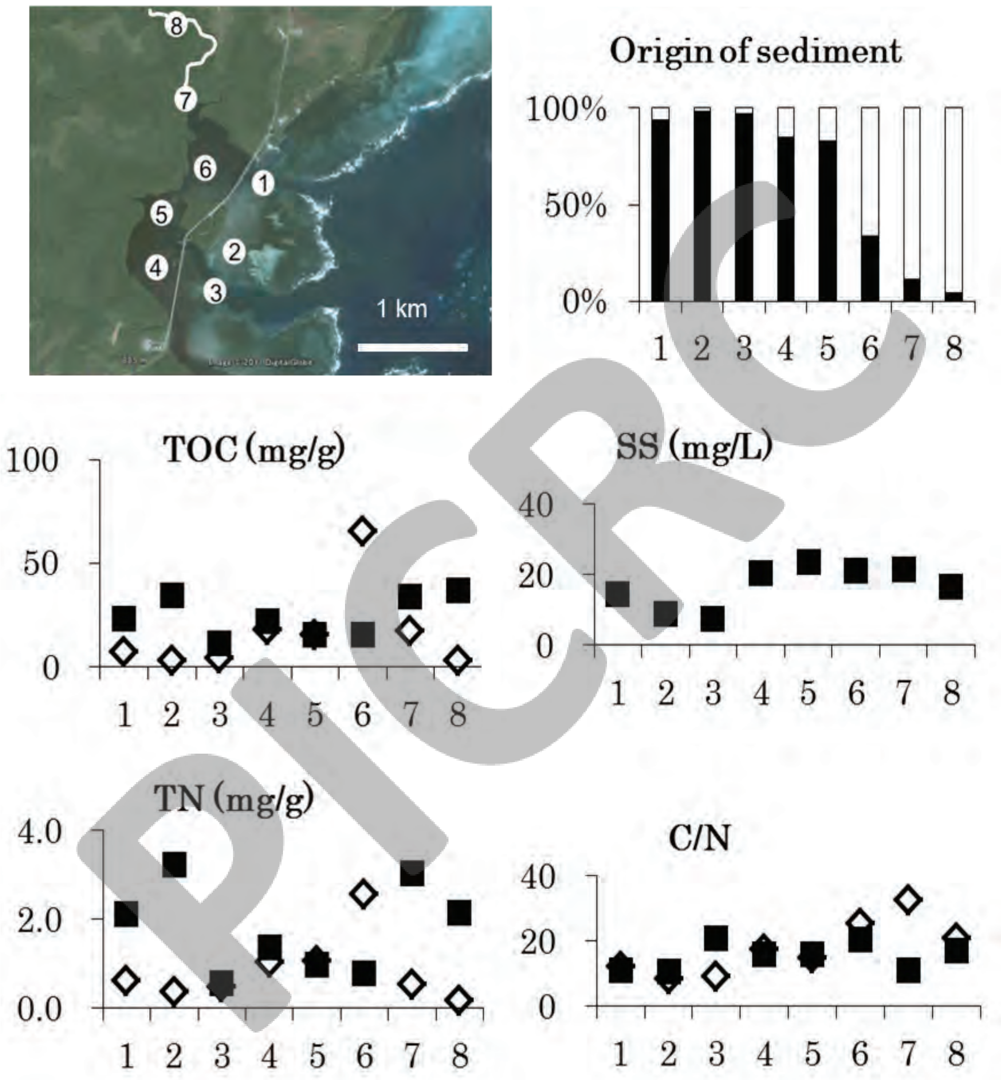

Figure 19-1. Stations (1-8) for collecting sediment and suspended materials at a river mouth area of Ngiwal, and results. Top right shows the composition of $CaCO_3$ (Black) in sediments. TOC: total organic carbon, SS: suspended materials, TN: total nitrogen, C/N: Carbon:Nitrogen ratio, ◇Sediments, ■: Suspended materials. Source: Tsuchiya et al., 2015.

It was hypothesized that organic materials in the sediments collected from the lagoon area were derived from mangrove plants and terrestrial origins, whereas those outside the lagoon were derived from phytoplankton. The effects of the road along Ngiwal's coast were visible.

Comparatively higher contents of calcium carbonate, higher than 80% in some cases, were found at sites 1–5 (***Figure 19-1, top right***). Calcium carbonate is considered to be biologically derived from corals, shellfish, and foraminiferans. As such, the above observations showed that, with the exception of river regions, bottom sediments in the marine areas surveyed had been influenced greatly by coral reefs.

Organic substance content analysis (total carbon content, ***Figure 19-1***) produced particularly high values at survey station 6. This suggests the formation of an environment where organic matter outflow from rivers tends to accumulate. At stations 4, 5, and 7 inside the lagoon area, comparatively higher contents of organic substances were detected.

CN ratio analysis of sediment samples taken from survey stations 6, 7, and 8, located between the estuarine region and upper reaches of the river, exhibited higher values. Commonly, high values for sediments containing substances derived from higher plants with thick cell walls suggest that a survey site, beginning with its mangroves, contains a significant accumulation of matter derived from higher plants.

Mangrove forests and enclosed lagoons thus store organic materials sourced from marine and coral reef areas.

A large amount of organic material will accumulate in mangroves and in the lagoon. It might be carried to coral reefs gradually and support many animals there. Of course, the organic matter is utilized by phytoplankton, seagrasses, and seaweeds when decomposed.

When data on the food sources of coral reef animals and data on the level of organic materials in foods that are derived from terrestrial plants, including mangroves, are collected, the connectivity among

Figure 19-2. Mangrove leaves floating on water surface or accumulated around mangrove roots. Photos by M. Tsuchiya.

coastal ecosystems will be clearer. We have shown a sample of this kind of research for sea cucumber (***see Chapter 23***).

Victor et al. (2004) studied the fate of fine sediment in the Ngerikiil and Ngerdorch mangrove-fringed estuaries around Babeldaob Island and reported that the sediment yield in Ngerikiil watershed is 10–19 times higher than in the less developed Ngerdorch watershed.

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Photo provided by PICRC.

PART 4
Tidal Flats and Seagrass Beds

CHAPTER 20

OBSERVATION OF FIDDLER CRABS

Makoto Tsuchiya

Critical Thinking:

Can a male crab eat enough using a single small claw?

Feeding behavior

Fiddler crabs (*Uca* spp., ***Figure 20-1***) are very common. Recently, the taxonomic status of *Uca* was re-examined and new genus names were proposed by Shihl et al. (2016). We used the popular genus name, *Uca*, in this article.

Fiddler crabs burrow in intertidal flat areas and are important consumers of detritus, bacteria, fungi, and benthic microalgae. Their burrowing activities can make oxidized conditions in the burrow or tidal flat surface, resulting in the occurrence of a large amount of aerobic bacteria or other micro- and meio-organisms there.

Fiddler crabs are considered to be semi-terrestrial crab groups and are active at low tides, returning to their burrows at high tides. The male crabs have one greatly enlarged claw, which can be up to 50% of its body weight and nearly the same length as its carapace width. The big claws are used for mating displays and for competition with other males to keep its territory around the burrow. Male crabs feed on sediments using only its small claw, while females have two small feeding claws.

One may ask if the male can get enough food using a single claw. In order to answer this question, we have to observe their feeding activities. In general, they are active on the tidal flat at low

Figure 20-1. Several fiddler crab species in Palau.

tide during the daytime. Several behavioral patterns of males are recognized: feeding, crawling, reproductive display, and resting.

During their feeding, a large number of feeding pellets are produced (***Figure 20-2***). These pellets are the aggregations of sandy particles after the selection of food materials in their mouth. First they pick up some amount of sediment, and then select foods from the sediment. The particles which are not ingested into the gut are consolidated into feeding pellets and then they are egested on the tidal flat. These pellets do not pass through their gut lining.

Figure 20-2. Feeding pellets produced by fiddler crabs. Difference in color is depending on the situation of sediments. Black or gray colored pellets are derived from the sediments in reduced environment and brown ones from oxidized environment.

Studies on the behaviors of four fiddler crab species in Indonesia (Weis and Weis, 2004) revealed that *Uca chlorophthalmus*, living in muddy mangrove areas, were inactive and spent most of the time feeding in place. Females fed 50% faster than males and spent more time feeding. *Uca vocans* was the dominant species at the muddy-sand areas. Its feeding rate was about twice that of *Uca chloropthalmus*. The females fed more rapidly than males, and many crabs of both sexes fed in droves at the water’s edge during low tides. Feeding aggregations of *U. vocans* have frequently been observed.

During low tide, they spent most of their time feeding, while at flood tide they engaged in a greater variety of activities, including burrow maintenance. They frequently walked while feeding and interacted aggressively. *Uca tetragonon* lived in a pebbly habitat in higher intertidal zones compared with the other two species. Their feeding rate was comparable in both sexes and slower than that of *U. vocans*; they fed largely on filamentous algae growing on the boulders, and fed faster during flood tide than ebb tide. The males spent more time waving their large claw and on other reproductive activities, and were seldom aggressive, except during the week of the full moon. *Uca dussumieri* also occurred in muddy substrates. They did not have any sex differences in feeding rates and their rate of scooping sediment into their mouths was slow, but the feeding claws made multiple pinches of the substrate.

Reproductive behaviors

During the reproductive season, male fiddler crabs put on a waving display using their claws to attract females. The pattern of waving is species-specific. Some species raise the big claw and wave from side to side. Some species repeat the rising and falling of the claw. When a female is approaching a male, the male will show more active waving to invite the female to its burrow for coupling. First, the male enters the burrow. If the female follows the male and enters the burrow, the "invitation" was successful. However, it is not so easy to observe this behavior in the field.

Finding an opportunity to look at the coupling of fiddler crabs on the tidal flat surface (***Figure 20-3***), we can see a male trying to catch a female for reproduction on the sand surface. Once the coupling starts, both male and female remain still and no movements are observed even when we approach for observation.

Fiddler crabs are excellent ecosystem engineers on the tidal flats. They excavate their burrow and repair them by digging out the sediments frequently. They do not use their burrows permanently. In some species it is reported that they use one burrow for several days

Figure 20-3. Other behaviors: Coupling of *Uca vocans*.

and then abandon it. New burrows will be constructed elsewhere.

During the incoming tide, they start to collect sediments on the tidal flat surface using their walking legs and cover the burrow entrance. They don't emerge from their burrows during flood tides.

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Photos provided by the author.

CHAPTER 21

BIOTURBATION BY GHOST SHRIMPS

Makoto Tsuchiya

Critical Thinking:

What organism makes sand mounds on tidal flats?

During low tides, you can observe many small sandy mounds on the tidal flats in Palau. Usually sea grasses with tiny leaves are growing there, but they are not found on the mounds (***Figure 21-1***).

In order to find out what organisms build these mounds, we have to dig out the sediments. However, it is not easy to collect them, because the animals that construct the mound live in the deeper part of the tidal flat.

These animals are callianassid shrimps (***Figure 21-2***). They are usually called ghost shrimps. They belong to the Callianassidae of the order Decapoda. These shrimps create a deep burrow (***Figure 21-3***) with a complex structure extending over 1 m into the sediment and carry a large amount of sediment to the tidal flat surface for as they repair their burrows. It looks like an erupting volcano when the sediments come out

Figure 21-1. A large number of sand mounds made by ghost shrimp (Palauan name: *Chelauesachel*) appeared on the sand flat at low tides. Photo by M. Tsuchiya.

Figure 21-2. Ghost shrimp (*Chelauesachel*).

of the hole during incoming high tides. The burrowing activity is called "bioturbation." This process modifies the biogeochemical characteristics of the sediments, interstitial water, and water column.

The ghost shrimp is common on many intertidal sandflats in the world. The substantial bioturbation activity of these shrimps has been shown to depress the density and abundance of smaller infaunal organisms because these organisms (e.g. polychaete worms and small snails) are unable to settle and recruit because of the shrimp's bioturbation.

Bioturbation has a positive impact. Large amounts of sediments are transported from the outer deeper part to the inner tidal flat surface. This conveyor-belt-like system brings water and oxygen from the outer deeper depths of the reef flat to the inner shallower depths which enables certain small benthic animals or aerobic bacteria to grow.

Ecological studies on the ghost shrimps in many tidal flats in the world have focused on the relationship between the ghost shrimp and other benthic organisms. According to field observations and experiments in South Africa, the ghost shrimp *Callianassa kraussi* negatively affected the development of sediment microbial biofilms and the recruitment of juveniles of most macrofaunal taxa. In areas where *C. kraussi* was absent or scarce, the abundance of microorganisms and the densities of recruiting macrofauna were 2 to

Figure 21-3. Burrow system of a ghost shrimp. Source: Felder, 2001.

4 times greater than in areas with dense populations of *C. kraussi*. The densities of juveniles of suspension-feeding taxa such as bivalves and a polychaete species were greater in areas where *C. kraussi* were rare. Some other bivalve and polychaete species were also more abundant in the exclusion treatment of the shrimp compared to those in the inclusion treatment (Pillay et al., 2007).

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Photos provided by the author.

CHAPTER 22

THE MOON SNAIL, SAND COLLAR, AND REPRODUCTIVE STRATEGIES OF BENTHIC ANIMALS

Makoto Tsuchiya

Critical Thinking:

What is in a sand collar?

Figure 22-1. A sand collar in which juveniles can be seen. Photo by M. Tsuchiya.

These frilly edged flat spirals are called sand collars (***Figure 22-1***) and are often seen on tidal flats in Palau. The sand collar is the egg mass of a marine benthic animal called a "moon snail." A moon snail (***Figure 22-2***) lays her eggs at night, combining these with mucus and sandy particles in a gelatinous sheet which hardens. The female snail lies at the center of the collar as she creates it, so the hole in the center of the collar gives an indication of the size of the mother snail. They

Figure 22-2. A moon snail. Photo by M. Tsuchiya.

are usually the same color and texture as the surrounding sand.

Each sand collar contains thousands of living eggs. When the eggs hatch, the collar disintegrates. Thus, an intact sand collar has a large number of living snails in it. It is important to not damage the sand collars.

The moon snail is a carnivore. Frequently we can find empty bivalve shells with small holes in the shell lying on the tidal flat (***Figure 22-3***). The moon snails feed on bivalves and snails. A moon snail wraps its huge foot around the prey species. A hole is slowly drilled through the shell with the radula.

Figure 22-3. Bivalve shells eaten by the moon snail. Photos by M. Tsuchiya.

Reproductive strategy of benthic animals

Among the benthic animals, this type of reproduction is unique. Marine benthic animals show a great variety of development modes. These modes differ depending upon the ecological niche they occupy during the development process, the spatial location of larvae, the trophic types, and the degree of parental care. Each type is found in all marine realms but distributed within different geographic regions.

Sexual and asexual reproduction

Sexual reproduction

In sexual reproduction, two individuals, male and female, produce offspring that have genetic characteristics from both parents. Sexual reproduction introduces new gene combinations in a population.

Asexual reproduction

Some animals reproduce asexually through fission, budding, fragmentation, or parthenogenesis.

Fission occurs in microorganisms and in some invertebrates. An organism splits into two separate organisms. This process occurs in many asteroids (echinoderms such as sea stars) through splitting of the central disk. Some coral polyps also reproduce through fission (***see Chapter 32***).

Budding is the outgrowth of a part of a body region that then separates from the original organism into two individuals.

Fragmentation is the breaking of the body into two parts with subsequent regeneration. If the animal is capable of fragmentation, and the part is big enough, a separate individual will regrow. Many sea stars reproduce asexually by fragmentation. When an arm of a sea star is broken off, it will regenerate a new sea star.

Parthenogenesis is a process where an egg develops into a complete individual without being fertilized.

Four types of larval development

1. **Planktotrophic development**: Many species have long pelagic larval stages in the water column. They have the potential to disperse over long distances. During their time in the water column, planktotrophic larvae feed on phytoplankton and/or small zooplankton including the larvae of other benthic species. Planktotrophic development is the most common type of larval development.
2. **Lecithotrophic development**: Larvae of this group generally have greater dispersal potential than direct developers. Many fish species and some benthic invertebrates have lecithotrophic larvae, which are provided with a source of nutrition to use during their dispersal, usually a yolk sac. These species have short pelagic larval durations and do not disperse long distances.
3. **Direct development**: This group has no larval stage and produces offspring showing very low dispersal potential and morphology of the offspring usually looks like the adult form of the animal called a juvenile.
4. **Ovoviviparity**: Embryos are developing inside eggs and remaining in the mother's body until they are ready to hatch.

CHAPTER 23
ROLE OF SEA CUCUMBERS

Makoto Tsuchiya

Critical Thinking:

What is the role of sea cucumbers in seagrass beds?

In Palau, tons of sea cucumbers have been harvested in the past for commercial export, but today export is prohibited by law. Overfishing of sea cucumbers has occurred in many countries. Fishery resources should be sustainably harvested for future generations and for integration of ecosystems in fisheries and nature conservation.

The feeding activity of holothurians plays an important role in changing sediment characteristics by removing substantial amounts of organic matter during their feeding process, i.e. ingesting and absorbing. This activity is essential to keeping coral reef ecosystems healthy. It has been shown that the efficiency of processing of the sediment and the amount of reworked sediment depends on the length and morphology of the digestive tract, particle sizes, and

Figure 23-1. Sea cucumbers in a seagrass bed. Photos by Y. Yano.

Figure 23-2. *Holothuria atra* is producing fecal pellets. Photo by Y. Yano.

digestive speed of the ingested sediments. These features vary among the holothurian species, thus sediment reworking efficiency is species-specific.

Holothurians feed on various organic detritus, bacteria, and foraminifera, which are rich sources of dietary lipids, particularly fatty acids, on the bottom surface. Fatty acids have been used as biomarkers to identify sources and fates of organic matter in marine environments, due to their structural diversity and high biological specificity. Specific fatty acids are synthesized by microorganisms, green algae and dinoflagellates, and animals that cannot synthesize essential polyunsaturated fatty acids. Since animals receive a considerable portion of their fatty acids through their diet, comparative analysis of the fatty acid composition in animal tissue can give us important information about their food sources. Namely, if a large amount of fatty acid that is synthesized by bacteria is found in a crab species, we can hypothesize that the main food of the crab must be bacteria.

Understanding the changes in the organic composition of plant detritus as it passes through the gut of sea cucumbers is important in order to identify organic inputs and their fate in marine sediments. Changes in fatty acid composition during passage through the gut of two sea cucumber species *Holothuria atra* and *Holothuria leucospilota* was studied in an Okinawan coral reef of southern Japan (Mfilinge

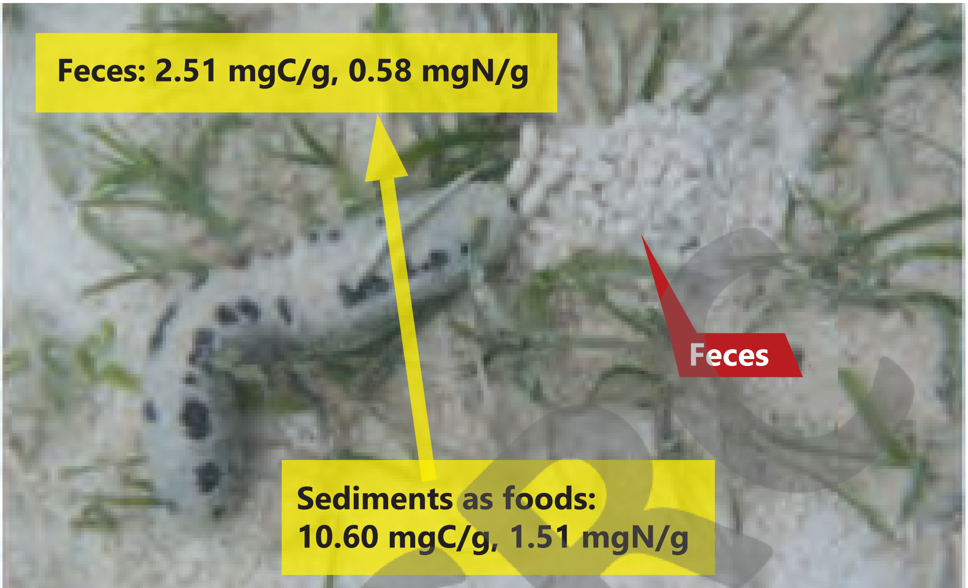

Figure 23-3. The amount of organic materials in the sediments is reduced by the feeding of sea cucumbers. Photo by Y. Yano.

and Tsuchiya, 2016). Fatty acid composition in the ambient surface sediment and fecal pellets was compared between the foregut, midgut, and hindgut.

Fatty acid composition and concentration changed significantly during passage through the gut of *H. atra* and *H. leucospilota*. Both species specifically selected algal and bacterial rich detrital particles which are rich in dietary fatty acids and assimilated dietary fatty acids in the tissues. Specific selection of organic rich particles was studied by measuring changes in fatty acid composition and the concentrations of some fatty acids in the foregut compared to the ambient bottom surface.

The levels of fatty acid biomarkers for bacteria, diatoms, dinoflagellates, and green macroalgae were also used as indicators that *H. atra* and *H. leucospilota* selected algal and detrital particles coated with bacteria. The significant decrease of most of the fatty acids in the hindgut and the complete elimination of some of the fatty

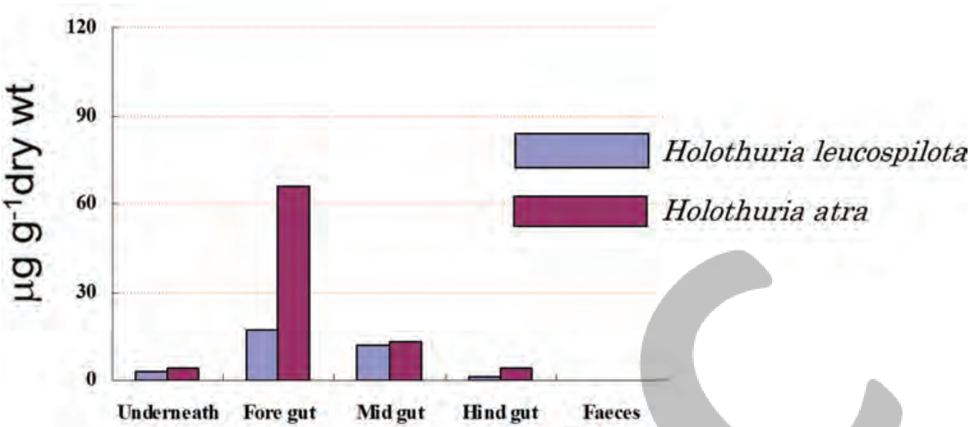

Figure 23-4. Changes in the fatty acid derived from bacteria in sediments, foregut, midgut, hindgut and feces of two sea cucumber species collected at the same rock pool. In the foregut, more quantity of fatty acid derived from bacteria was detected in *Holothuria atra* than *H. leucospilota*. Source: Modified from Mfilinge and Tsuchiya, 2016.

acids in faecal pellets were possibly due to selective absorption of the fatty acids during digestion. These findings have implications for nutrition, metabolic functions of holothurians, and the fate of dietary fatty acids in marine sediments.

Like many other taxa, the International Union of Conservation of Nature (IUCN) has placed 16 species of sea cucumbers on its Red List of Threatened Species. Nine are present in Palau. Among them four species are listed as endangered or are considered to be a species facing a very high risk of extinction: sandfish (*Holothuria scabra*), golden sandfish (*Holothuria lessoni*), black teatfish (*Holothuria whitmaei*), and prickly redfish (*Thelenota ananas*). The other five species are considered to be vulnerable to extinction, or are species that are likely to become endangered if no management measures are taken in the short to medium term: deep water redfish (*Actinopyga echinites*), surf redfish (*Actinopyga mauritiana*), hairy blackfish (*Actinopyga miliaris*), white teatfish (*Holothuria fuscogilva*), and curryfish (*Stichopus herrmanni*). All nine are shallow- to mid-water species. Golden sandfish, sandfish, hairy blackfish, and deep water redfish are restricted to very shallow mangrove-influenced and seagrass habitats.

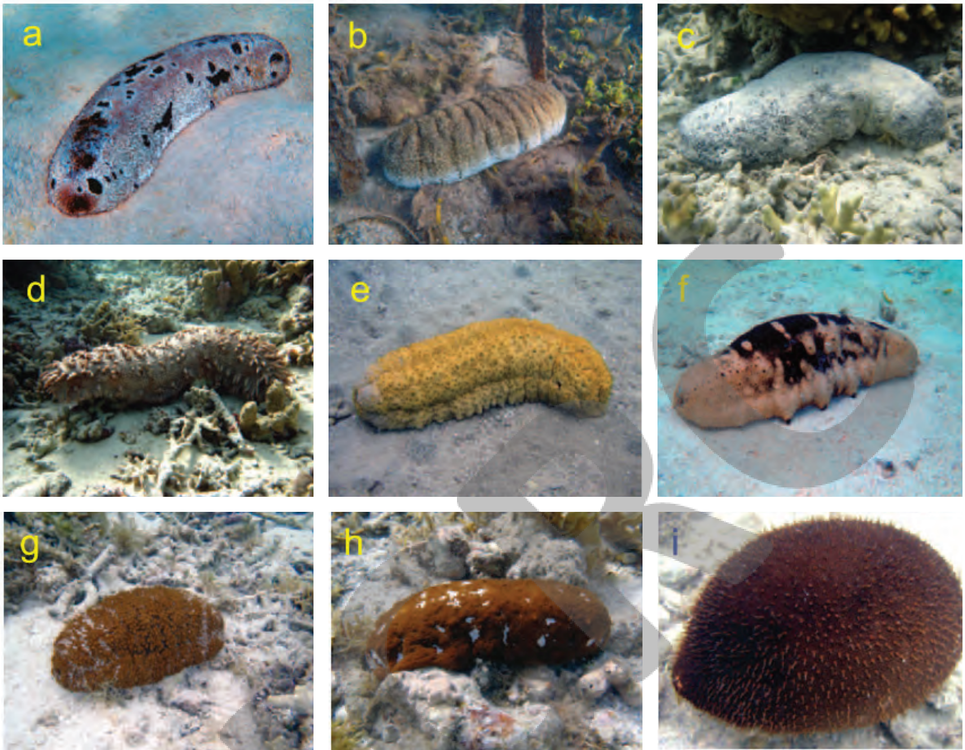

Figure 23-5. IUCN Red Listed sea cucumber species present in Palau: a) Golden sandfish (photo: Kalo Pakoa); b) sandfish (Photo: Kim Friedman); c) black teatfish (photo: Emmanuel Tardy); and d) prickly redfish (Photo: Emmanuel Tardy) are endangered with extinction. e) Curryfish (Photo: Kim Friedman); f) white teatfish (Photo: Kalo Pakoa); g) deepwater redfish (Photo: Kalo Pakoa), h) surf redfish (Photo: Kalo Pakoa); and i) hairy blackfish (Photo: Kim Friedman) are vulnerable to extinction. Source: Pakoa et al., 2014.

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CHAPTER 24

SEAGRASS ECOSYSTEM

Makoto Tsuchiya

Critical Thinking:

Why are seagrass beds important?

Seaweeds and seagrasses are systematically different plant groups in terms of their reproductive and morphological characteristics. Seagrasses are vascular plants with flowers, fruits, and seeds. They have a root system and underground nutrient stems called rhizomes that hold the plants in place. In contrast, seaweeds or algae produce spores for reproduction. Their holdfasts anchor plants to a hard surface and there are no roots extending below the surface.

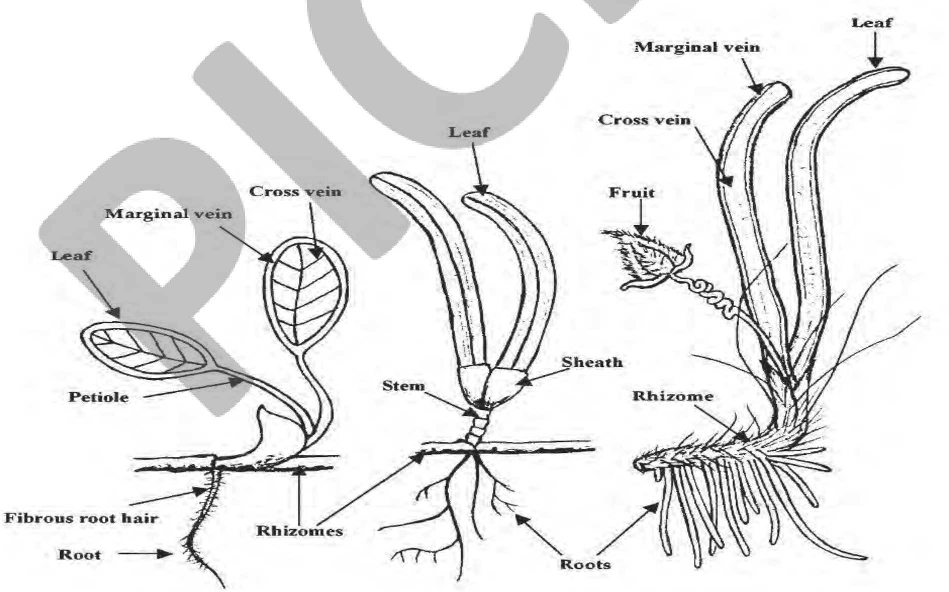


Figure 24-1. General Morphology of seagrasses. Source: *Tropical Marine Plants of Palau*, Ohba et al., 2007.

Seagrasses have rhizomes extending horizontally below the sediment surface. The rhizome is responsible for extending the plant's distribution. The rhizome provides anchorage and mechanical support. It also plays an important role as a structure for nutrient storage. Numerous long hair roots are present on the rhizome.

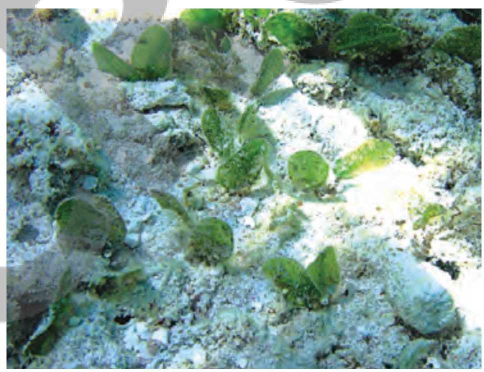
Stems grow at each rhizome node. Surrounding the stem is a protective basal sheath, which is often buried in the sediment. New leaves emerge within the leaf sheath. Leaves of seagrasses are covered by a thin, porous cuticle, across which the transfer of gases and solutes takes place. Different leaf types such as ribbon shape, oval shape and fern shape can be observed.

Seagrasses in Palau

A total of 10 seagrass species listed below have been recorded in Palau. Several species can be easily found in each local seagrass bed.

1. *Thalassodendron ciliatum*
2. *Cymodocea serrulata*
3. *Cymodocea rotundata*
4. *Thalassia hemprichii*
5. *Halodule pinifolia*
6. *Halodule uninervis*
7. *Halophila minor*
8. *Halophila ovalis*
9. *Enhalus acoroides*
10. *Syringosium isoetifolium*

Among them, a few species such as *Halophila ovalis* and *Thalassia hemprichii* are common and easily observed at low tides. They are widely distributed in tropical waters in the Western



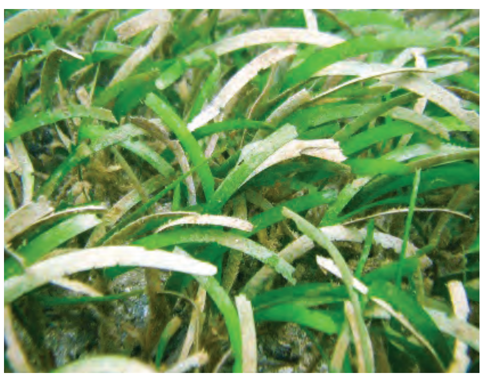


Figure 24-2. *Halophila ovalis* (top) and *Thalassia hemprichii* (bottom).

Pacific and Indian Oceans. *Enhalus acoroides* is also seen frequently at some places.

Halophila ovalis (Figure 24-2, top)

This seagrass species is native to Asia and the South Pacific. This species grows from a single rhizome in shallow, calm protected habitats. Sometimes it is observed in rock pools. The leaves grow to about 1.5 cm in length and 1 cm in width. *H. ovalis* is reported to tolerate a large range of salinities ranging from 20 to 40.

Thalassia hemprichii (Figure 24-2, bottom)

This is a dominant seagrass species in the western Pacific region, and especially throughout Micronesia and Melanesia. It is often associated with coral reefs and is common on reef platforms where it may form dense meadows. It can colonize muddy substrates, particularly in water pools at low tide.

It is the most widespread seagrass species in Palau, where it occurs in monospecific beds over a wide range, from the intertidal zone down to the lower subtidal zone.

Enhalus acoroides (Figure 24-3)

This species is mainly found in the subtidal zone and is slow to produce new shoots, but has a high biomass because it is a very large seagrass. It occurs on the tidal flats exposed at low tides. The siltier the water, the longer the leaves grow in order to capture more light. It is the species that releases pollen on the surface of the water in sexual reproduction, which restricts its distribution to intertidal and shallow subtidal areas.

Figure 24-3. *Enhalus acoroides.*

E. acoroides is a common species in the major seagrass beds of Southeast Asia. In Thailand, it occurs in brackish water canals down to the lower intertidal and subtidal zones on mud, muddy sand, and sandy coral substrates. In the Gulf of Thailand, it grows on substrates ranging from medium and coarse sand to coral rubble at a depth of 0.5-1.0 meters. *E. acoroides* grows in a variety of different sediment types from silt to coarse sand. In the Philippines, it is reported to colonize turbid, quiet, protected areas such as bays and estuaries.

Degradation of seagrasses

As new growth replaces older seagrass leaves, the dead leaves decay, becoming a valuable source of organic matter for microorganisms at the base of the seagrass bed food chain.

Their decomposition processes have been studied in the field. Seagrass leaves kept in litterbags were collected periodically and weighed. The decomposition process of *Halophila ovalis* was studied in Thailand. They gradually decomposed with time and the color changed to brown or dark brown at the 3rd week. At the 5th week the features of leaves and rhizomes could be detected but they were much more decomposed. From the 6th week onward the leaves become small fragments. At the 10th week, the end of experiment, they turned to very small fragile fragments and had very light yellow color and light brown fiber could be detected.

Seagrass beds are like huge lungs in the coastal zone. Seagrass leaves also use a large amount of nutrients. When the bed is established, the speed of current or water flow is reduced according to its physical structure, and sandy or muddy particles accumulate on the bottom. The roots and rhizome can trap a large amount of sediment and stabilize the bottom environment, which not only helps improve water clarity and quality, but also reduces erosion and buffers coastlines against storms.

Seagrasses can further improve water quality by absorbing nutrients in runoff from the land. In nutrient-poor regions, the seagrass plants themselves help nutrient cycling by taking up nutrients from the soil and releasing them into the water through their leaves, acting as a nutrient pump.

Seagrasses are often called nursery habitats because the canopy provides shelter for small invertebrates (like crabs and shrimp and other types of crustaceans), small fish, and the young of larger fish species. Many species of algae and microalgae (such as diatoms), bacteria, and invertebrates grow as "epiphytes" directly on living seagrass leaves. Other invertebrates grow nestled between the blades or in the sediments, including sponges, clams, polychaetes, and sea anemones. The accumulation of smaller organisms amongst and on the seagrass blades, as well as the seagrass itself, attracts bigger animals. As a result, seagrass beds can be home to many types of fish, sharks, turtles, marine mammals (dugongs), mollusks (octopus, squid, cuttlefish, snails, bivalves), sponges, crustaceans (shrimp, crabs, copepods, isopods and amphipods), polychaetes, sea urchins, and sea anemones—and many other organisms.

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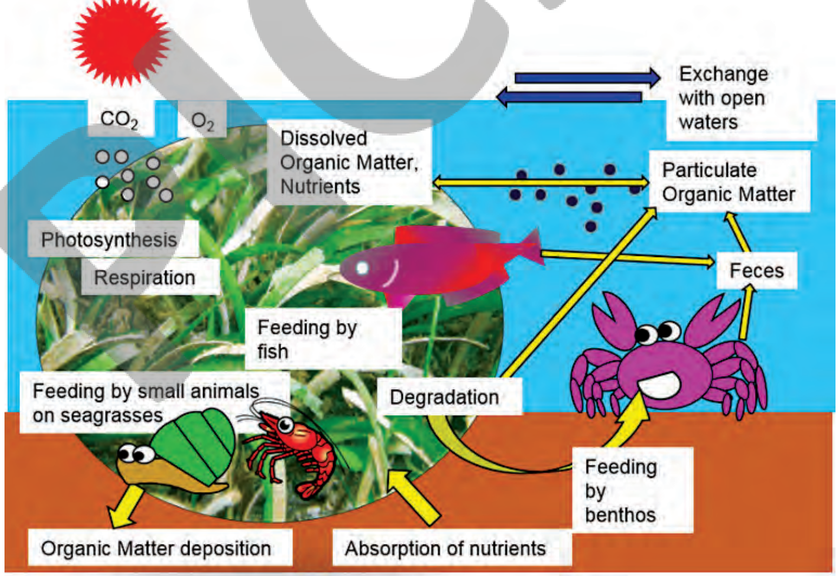

Figure 24-4. Dynamics of organic matter and nutrients in seagrass bed.

Except where sourced, photos and graphics provided by the author.

CHAPTER 25

FOOD FOR DUGONG

Makoto Tsuchiya

Critical Thinking:
What do dugongs eat?

The dugong is the only mammalian herbivore that is strictly marine. Their diet is comprised of several species of seagrasses (Adulyanukosol et al., 2001). Dugongs are culturally important, symbolic species in Palau.

In the Micronesian region, dugong occur only in Palau, and are the most isolated dugong population in the world. Dugongs are under threat from human exploitation and environmental disturbance.

Recently, many studies on the dugong have been conducted, for example: on population size (e.g. Mash, 1995; Marsh et al., 2004; Hines et al., 2005); life history (Kwan, 2002); feeding behavior and studies on diet and digestive tract (e.g. Lanyon and Sanson, 2006) and movement (e.g. Chilvers et al., 2004; Sheppard et al., 2006).

It is difficult to observe dugongs as they do not like motor boats, but we may be able to observe some signs of their activities on tidal flats dominated by seagrasses. Although dugongs have been featured in exhibitions (***Figure 25-1***) and general observation samples accumulated from interviews for fishermen are available, the scientific information on their ecology is minimal in Palau.

It is well known that the main food of dugongs is seagrass. Feeding tracks of dugongs grazing on seagrass beds dominated by *Halophila* have been observed in intertidal and shallow subtidal habitats (***Figure 25-2***). Dugongs swim into the intertidal and subtidal zones to feed on seagrass blades and rhizomes. They inhabit the in-

Figure 25-1 (left and right). Some exhibitions of dugongs in Palau. Photos by M. Tsuchiya.

Figure 25-2 (top and bottom). Feeding scars by dugong in Thailand. Photos by M. Tsuchiya.

tertidal zone during high tides to eat and retreat to deeper habitats during low tides.

Regrowth of the seagrass *Halophila* after dugong feeding has been studied. The feeding areas were covered with *Halophila* within 2-3 months (***Figure 25-3***).

Seagrasses such as *Thalassia* and *Enhalus* are also a food source for dugongs. Seagrass beds are important not only for dugongs but also for others large animals such as dolphins and turtles. In other seagrass areas, sea turtles, dolphins, and other coastal species are seen regularly foraging in the seagrass beds.

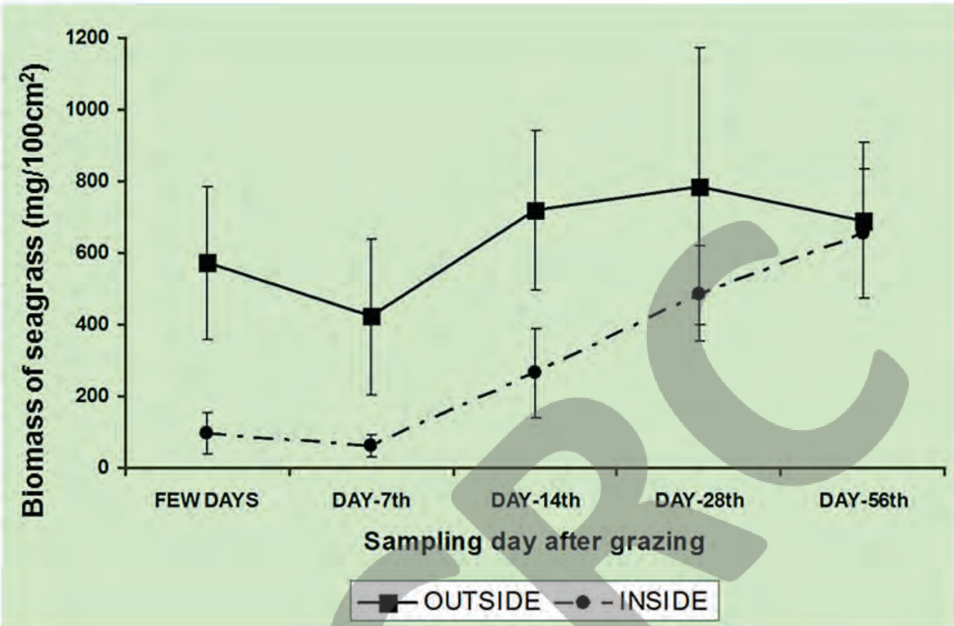

Figure 25-3. Changes in the biomass of seagrasses inside and outside of the feeding tracks of dugong in Thailand. Source: C. Aryutaka, pers. comm.

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Photo by Ron Leidich.

CHAPTER 26

MARINE TURTLES IN PALAU

Yalap P. Yalap

Critical Thinking:

What leaves tracks in the sand?
What is underneath the sand?

The marine turtle is a saltwater reptile that has been in existence for more than 100 million years. Worldwide, there are a total of 7 species and 1 subspecies (Guilbeaux et al., 1994). These include the Green turtle or Melob (*Chelonia mydas* and *C. mydas agassizii*), hawksbill turtle or Ngasech (*Eretmochelys imbricata*), Leatherback turtle or Bekuu (*Dermochelys coriacea*), Loggerhead turtle (*Caretta caretta*), Olive Ridley turtle or Metau (*Lepidochelys olivacea*), Kemp's Ridley turtle (*Lepidochelys kempii*), and the Flatback turtle (*Natator depressa*). Two species, the Flatback and Kemp's Ridley turtle, have never been sighted in Palau. Of the five species found in Palau, only the Green and Hawksbill turtles are known to commonly feed and nest here. They can be found as far north as Kayangel island and along both the east and west coasts of Babeldaob down past the Rock Islands Southern Lagoon, with most nesting activities occurring in the southwest islands of Sonsorol and Hatohobei.

Figure 26-1. Tracks left by a nesting sea turtle. Photo by Y. Yalap.

Did you know?

- Green turtle hatchlings enter the water as omnivores but become vegetarian around 3 years of age.
- Each year for mating, male Green turtles will return to the same location where they were born; while females may visit more than one breeding ground.
- Green turtles can stay under water for as long as five hours.
- The heart-shaped shell of a young Hawksbill turtle will grow longer and change shape as it gets older.
- Sponges are the Hawksbill turtle's main source of food, but they also eat jellyfish, fish, mollusks, crustaceans, and worms.
- Hawksbill hatchlings are very susceptible to predators because they float before they develop the capability to dive.

Culture

Marine turtles are deeply rooted in Palau's culture and traditions with a known historical subsistance use. Important cultural uses include use of the *toluk* during customary functions as a symbol of societal status or rank. The prized shell is used as a Palauan woman's money for exchange during marriage, funerals, and other traditional events. More recently, marine turtle products have been made into commodities such as combs, earrings, bracelets, rings, and elaborate furniture adornments.

Figure 26-2. A sea turtle nest. Photo by Y. Yalap.

Biology

Marine turtles have flipper-like limbs and are strong swimmers able to swim across oceans. Turtles must surface to breathe but can stay underwater for long periods of time. Adult female turtles must return to land to nest, but they are migratory and may travel great distances to feed. To identify a turtle species, count the number of plates or "scutes" on the shell (include plates on the head) and identify the shape of their shell (see pictures below):

Figure 26-3. Green Turtle. Photo by Yubee K. Isaac.

Green turtle or Melob (*Chelonia mydas*)

- Hard shell
- 4 pairs of lateral scutes
- 5 central scutes
- 2 prefrontal scales
- Brown/yellow greenish color
- Commonly feed and nest in Palau
- IUCN-Endangered (2016)

Figure 26-4. Hawksbill Turtle. Photo by Yubee K. Isaac.

Hawksbill turtle or Ngasech (*Eretmochelys imbricata*)

- Hard shell
- 4 pairs of lateral scutes
- 5 central scutes
- 4 prefrontal scales
- Hawk-like beak
- Overlapping scutes
- Commonly feed and nest in Palau
- IUCN-Critically Endangered (2016)

Threats

Natural threats to marine turtles include high mortality during early life stages and slow growth rates, averaging 30 years to reach reproductive maturity. Other threats include marine pollution, coastal development, degradation and destruction of nesting beaches, poaching or hunting of turtles or eggs, capture via by-catch in fisheries, and accidental death caused by drowning from fishing gear entanglement. In Palau, the most significant threat to the marine turtle population is human activity through degradation and destruction of nesting beaches as well as poaching or hunting of turtles or eggs.

Protection

Globally, all species are listed as IUCN endangered species. The importance of marine turtles to Palau's heritage is shown through centuries of traditional conservation and management laws. Enforcement of local traditional laws was carried out by village chiefs in an attempt to balance conservation, management, and availability for sustenance and customary obligations. As systems of governance change from traditional to more contemporary forms, the modern day government is embattled with what seems to be rapid population decline and increased demand for harvest, similar to current global issues. Given the recent circumstances, Palau's national, state, and traditional governments are raising awareness and finding better strategies to manage marine turtle populations.

Laws

Through the years several laws, regulations, and moratoriums have been passed or adopted by local traditional jurisdictions, the 16 State Governments, and the National government to protect and conserve Palau's Marine turtles:

Applicable Laws		
Laws/Regulations	**Year**	**Summary**
Naval Administration “Interim regulations” and US DOI TT: "Limitations on the Taking of Turtles" (24 PNCA 1201)	1947–1994	Prohibitions and limitations on the harvest of sea turtles
U.S. Endangered Species Act	1973	Pacific Green and Hawksbill turtle populations were respectively classified and listed as “Threatened” and “Endangered"
USA Signed Convention on CITES	1975	Subject to additional sea turtle export and import regulations under the international jurisdiction of the Convention on International Trade of Endangered Species (CITES)
Palau’s Endangered Species Act of 1975 (24 PNC 1001-1012)	1975	Limitation on taking turtles, 24 PNCA § Protected Sea Life, Subchapter 1, Turtles
Palau’s ratification of the Convention on Biological Diversity (CBD)	June 1999	Palau NBSAP (National Biodiversity Strategic Action Plan) for sustainable management of biological diversity, through Palau strategic plan. Turtles are included.
Republic of Palau Public Law: 8-23	December 2010 – December 2015	Five-year moratorium on taking and killing of critically endangered Hawksbill Turtles
Republic of Palau Public Law: 9-52	November 2015 – April 2021	Six-year moratorium on taking and killing of critically endangered Hawksbill turtles

What can you do to protect turtles in Palau?

- During nesting months, stay away from nesting sites.
- Keep pets away.
- Use minimal lights in the area.
- Avoid using flash photography directly on the turtle’s face.
- Do not interfere with crawling to nesting sites or hatchling attempts to reach the sea.
- In the water, keep a good distance from turtles; do not touch or feed them.

- While on a moving boat, watch out for turtles when you are in their feeding or resting areas.
- Palau is a member of CITES (Convention on International Trade of Endangered Species). Refrain from purchasing or selling turtle products. CITES laws protect turtles.
- Support Palau conservation initiatives by donating or volunteering, or by promoting ecotourism.
- Respect the laws and do not eat or buy turtle products when not allowed.
- Raise awareness by informing your families and friends of the threats to turtles and what they can do to help!

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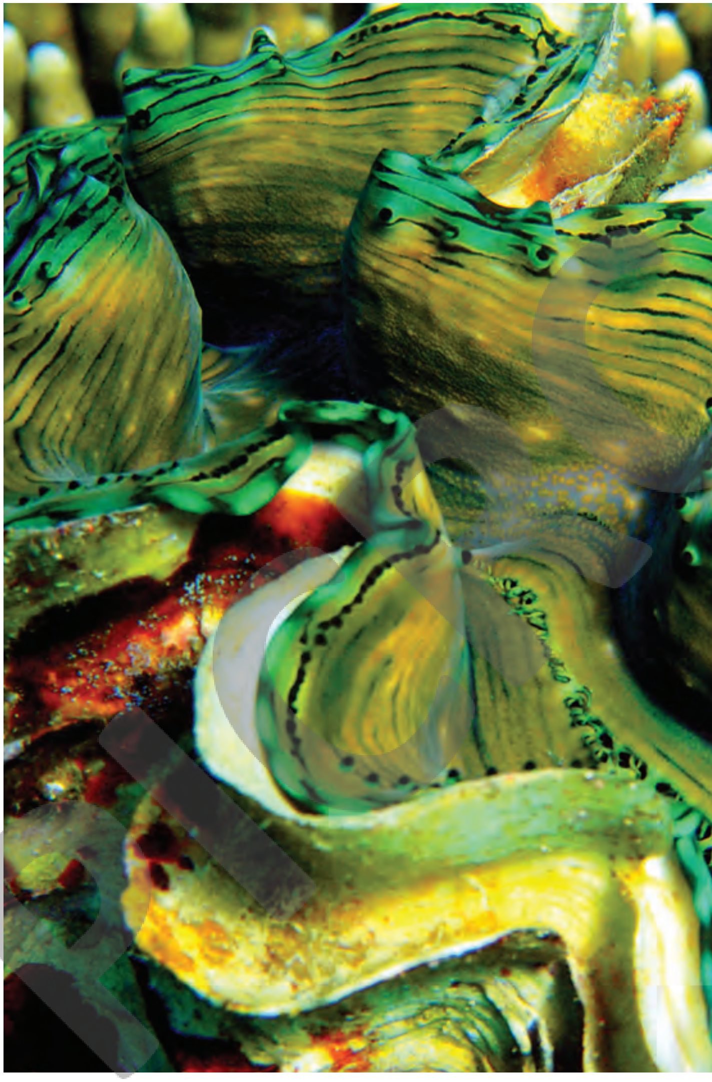

Photo by Hannah Muggue.

PART 5
Rocky Shores and Coral Reefs

CHAPTER 27

THE ROCKY INTERTIDAL ZONE AT LOW TIDES

Makoto Tsuchiya

Critical Thinking:

Why is the zonation pattern so distinct?

High and low tides

The moon causes tides on our planet (***Figure 27-1***). The moon's gravitational force pulls on water in the oceans so that there is a bulge in the ocean on the site (red star in the figure) where you are standing to observe the shore. The bulge on the opposite side of the Earth also occurs because of the centrifugal force caused by the Earth's turning on its axis.

Intertidal organisms live under environmental conditions with regular periods of immersion and emersion. They may be submerged underwater or exposed to the air. Therefore intertidal organisms are adapted to a large range of environmental conditions like varying

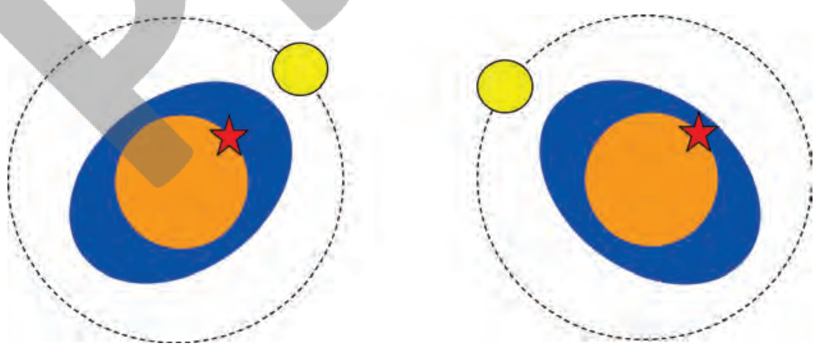

Figure 27-1. Tides depend upon the position of the moon (yellow). Star shows the site at high tide (left) and low tide (right). Graphic provided by the author.

water and air temperatures and desiccation. The intensity of environmental stressors varies with tidal height because organisms living in areas with higher tide heights are emerged for longer periods of time than those living in areas with lower tide heights.

The distribution patterns of organisms are dependent upon the environmental gradient. Organisms adapt to gradients with various behavioral, morphological, and physiological characteristics.

Figure 27-2. Zonation pattern of intertidal organisms on a pier of a port. Oyster show a wide range of distribution on the pier. Photo by M. Tsuchiya.

There are several types of intertidal habitats that have different substrates such as rocky shores, boulder shores, sandy beaches, and muddy shores. In Palau, very flat intertidal habitats are common both on rocky shores, i.e. coral reefs, and tidal flats. Because of this topography, accumulation of sandy particles is found on rocky intertidal habitats too. In the mangrove forests, intertidal habitat includes the mangrove root systems where several intertidal species occur.

Let's go to a port to observe the animals on its pier or breakwater (***Figure 27-2***). The distribution pattern or "zonation" of animals and seaweeds is conspicuous. Several questions may come to mind:

1. Why does species A occupy this zone?
2. Why is the vertical distribution of species A higher above sea level than that of species B?
3. What is the mechanism for establishing this zonation pattern?

These are very basic ecological questions that are suitable topics for discussion with your friends, family, or teachers.

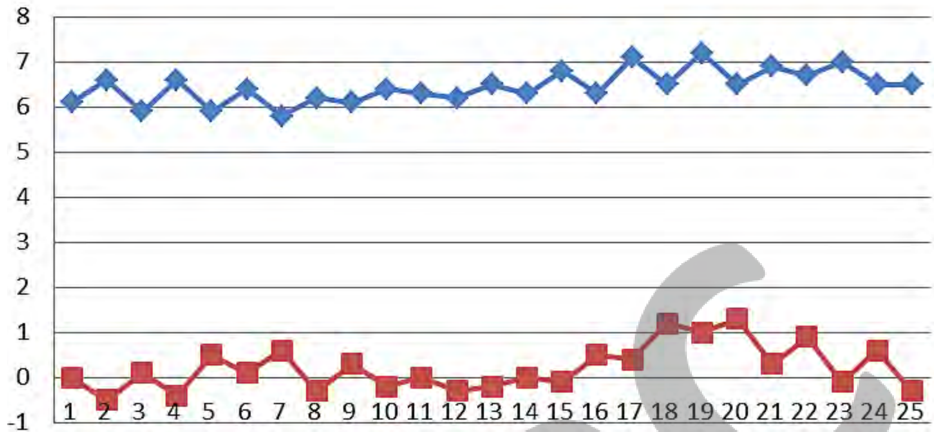

Figure 27-3. Change in high (blue) and low (orange) water levels in spring tides. Do these graphs represent mean and if so for how many years? Source: Drawn using the Art and Tides Calendar published by PICRC.

Sea levels during spring high and low tides fluctuate during the year (***Figure 27-3***). The tides are lower in June to August and higher during October and November. The highest sea level during high tides is called Extreme High Water of Spring tides (E.H.W.S.) and the lowest is Extreme Low Water of Spring tides (E.L.W.S.). The mean high and low water levels at spring tide, M.H.W.S. and M.L.W.S., respectively, can be calculated.

On the flat intertidal zone of coral reefs, we can observe intertidal organisms in the offshore areas during the low tides of June, July, and August. The effect of wave action is an important factor to consider when comparing the distribution of intertidal animals and seaweeds between the inner harbor and exposed shore. There is a wider distributional range of organisms on the exposed shores.

In tropical countries like Palau, it is easy to speculate that intertidal organisms that inhabit the upper vertical area must tolerate higher temperatures and severe desiccated conditions. Please observe intertidal animals and plants and consider the difference in their environmental conditions. Zonation patterns of intertidal organisms are well studied globally and a general pattern has been reported. This will be shown in the next chapter.

CHAPTER 28

DISTRIBUTION OF REEF FLAT ORGANISMS

Makoto Tsuchiya

Critical Thinking:

What factors control the distribution of intertidal organisms?

Zonation

The rocky intertidal zone is periodically covered with seawater and exposed to air. This interface between terrestrial and ocean environments is a complex environment where species are well adapted to the changing habitat conditions.

Intertidal ecology has been developed since the 19th century and its characteristics were well documented for temperate regions all over the world. Since information on the tropical intertidal is not completely known, however, research results conducted in temperate regions are frequently applied to the tropics.

Usually, intertidal zones, sometimes called littoral zones, are divided into subzones using distribution patterns of animal and plant species (***Figure 28-1***). Although a variety of descriptions are available for this zonation pattern, we use a classic description based on research in European countries here.

Subzones are defined by the distribution of plant or animal species. Subzone widths are affected by the wave action. In calm waters such as a port, they are narrow, but they expand in wave-beaten environments. Lower littoral fringe is characterized by the distribution of large seaweed species (Lewis, 1964), but it is replaced with corals in tropical regions.

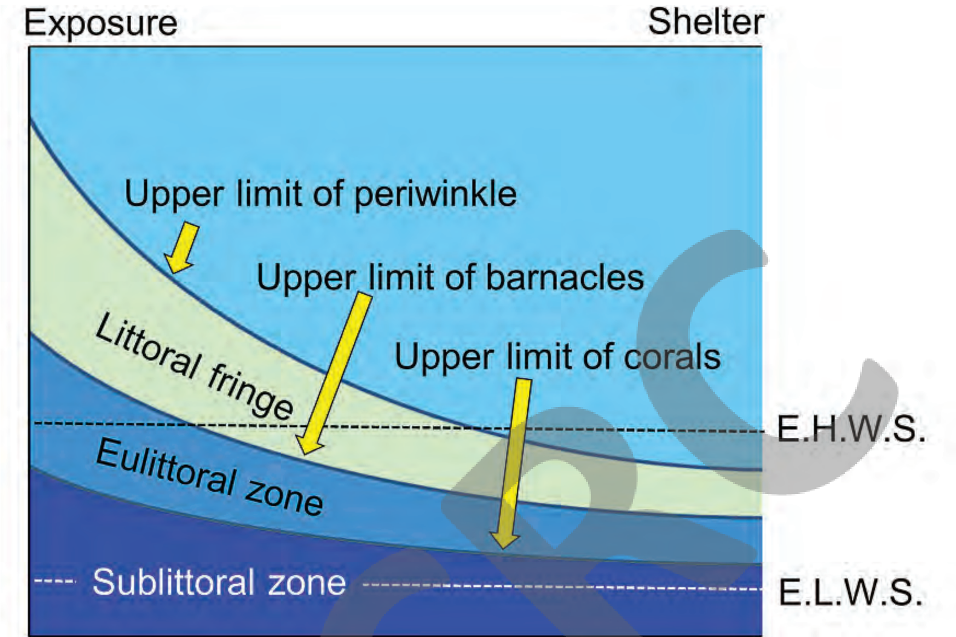

Figure 28-1. Intertidal zonation of plant and animals. E.H.W.S. is extreme high water spring tides; E.L.W.S. is extreme low water spring tides.

The upper part of the upper periwinkle zone is called the supralittoral fringe and is mainly characterized by lichens, cyanobacteria, and isopods.

The zone between the upper limit of the periwinkle zone and the upper limit of the large seaweed zone, which corresponds to the coral zone in tropical waters, is called littoral zone. This zone is divided into two subzones: the upper littoral fringe and midlittoral (or eulittoral) zone. The littoral fringe is characterized by the distribution of periwinkles and the midlittoral zone by barnacles and mussels. Mussels are not abundant in tropical waters; so this zone is usually characterized by the distribution of barnacles and oysters in the tropics. This is seen on some breakwaters in Palau (***Figure 28-2***).

The zone below the upper limit of large seaweeds, or corals, is called a sublittoral zone. As shown in ***Figure 28-1***, the effect of wave action is conspicuous. Each zone is much wider on exposed shores than sheltered areas. Sublittoral zones are frequently exposed to air, but splashed by waves at low tides.

Seaweeds also show marked distribution patterns in temperate regions, but this is not common in Palau. Seasonality of their abundance is usually recognized.

Distribution of intertidal organisms

Barnacles are very common on the rocky intertidal zone in temperate regions, but their dense distribution is not so common in Palau. Scattered distribution or small aggregations are seen in some places.

Since barnacles are suspension feeders and feed on plankton or other suspended organic materials when submerged, their upper limit in ports showing very calm conditions is at the high water mark.

The upper part of the sublittoral zone is characterized by the distribution of coral species such as *Goniastrea* and *Porites*.

Because intertidal organisms endure regular periods of immersion and emersion, they essentially live both underwater and on land and must adapt to a large range of climatic conditions. The intensity of climate stressors varies with relative tide height because organisms living in areas with higher tide heights are emerged for longer periods than those living in areas with lower tide heights. This gradient of climate with tidal height leads to patterns of intertidal zonation, with high intertidal species being more adapted to emersion stresses than low intertidal species.

As stated, these adaptations may be behavioral, morphological, or physiological. Many mobile organisms, such as snails and crabs, avoid temperature fluctuations by crawling around and searching for food at high tide and hiding in cool, moist refuges (crevices or burrows) at low tide. For example, high intertidal organisms have a stronger stress response, such as a physiological response of making proteins that help recovery from temperature stress just as an immune response aids in the recovery from an infection.

Figure 28-2. Examples of animals found in the rocky intertidal zone.

Intertidal organisms are also especially prone to desiccation during periods of emersion. Again, mobile organisms avoid desiccation in the same way that they avoid extreme temperatures: by hunkering down in mild and moist refuges. Many intertidal organisms, including *Littorina* snails, prevent water loss by having waterproof outer surfaces, pulling completely into their shells, and sealing shut their shell opening.

In addition to these exposure stresses (temperature, desiccation, and salinity), intertidal organisms experience strong wave action. Morphologically, many mollusks, such as limpets and chitons, have low-profile, hydrodynamic shells. Types of substrate attachments vary in oysters and some other bivalve species.

For each of these environmental stresses, species exist that are adapted to and thrive in the most stressful of locations. Adapting to such challenging environments gives these species competitive edges in such locations. On the lower intertidal, you may even be able to meet some foraging lizards at low tides.

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Graphics and photos provided by the author.

CHAPTER 29

TIDAL POOLS AS REEF HOLES

Makoto Tsuchiya

Critical Thinking:

How can we enjoy tidal pools?

When the tide recedes, water often remains trapped in coral depressions called rock pools or tidal pools. These pools are colonized by intertidal animals and plants. Typical animal and plant species are shown in ***Figures 29-1*** and **29-2**. Rock pools may be classified either according to their position within the intertidal zone—Low, middle or high—or according to the dominant plant form within the pool. Rock pools can be distinguished as dominated by green algae, calcareous red algae, or brown algae. Their combinations are also found in places.

Pools located in higher intertidal zones are easily affected by rainfall and higher temperature conditions as well as evaporation. Mass mortality of some species has been recorded on very warm days. Even in rock pools at the lower intertidal, mortality of corals has been observed frequently. This is mainly related to bleaching (***see Chapter 37***).

How can we enjoy the organisms in tidal pools? Tidal pools are natural aquaria. Small fish swim around corals and they are frequently competing with each other. You may have an interesting question, such as how do they coexist in a small pool? You may find ring-type *Porites* colonies, sometimes called micro-atoll. What is the forming process of this coral type?

Giant clam *Tridacna crocea* is also common. *T. crocea* can get their food from zooxanthellae living in the mantle. It is difficult for you to collect them by hand, because they are buried in rocks. Their larvae exhibit their planktonic stage for about one month, during which

Figure 29-1. Examples of rock pool species.

they recruit zooxanthellae. Before settling on a rock surface, young specimens search for a suitable habitat, such as a small hole or crevice, so that most of their body is hidden for their survival. In Okinawa, fishermen drill small holes and place young clams there. Specimens in holes and crevices try to excavate rock. This is bioerosion.

You may find some seagrass and seaweed species. These are competitors with corals for space, but it is also true that they are sometimes neighbors. What kind of competition occurs on the reefs?

These are merely examples. Please find interesting questions by yourself and talk with your family and friends. Rock pools are interesting and important places to enjoy nature.

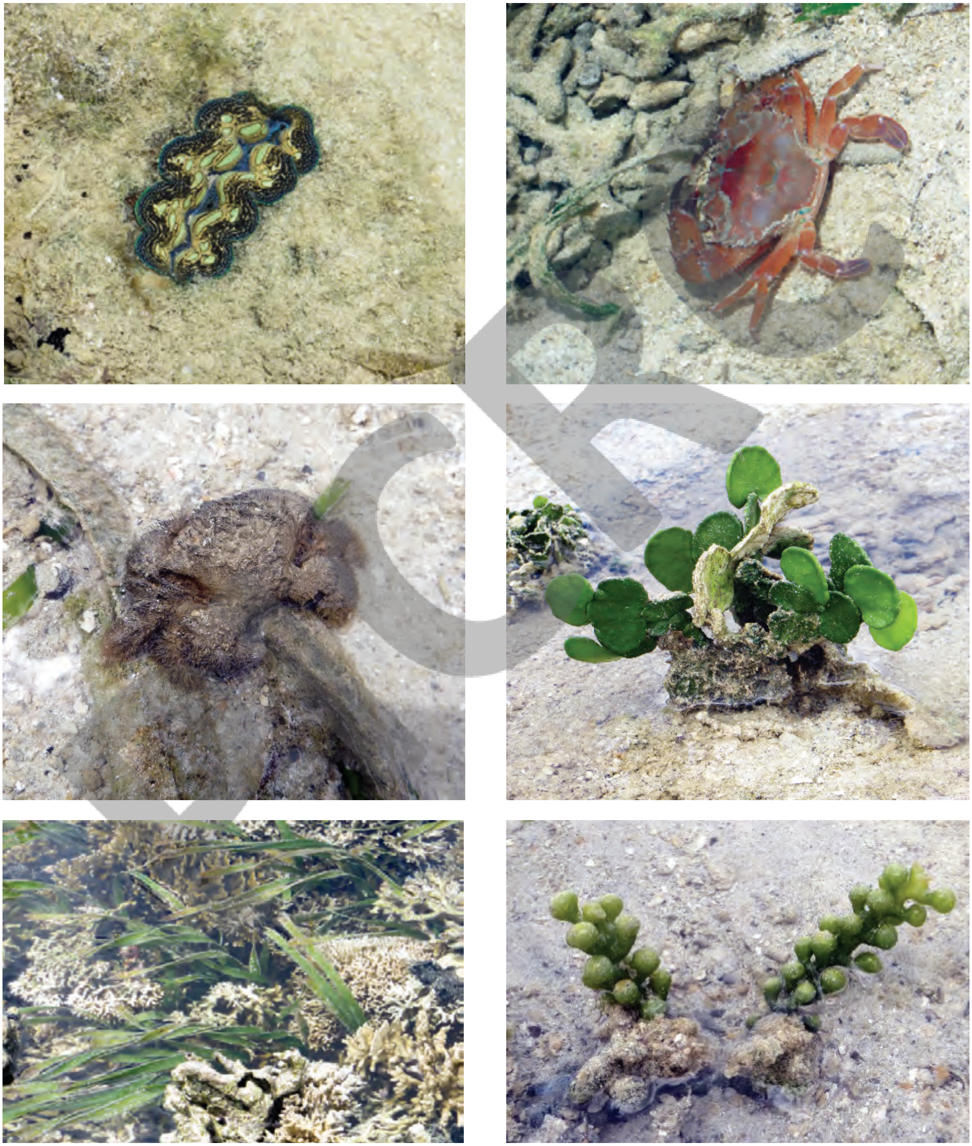

Figure 29-2. Some animal and plant species found in rock pools.

Photos provided by the author.

CHAPTER 30

HOMING BEHAVIOR OF THE LIMPET-SHAPED PULMONATE GASTROPOD *SIPHONARIA*

Makoto Tsuchiya

Critical Thinking:
Why does the limpet return home?

Limpets are flat dome-shaped gastropods without spiraling of the shell. It is well known that several intertidal limpet siphonarid species characteristically return to their rock homes after feeding or breeding. These limpets move away from their homes presumably to feed on microalgae growing on rock surfaces. Their homes are easily identified as scars (***Figure 30-1***) during their feeding excursions.

This behavior has been well known since ancient times. Aristotle first described this excursion behavior, but homing behavior was unclear. Since the 1980s, much research has been conducted on the homing behavior of *Patella*, *Acmaea*, and other limpet species worldwide.

One of the pioneer studies on the homing behavior of the pulmonate gastropod was conducted in Palau. It was research reported by Dr. Noboru Abe working at the Palao Tropical Biological Station (***see also Chapter 16***) (Abe, 1941).

Two pulmonate gastropod species, *Siphonaria atra* and *S. laciniosa*, occur in the rocky limestone or basalt intertidal habitats in Palau. *S. atra* is distributed around the mean tide level, while *S. laciniosa* is seen higher above the tide level. The behavior of *S. atra* is well documented (Abe, 1941) as follows.

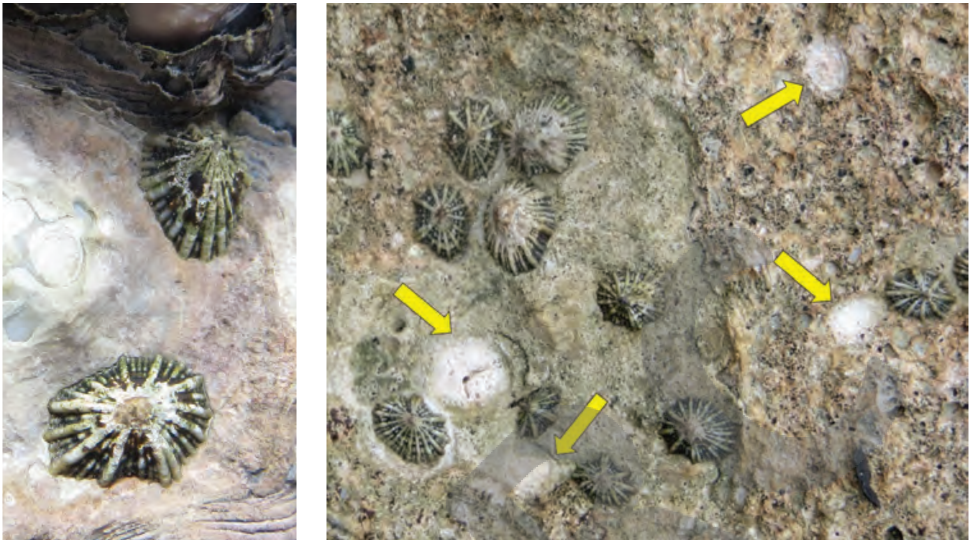

Figure 30-1. *Siphonaria atra* shown on a pier of a port in Palau. Their homes (whitish scars) are indicated by yellow arrows. Photos by M. Tsuchiya.

S. atra starts its feeding migration only after the body is exposed to the air during ebb tide during the day and night. They do not enter the water column. After the feeding excursion, they return to their original positions or "home." The distance of their feeding trail is 13-34 cm and the duration is 5-50 minutes in the daytime. At night, their feeding trail is 20-65 cm. On a vertical surface, the initial direction of migration was different for every individual. The majority of them moved to the higher part of the rock face, or to the left or right side of the home. For individuals inhabiting the rather horizontal flat rock surface, no relationship was found between the initial migration direction and the direction of sunlight (***Figure 30-2***).

S. atra returned to its initial position or "home" when removed and placed about 15 cm away from its "home." One individual returned "home" after being removed and placed 30 cm away. This species might be able to return home after finding its previous feeding path.

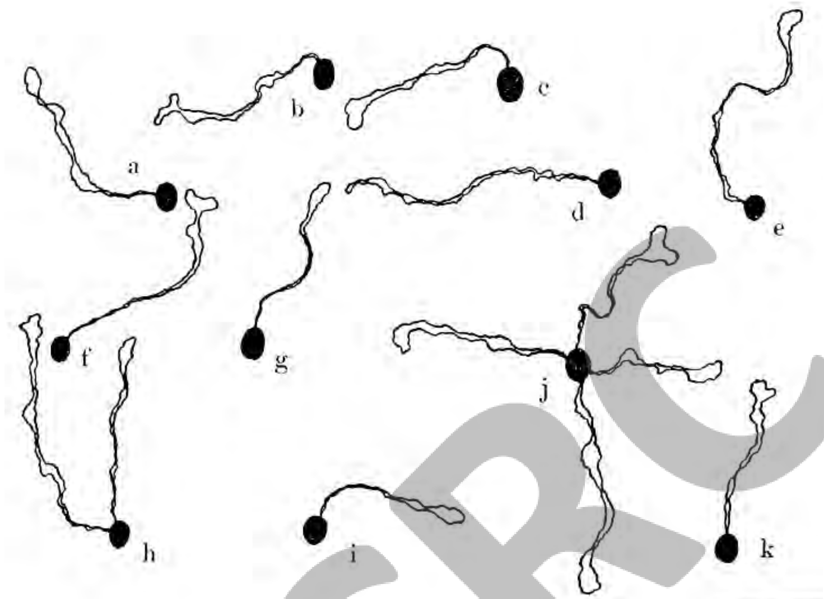

Figure 30-2. Feeding paths of *Siphonaria atra.* For the specimens h and j, feeding excursions were observed in two and four days, respectively. Source: Abe, 1941.

Since the migrating *S. atra* constantly feeds on microalgae on rock surfaces covered with fine particles, its feeding trails are clearly marked on the rock. When it reaches home, it turns around slowly about two times as if searching for its original position in the irregular rock surface. Once it morphologically fits its shell margin into the rock surface, it settles. Its tight fit within the rock surface reduces desiccation and predation. This is an important factor in finding its initial position or "home."

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CHAPTER 31

GIANT CLAMS

Lincoln Rehm

Critical Thinking:

What is a symbiotic relationship?

Giant clams, genus *Tridacna* and *Hippopus* (**Table 1**), are unique bivalves because of their vibrant siphonal mantle tissue and their obligatory symbiotic relationship with zooxanthellae, the dinoflagellate *Symbiodinium* spp. Found in shallow coral reef ecosystems, giant clams rely on two forms of feeding behaviors, heterotrophic and autotrophic feeding.

Organisms which rely on heterotrophic feeding behaviors cannot produce organic compounds on their own and rely upon the consumption of other organisms for the organic compounds they

Classification of Giant Clams in Palau

Level	Group/Name		
Kingdom	Animalia		
Phylum	Mollusca		
Class	Bivalvia		
Order	Cardiida		
Family	Cardiidae		
Subfamily	Tridacninae		
Genus	*Tridacna*		*Hippopus*
Species	*T. gigas* * *T. derasa* * *T. squamosa* * *T. maxima* * *T. crocea* *	*T. mbalavuana* *T. noae* *T. rosewateri* *T. squamosina* *T. lorenzi*	*H. hippopus* * *H. porcellanus* * *H. brassica* *H. equinus* *H. maculatus*

Table 31-1. The classification of species found in the Tridacninae subfamily, according to the World Register of Marine Species. (* Indicates species found in Palau, as of 2016).

Figure 31-1. A large *Tridacna gigas* found in Palau. The yellow tissue exposed to light is the siphonal mantle, the location of the symbiotic algae *Symbiodinium* spp.

need. The giant clam feeds heterotrophically through filter feeding, typical of most mollusks. However, autotrophic organisms can produce or synthesize their own organic compounds without relying on the consumption of other organisms; an example of this would be a higher land plant. The zooxanthellae found in the siphonal mantle of the giant clam are autotrophic and feed via photosynthesis. These zooxanthellae photosynthesize the light, producing organic compounds which they consume and also translocate to the giant clam. Some studies suggest the giant clam receives over 50% of their daily nutritional needs from the zooxanthellae (Hawkins and Klumpp, 1995; Klumpp et al., 1992; Klumpp and Griffiths, 1994; Muscatine, 1967). Giant clams are of importance ecologically, culturally, and as a food source for many island nations and because of their importance, the giant clam is a heavily exploited marine organism which has led to many conservation efforts to protect these animals, such as their placement on IUCN's Red List of Threatened Species and their listing in the CITES agreement.

Anatomy

The anatomy of the giant clam is similar to that of other bivalves. The giant clam has an outer shell comprised of two valves which are morphologically different between species. For example *T. gigas* has a smooth exterior while *T. squamosa* has flutes which protrude from the shell. The vibrant tissue exposed to the water is the siphonal mantle tissue, where the symbiotic dinoflagellates are located. The siphonal tissue has two siphons located at each end of the clam, an incurrent, or inlet siphon, where water is pumped into the clam. The second siphon is the excurrent, or exhalent siphon, where waste and water is pumped out of the clam. As water is pumped through the incurrent siphon across the gills of the clam, also known as ctenidia, the clam will filter the water for particulate matter and nutrients which it can use as food. The food is then passed into the stomach where the filtered matter is processed, turned into waste matter, and then passed through the anus and the excurrent siphon (***Figure 31-2***).

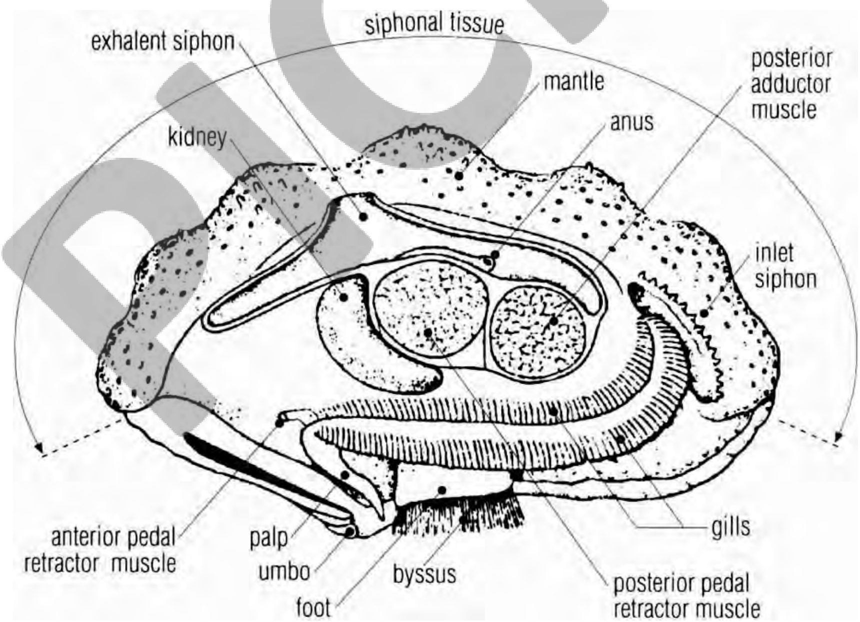

Figure 31-2. The internal anatomy of the giant clam. Source: Adapted from Yonge, 1975.

The stomach is the origin of the zooxanthellal tube system (Norton et al., 1992). This tube system plays an important role; as zooxanthellae are engulfed they will pass through this system until they reach the siphonal mantle of the clam where ample light is available. The nature at which clams can select zooxanthellae to be actively passed into the siphonal mantle is currently unknown.

The siphonal mantle is the primary location of the symbiotic dinoflagellates, *Symbiodinium*. The location of this mantle tissue allows for the zooxanthellae to harvest light energy to produce simple sugars, which are then translocated to the clam for nutrient uptake. The symbiosis between the giant clam and *Symbiodinium* spp. is obligatory, meaning the clam cannot survive without the dinoflagellate. Near the zooxanthellae are iridocyte cells which typically have a shimmering blue or yellow color. These cells are produced by the giant clam and as a recent study suggests, allows the zooxanthellae to efficiently harvest sunlight by filtering the incoming wavelengths and bending light photons at angles to which all zooxanthellae deep in the mantle tissue can undergo photosynthesis (Holt et al., 2014).This mechanism of light harvest is different from coral reefs as the zooxanthellae on the surface are usually undergoing photosynthesis, while those deeper in the coral tissue are not exposed to light. On the edges of the siphonal mantle tissue are the primitive eyespots which can detect changes in light, triggering the clam to pull the mantle back into the shell and close (Wilkens, 1986).

The giant clam, like other bivalves, has a byssal gape at the bottom of the shell, where the foot and byssus are located. The byssus is a structure which the giant clam uses to attach itself to the surface. All clam species have a byssus, however some species have a reduced byssus at which point their size and shape help to maintain their upright position. The giant clam has a heart, a kidney, and an important retractor muscle which is used to pull the siphonal mantle into the shell.

Development

Like most animals, the giant clam reproduces sexually. However, due to their sessile nature, these clams broadcast spawn through their excurrent siphon. This form of reproduction is similar to many coral reef species. Gametes are released into the ocean where they mix and also attract predators that feed upon the gametes. In order to increase the success of reproduction, clams broadcast millions of eggs and sperm into open water. A substance is produced and released by the clam when they undergo broadcast spawn which triggers other nearby clams to begin spawning (Beckvar, 1981; Crawford et al., 1986). Thus, during spawning entire colonies of clams will take part in this reproductive phase. Giant clams are simultaneous hermaphrodites, able to produce sperm until they reach full maturity, at which time, the giant clam will produce both sperm and eggs. The age at which a giant clam reaches full maturity is interspecifically variable which means that this age differs between species. Although giant clams are a simultaneous hermaphrodite, they are unable to self-fertilize as their gametes are unable to mix and the clams will not expel both their sperm and eggs at the same time (Knop, 1996). The exact nature of the parameters which induce spawning is unknown. However, many factors have been used to initiate spawning such as reach-

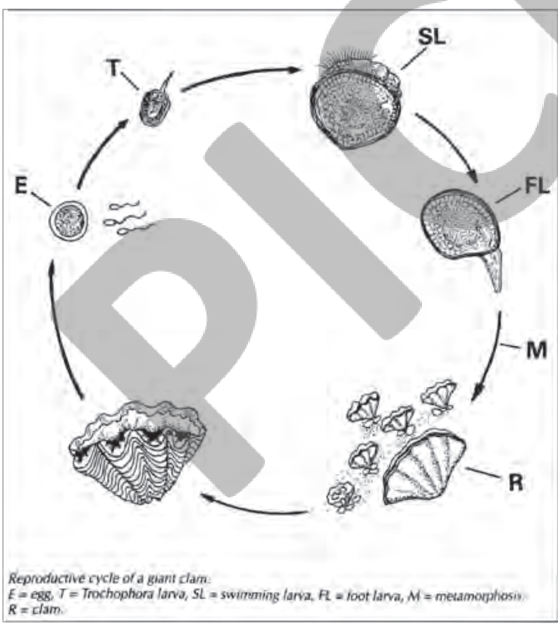

Figure 31-3. A diagram of the reproductive cycle of the giant clam. Source: Adapted from Knop, 1996.

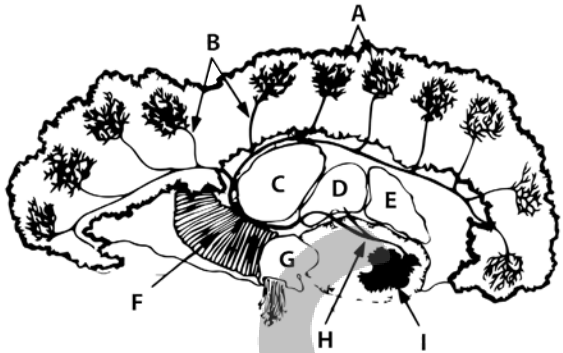

Figure 31-4. A diagram of the internal anatomy of the giant clam. A = the outer mantle tissue, B = the zooxanthellal tubule system, C = the abductor muscle, D = the stomach, E = the kidney, F = the ctenidia, G = the byssus organ, H = the primary zooxanthellal tubule system, I = the stomach. Source: Adapted from Norton and Jones, 1992.

ing a certain ambient temperature, stressing the individuals, and via hormone introduction (Beckvar, 1981; Crawford et al., 1986; Ellis, 1997; Soo and Todd, 2014).

Giant clams are meroplanktonic, meaning they spend part of their life in the plankton and then part of their life on the benthos. Specifically, giant clams are planktonic during the early stages of their life (***Figure 31-3; E & T***) until they develop a foot as a foot larvae (FL) and are able to metamorphose into a clam (***Figure 31-3***). During the swimming larva (SL) stage or veliger stage, the giant clam is able to actively swim and consume phytoplankton. From this veliger stage the giant clam begins developing the zooxanthellal tubule system from their gut (***Figure 31-4***). As this tube system begins developing, the clam begins consuming *Symbiodinium* spp. from the water in order to establish the symbiosis. Unlike corals, the clam does not inherit the zooxanthellae from their parents, rather they must consume them in the early stages of life. The clades or species of *Symbiodinium* found in the mantle of the clam are similar to those of their coral neighbors. However, some studies have shown evidence for a possible dominant clade found in giant clams, *Symbiondinium tridacnidorum* (Lee et al., 2015).

Similar to coral reefs, the symbiosis between *Symbiodinium* spp. and giant clams can break down and result in bleaching. The severity or the exact mechanism which induces bleaching is still unknown (Addessi, 2001; Buck et al., 2002). Giant clams, like corals reefs, can

Figure 31-5. A *Tridacna crocea* individual bored into the rock substrate.

recover from a bleaching event (Soo and Todd, 2014).

Once the giant clam establishes symbiosis it metamorphoses into a juvenile clam. The duration of time the clam spends in the planktonic phase is species-specific but can range from 10-15 days. Once the clam reaches the juvenile phase it produces byssus threads through the byssal gape which adhere the clam onto the substrate (Norton and Jones, 1992). Some species of giant clams (i.e. *T. gigas* and *T. derasa*) will eventually reduce these byssus threads and grow large enough to move about the substrate. Two species found in Palau, *T. crocea* and *T. maxima,* will begin producing an acid through its byssal gape, which enables the clam to bore into the hard substrate (***Figure 31-5***). Due to the location of the siphonal mantle and its reliance on photosynthesis byproducts from the zooxanthellae, the giant clam positions itself with the mantle tissue exposed towards the sun, different from most other bivalves. Throughout the juvenile phase, the clam is still small in size and thus still vulnerable to predators like squid, snails, and crabs. However, as they grow larger or bore deeper into the reef, they become less vulnerable to predators.

After about 2–6 years the juvenile clam will begin to produce sperm and broadcast spawn. It is not until the clam reaches full maturity, from 3–10 years, that the clam will produce eggs via a set of ovaries found near the testes and become a full hermaphrodite, spawning sperm and eggs (Lucas, 2014). Adult giant clams range in sizes from about 15 cm shell length for *T. crocea*, to over 1 meter in shell length for *T. gigas*. Of the species found in Palau, size ranges from smallest to largest shell length are as follows: *T. crocea, T. maxima, T. squamosa, H. hippopus, H. porcellanus, T. derasa*, and *T. gigas*. Throughout their life cycle, giant clams are of ecological significance as they provide ecosystem benefits in the form of food for people and predators, shelter for marine organisms, and a substrate for reefs to build upon (Neo et al., 2015).

Conservation efforts

Currently, the giant clam species are listed as either lower risk or vulnerable under the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. The Red List is an initiative developed by the IUCN Global Series Programme and the IUCN Species Survival Commission in which data from surveys conducted throughout the world are compiled and an organism's conservation status can be determined.

Despite their listing as lower risk or vulnerable, giant clams are under constant threat of exploitation for their shells, which can be designed into ornaments (Larson, 2016). Recently, a petition has been written to raise their conservation status to vulnerable or endangered in order to protect the giant clam from further exploitation (Meadows, 2016).

Along with the IUCN, the giant clam is listed as a species under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). CITES is an international treaty between the members of the United Nations that protects species from trade which would negatively impact their survival. Currently, Tridacnidae species are listed under Appendix II of the CITES agreement, which is specifically for species that are not under immediate threat of extinction but rather their protection ensures their survival from trade threats. In Palau, export of giant clam species requires an official permit. In Palau, in addition to CITES regulations, giant clam species are listed as protected species, requiring government approval for exploitation and exportation.

Also, in an effort to relieve the pressures of harvesting on the natural populations of giant clams, the Palau Mariculture Demonstration Center (PMDC) promotes local aquaculture by rearing stocks of many popular species of giant clams. These stocks of clams provide seeds for many local aquaculture farmers who can use these seeds to grow giant clams for export and for the local markets. Since its establishment in the early 1970s, PMDC has advanced both aquaculture and research of the giant clams (Beckvar, 1981; Fitt et al., 1993; Heslinga et al., 1986; Heslinga et al., 1984; Heslinga et al., 1990). Upgrades to facilities and engagement with the Palauan public has led to a successful aquaculture industry in Palau, continuing to grow and promote conservation of giant clams. These conservation efforts have enabled Palau to maintain natural populations of seven of the giant clam species found throughout the world.

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Photos provided by the author.

CHAPTER 32

WHAT ARE CORALS?

Takashi Nakamura

Critical Thinking:

How do corals live in an ocean with low nutrients and little food?

Taxonomy of corals

The tiny builders of coral reefs, including "reef-building corals" or coral polyps ("corals" hereafter) are important organisms especially around coastal areas in the tropical and subtropical region. The accumulation of their skeletons, made of calcium carbonate excreted by corals, over hundreds to several thousands of years becomes a limestone-based structure ("reef") that functions as a natural breakwater around an island. Coral reefs provide many habitats for a high diversity of organisms, including the corals species themselves. Corals are the essential backbone of a coral reef ecosystem.

In the biological categorization of various organisms (called **taxonomy**), corals are a member of the Phylum Cnidaria. Cnidarians are a group of organisms that include jellyfish, sea anemones, and corals (***Figure 32-1***) with stinging cells called **cnidocytes** that can be used to catch their prey or for defense from predators. The major difference among corals, jellyfish, and sea anemones is the ability to produce a dense calcium carbonate skeleton. Many corals grow as colonies comprised of many individual units called **polyps**. Each polyp is fully equipped with a mouth, stomach, and tentacles. In many cases, several hundreds to thousands of polyps exist in one colony. Polyps found in a colony are all genetically identical with individual skeletons attached to each other. The polyps are dependent upon each other for their survival as a colony.

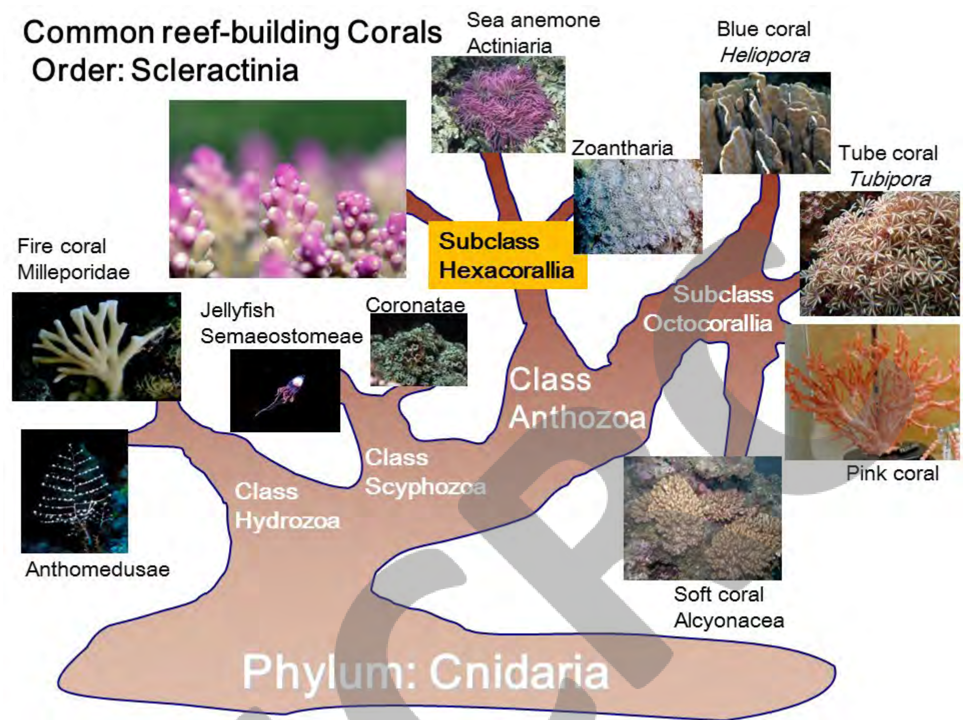

Figure 32-1. Taxonomic relationships among corals, sea anemones, jellyfish, and other organisms within the Phylum *Cnidaria*. Common reef-building corals are categorized as: Order Scleractinia within subclass Hexacorallia of the class Anthozoa. Source: Veron, 2000 and Daly et al., 2007.

Structure of corals

A coral's life cycle usually starts as a planktonic larva called a planula. The planula can swim with but not against strong currents. Planula larvae develop from the fertilization of sperm and egg released into the seawater from their parental coral colonies (***Figure 32-2***). For several hours to weeks or even months, the planula remains in suspension in the water column until it detect a suitable place to settle and grow. After attaching its body onto the suitable substrate, the process of **metamorphosis** occurs in which the larva's body shape is transformed into a polyp. A polyp begins to produce a calcium carbonate skeleton as it grows.

How do these small polyps grow into big coral colonies? The clue to solving this question can be found in their ability to produce their own identical sisters and brothers with genetically identical DNA through the **budding** process while forming a carbonate skeleton together. For example, the first polyp (usually measuring a few millimeters in diameter) starts budding to produce several new polyps around the first settled polyp to form the initial colony (several millimeters to centimeters in diameter). Then, the newly formed polyps also start budding simultaneously to produce many more new polyps around them to form a larger colony (several cm in diameter). This budding process will continue, forming a large colony with thousands to millions of polyps that can be several meters in diameter. The next time you see a coral colony, take a closer look and try to count how many polyps are in a single colony.

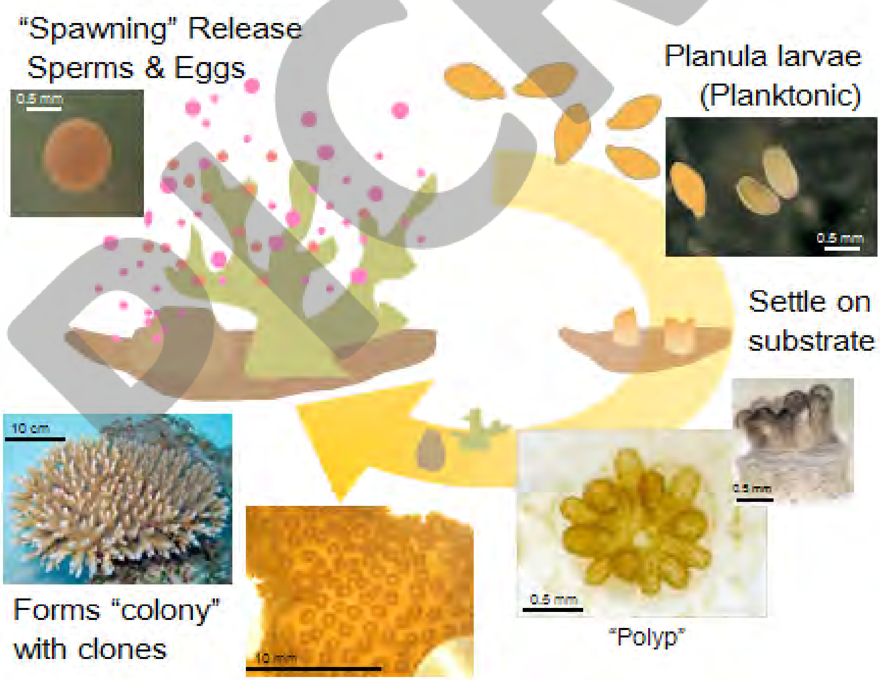

Figure 32-2. Life history of coral. A coral colony begins as a single, tiny polyp developed from the fertilization of egg by sperm during the spawning period. Drawn by T. Nakamura.

Symbiosis with zooxanthellae

The colors of coral colonies are often dark brown to greenish-brown (unless it has bleached) (***Figure 32-3***). The reason for such darker coloration is the zooxanthellae, which are single celled algae within the coral tissue and the secret to corals' vigorous growth in nutrient-limited tropical oceans. The density (number per area) of zooxanthellae in corals is actually very high. If you look at coral tissue very closely (using a microscope), you might find millions of zooxanthellae cells in the area of your finger tip (***Figure 32-4***).

Figure 32-3. A 3.5 m x 3.5 m permanent quadrat view taken for the coral community at Short Drop Off's inner reef in 2015. Note the dark pigmented colonies of diverse coral species covering >50% of the substrate. Photo by Y.S. Yuen.

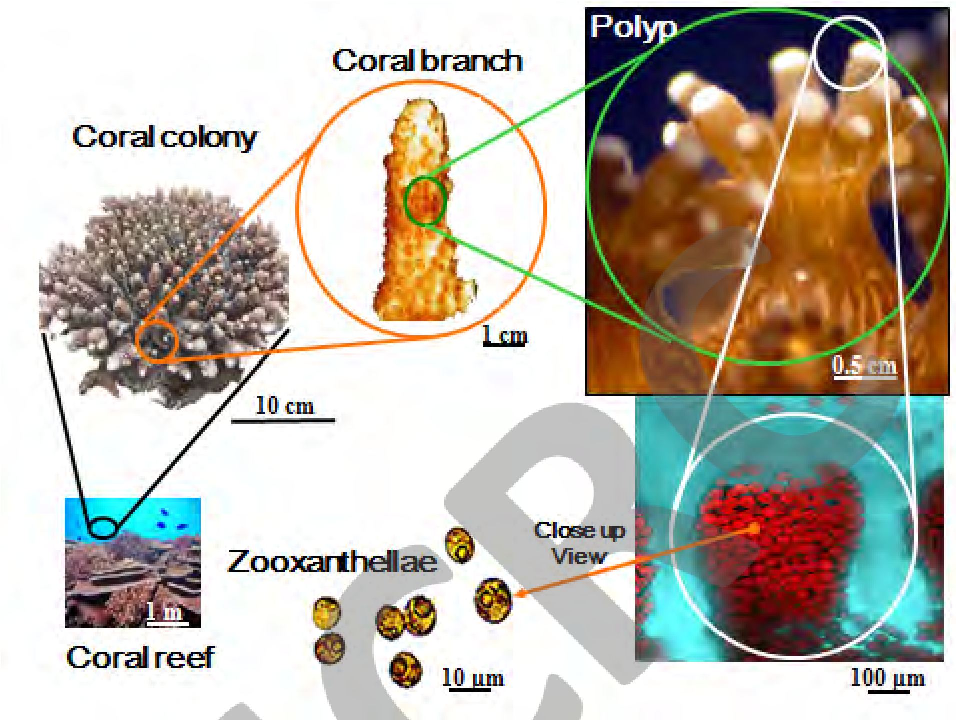

Figure 32-4. Close up view of a coral colony. The dense population of zooxanthellae is responsible for the dark color of corals. Drawn by T. Nakamura.

Coral reefs are often found in habitats with clear water where abundant sunlight reaches to the bottom. Clear water is an essential factor for coral growth in Palau. How can clear water be maintained? Around the tropical to subtropical regions, including Palau, surface waters are heated by powerful solar insolation especially during the dry season. The heated warm waters are less dense than cooler, deeper waters, and is located at the surface. Mineral nutrients in shallow waters are progressively consumed by phytoplankton and zooplankton, which sink to deeper waters as they die. The dead plankton falling from the surface is rapidly mineralized by micro-organisms such as bacteria, but stratification of the water column ensures that the minerals are kept in deeper water and that shallow waters are nutrient-deficient. Low productivity waters are termed

oligotrophic. That is the main reason for clear transparent seawater in the tropical oceans such as around Palau. In nutrient-deficient oceans, food supplies for benthic organisms (including corals attached to the bottom substrata for most of their lives) depend upon plankton production for their energy source; it is very limited. However, due to the clear water, the sunlight can reach deep into oligotrophic seawater. Then, how do these benthic organisms survive? Corals utilize sunlight as their energy source. How do corals utilize sunlight to maintain vigorous growth under such conditions?

Corals have a symbiotic relationship with zooxanthellae algae. Zooxanthellae are photosynthetic, and they are not mineral nutrient-limited like other planktonic algae floating in the open water. Zooxanthellae can directly receive their necessary nutrients and minerals from the coral's metabolism, including carbon dioxide (as a waste product of respiration by coral), ammonium, nitrate, and phosphate ions. A significant proportion of algal photosynthesis

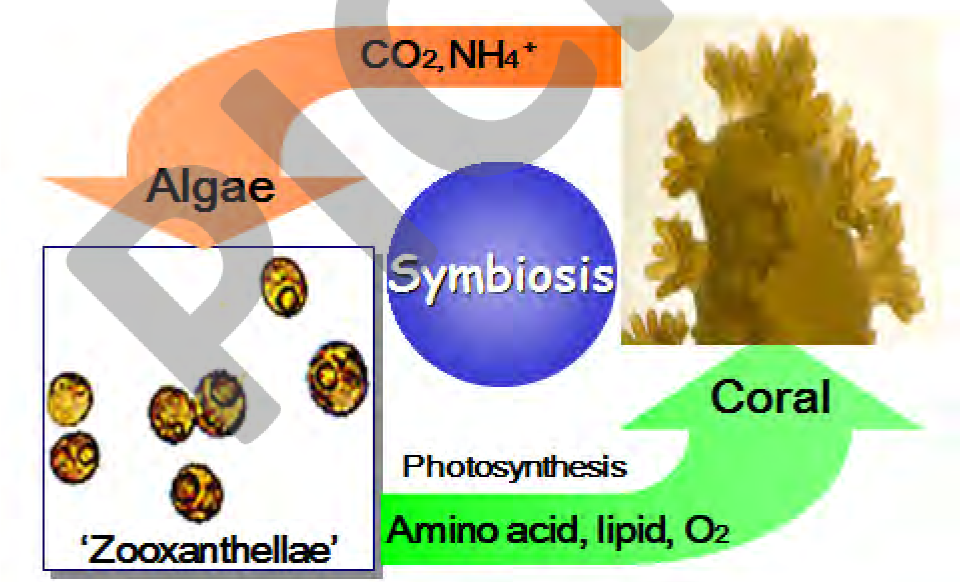

Figure 32-5. Symbiotic relationship between coral polyps (upper right) and zooxanthellae (lower left). Their symbiosis with zooxanthellar algae allows corals to flourish in nutrient-limited environments. Drawn by T. Nakamura.

production is known to be transferred to the coral polyp; the products transferred include glycerol, glucose, and amino acids (***Figure 32-5***). For example, most (ca. 90%) of the energy required by cauliflower coral (*Pocillopora damicornis*) is provided by the photosynthesis of symbiotic zooxanthellae. That is the physiological and biochemical mechanism used by corals to survive and grow in oligotrophic waters.

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Photo by Rod Salm.

CHAPTER 33

CORAL SPAWNING AND CORAL RECRUITMENT IN PALAU

Marine Gouezo

Critical Thinking:

What is gained by understanding coral spawning patterns?

Coral reefs are critical habitats for marine biodiversity, a source of food, a storm buffer, and an integral part of Palau's culture. Understanding the processes of coral spawning and recruitment is needed to study coral reef resilience to climate change impacts. It is essential to conduct research and monitoring over long periods of time to collect data on seasonal spawning timing and synchrony in coral populations (Baird et al., 2009) and to better understand the impacts of climate change on our reefs in the near future.

For researchers, understanding how the most common coral species reproduce and recruit into new reef spaces is an essential milestone in coral reef recovery research. Corals are colonial organisms made of many small polyps that secrete a calcium carbonate skeleton. The way corals reproduce is diverse among species and regions of the world (Richmond and Hunter, 1990; Baird et al., 2009). Some coral species are gonochoristic which means than they only have one sex (male or female). Some coral species are hermaphroditic which means that they have both male and female gametes developing in either the same polyp or in different polyps within the same colony. For gonochoristic and hermaphroditic corals, fertilization occurs in two different ways: **brooding** and **spawning**. Fertilization that occurs inside the maternal polyp is called **brooding** and small

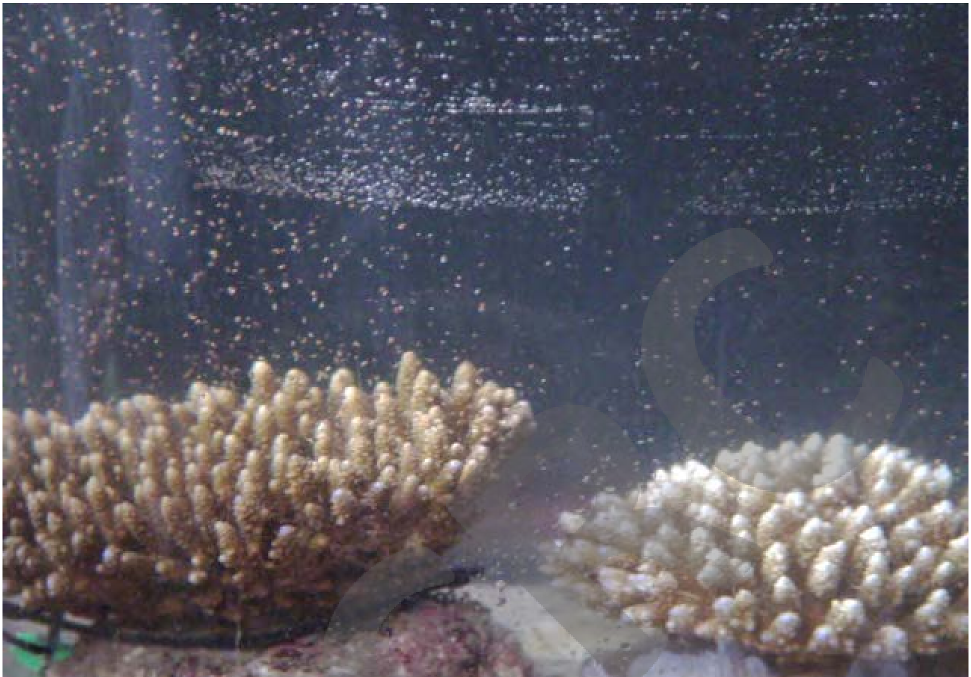

Figure 33-1: Two *Acropora* spp. colonies spawning in an aquarium at PICRC. Photo by Carol Emaurois.

larvae, called planula larvae, are released into the water column. Fertilization that occurs directly in the water column with the embryo developing in the water is called **spawning**.

Spawning is the most common method of reproduction for corals (Baird et al., 2009). As fertilization occurs in the water column, both male and female gametes must be released at a specific time; this is called **spawning synchrony** (***Figure 33-1***).

The synchrony or timing of coral spawning is triggered by specific environmental cues which are different among countries and regions worldwide. In Palau, two studies have shown that the timing of peak coral spawning occurs during two main periods: in spring (February to June) and in late summer (August and September) (Penland et al., 2004). These seasonal events are thought to be triggered by solar

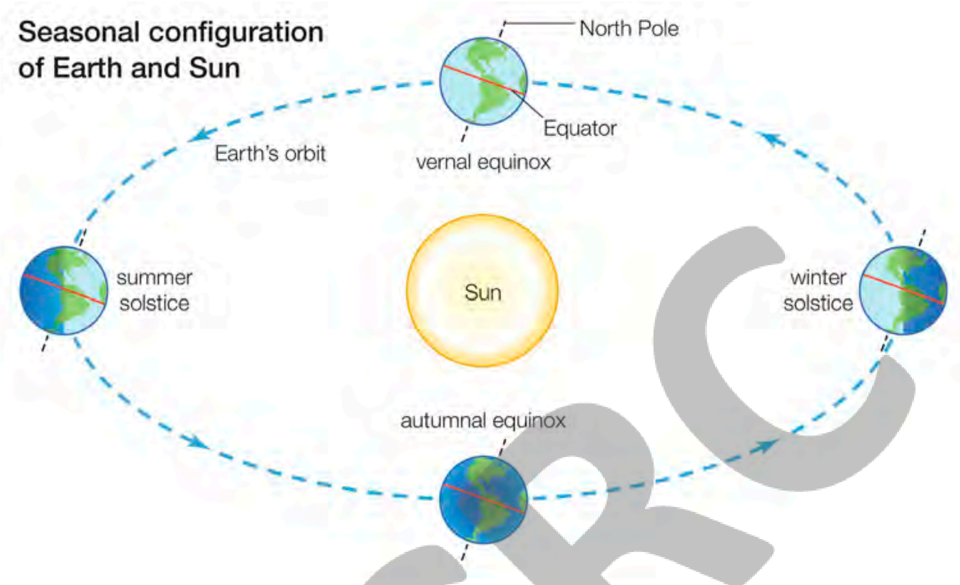

Figure 33-2: Diagram showing how the sunlight hits the surface of the earth throughout the year. Source: Encyclopedia Brittanica, 2017.

insolation and low wind conditions (Penland et al., 2004; Van Woesik, 2009). Solar insolation is the amount of solar radiation that hits the surface of the earth. Maximum solar insolation occurs when an imaginary line coming from the center of the sun crosses the equator perpendicularly (***Figure* 33-2**).

In Palau, the rise toward maximal solar insolation, the vernal equinox occurring in February to May, and the fall from maximal solar insolation, the autumnal equinox occurring in August to September, coincide with coral spawning (Penland et al., 2004). During these two periods there are also low wind conditions that influence coral spawning (Van Woesik, 2009). Low wind conditions offer advantages for gamete release, fertilization success, and larval retention close to the reefs resulting in successful coral recruitment (Van Woesik, 2009). During the two main spawning seasons, corals release their gametes a few days after the full moon. The sun and the moon direct the tides by gravitational forces. During full and new moons, the sun and the moon are aligned, strengthening the gravitational forces, and producing high tidal ranges. Corals in Palau spawn at night, 1 to 7 days after the full moon. Why after the full moon and not the new moon? Researchers discovered that some of the genes of corals are able to sense moonlight and therefore "know" that after the full moon it is a good time to spawn (Levy et al., 2007). In Palau, corals spawn a few days after the full moon at night, a few hours after sunset. Within 5 to 15 days, most coral larvae are carried by the current to a suitable spot to settle; this is called **coral recruitment**.

Coral reef researchers study coral recruitment to determine how many new corals successfully settle on a reef. After super typhoon Bopha in 2012 and super typhoon Haiyan in 2013, PICRC researchers were especially interested in the success rate of recruitment on the severely damaged reefs. If a reef is receiving a large supply of coral larvae and has successful recruitment, then it is a good indication of reef recovery. From 2016 until present, PICRC researchers have been studying coral recruitment at many sites along the damaged eastern reefs. Researchers use recruitment tiles which have a similar surface as the substrate and are fixed to the dead reef and deployed before a coral spawning event to measure coral recruitment (***Figure 33-3***).

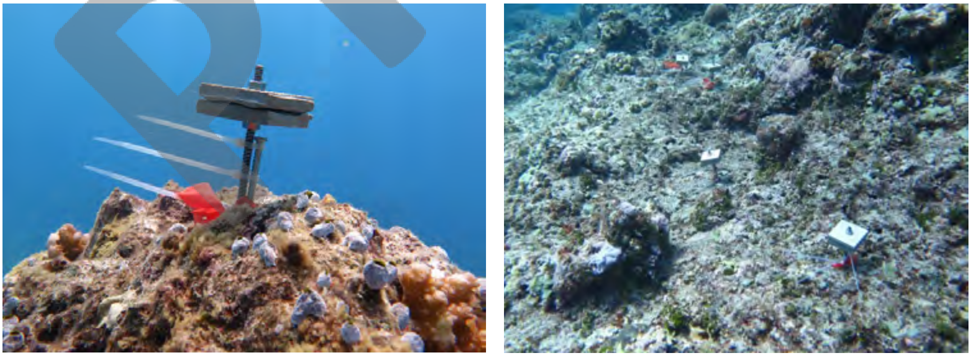

Figure 33-3: Coral recruitment tiles attached to the substrate on a damaged eastern reef. The left photo shows a close up of the recruitment tiles. Photos by Marine Gouezo.

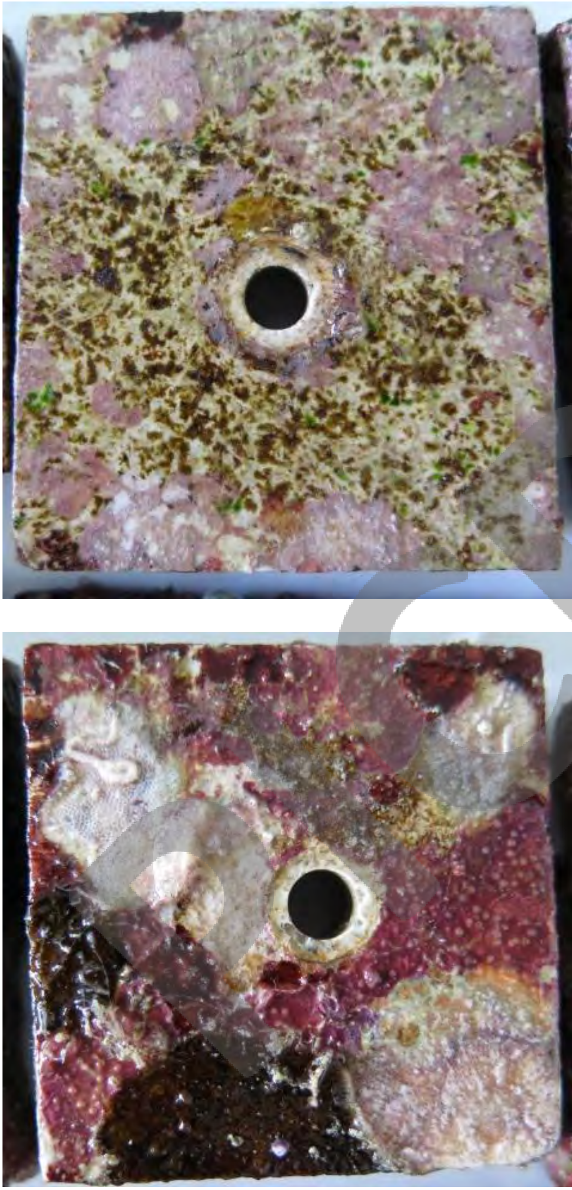

Figure 33-4: Close-ups of recruitment tiles right upon retrieval. Photos by Marine Gouezo.

A few weeks following the spawning event, coral recruitment tiles are retrieved. Upon retrieval, tiles are overgrown by many organisms like algal turf, sponges, encrusting algae, crustose coralline algae or ascidians (***Figure 33-4***), some of which are also important to coral metamorphosis and successful growth.

Coral recruits are very small, often less than 0.5 mm. It is hard to see them with the naked eye. Therefore, recruitment tiles are inspected under a dissecting microscope and coral recruits are counted, identified, and measured (***Figure 33-5***).

Knowledge gained from research conducted on the timing of coral spawning and the locations of where coral larvae recruit is essential to understanding the process of coral reef recovery after large disturbances such as typhoons

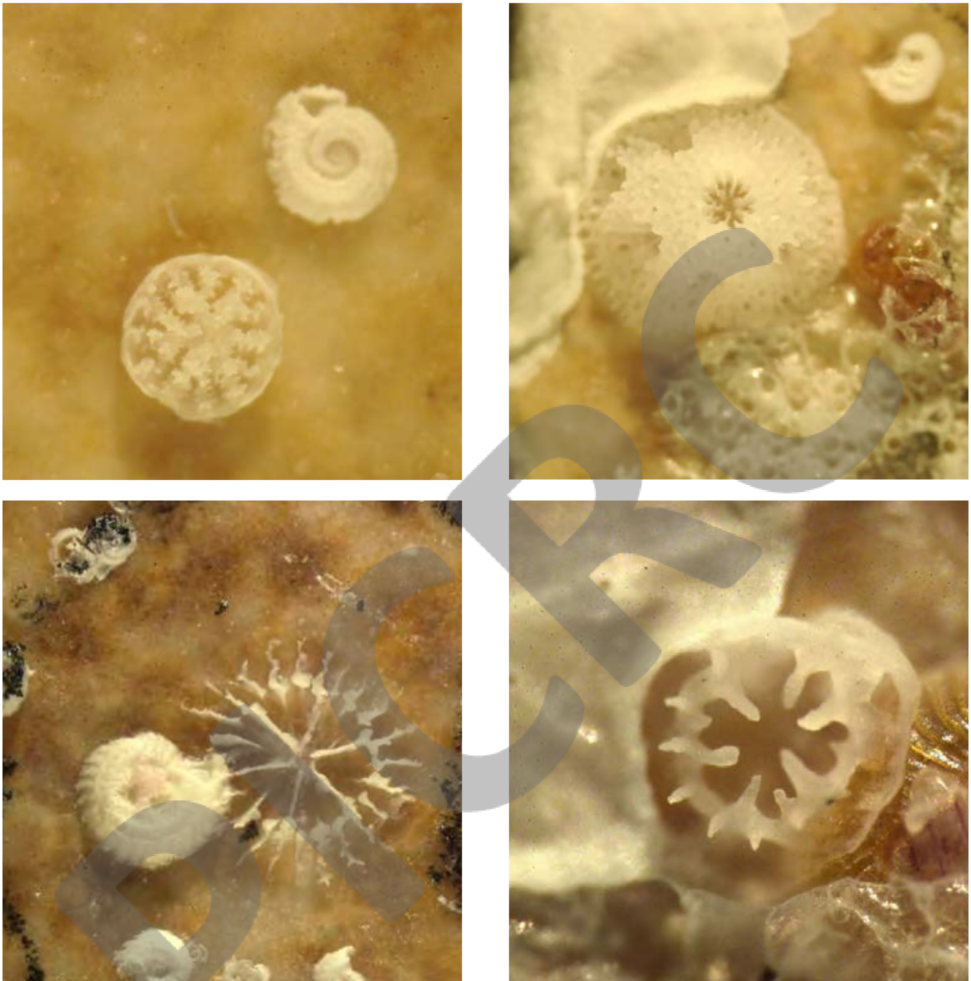

Figure 33-5: Microscope photography of coral recruits (1 to 3 months old). Photos by Marine Gouezo.

More Critical Thinking:

1. ***How and when do corals reproduce in Palau?***
2. ***How do we measure coral recruitment on the reef?***

or bleaching events. In combination with long term monitoring data on coral reef growth, PICRC researchers are hoping to make predictions on how long it takes for coral reefs to recover, and test if some management actions can assist and speed up the recovery process. In a future of uncertain weather patterns caused by global climate change, this research will greatly benefit conservation actions if new disturbances damage Palau's coral reefs.

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CHAPTER 34

CORAL REEF FISH

Alyssa Marshell

Critical Thinking:

What do coral reef fish eat and why are they an important part of the ecosystem?

Coral reefs are second only to rainforests in terms of having a great biodiversity of species, and provide homes and nursery grounds to many fish species. In fact, about 5000 species, or 25% of all saltwater fish species, live on coral reefs. This is amazing when you consider that coral reef habitat covers less than 0.2% of our oceans.

The coral reef food web is very complex because it is such a diverse biological community. Coral reef fish range from large predators—like sharks, grouper, and barracuda—that prey on other fish, to small and colorful fish – like clownfish or mandarinfish—that eat plankton. Along with their respective roles in the food web, many of these fish serve other important roles in our oceans. For example, herbivores, like surgeonfish and parrotfish, keep seaweed-like algae from taking over coral reefs (***Figure 34-1, right***).

Figure 34-1. Coral reef. Source: Green and Bellwood, 2009.


Figure 34-2. Cleaner wrasse.

Cleaner wrasse (***Figure 34-2***) help keep larger fish healthy by removing parasites and dead skin.

Because the coral reef food web is so complex, attempting to describe all of the links in any coral reef food web is very difficult (***Figure 34-3***). Instead, we can focus on three basic trophic levels that are characteristic of all coral reef food webs to reduce the complexities of feeding relationships in coral reef communities. Each **trophic level** represents a group of species that acquires its energy and raw materials by different means and from distinctly different sources. Typically, the three main trophic levels are:

- **Producers** (plants)
- **Primary Consumers** (herbivores)
- **Secondary Consumers** (carnivores)

Producers are plants or organisms that can photosynthesize (produce chemical energy from sunlight energy), and are at the bottom of the food chain. These organisms are called "producers" because they are a critical link between the sun and all life on Earth, as all other animals and organisms rely on them for food.

An animal's level in the food chain is determined by what it eats. **Herbivores** are animals that only eat vegetation, such as grasses, fruits, leaves, vegetables, roots, and bulbs. Herbivores are the transportation system of photosynthetic energy through the food chain, and are called "primary consumers," which means that

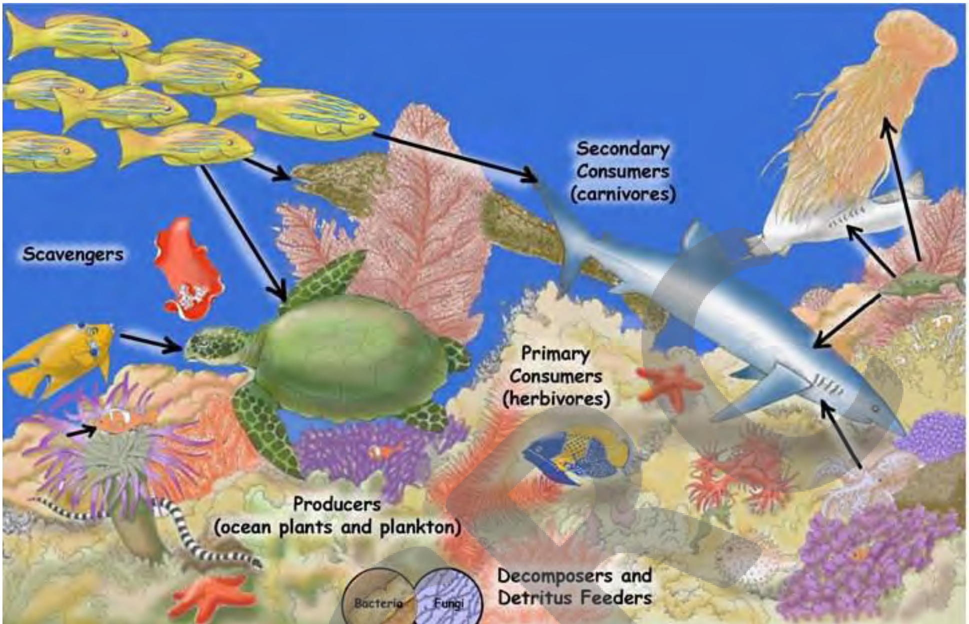


Figure 34-3. Coral reef food web. Source: http://katini-747.wix.com/coral-reefs#!_home-page.

they are the first animals to eat the producers. A wide variety of herbivorous animals reside on coral reefs, including invertebrates (such as snails and crabs) as well as fishes. The most important families of the herbivorous coral reef fishes are the parrotfish, surgeonfish, rabbitfish, rudderfish, and damselfish (***Figure 34-5***).

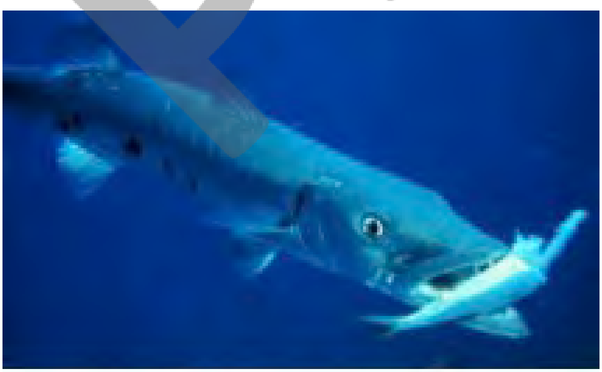


Figure 34-4. Barracuda - a top carnivore.

Carnivores include those predators that feed primarily on passing zooplankton as well as those that feed upon other animal members of the coral reef community. Carnivores are abundant on coral reefs and the largest carnivores that dwell on

Figure 34-5. Herbivorous reef fishes (clockwise from top left): parrotfish (*Scarus frenatus*) (Image: Mark Priest), surgeonfish (*Acanthurus nigricauda*), rudderfish (*Kyphosus vaigiensis*), angelfish (*Centropyge bicolor*), damselfish (*Dischistodus chrysopoecilus*) and rabbitfish (*Siganus virgatus*). Source: Except where noted, images by G. Allen from Green and Bellwood, 2009).

coral reefs are the piscivores—those fishes that feed heavily upon smaller herbivorous and planktivorous fish. These include barracuda (***Figure 34-4***), sharks, large seabasses (groupers, hinds), trumpetfish, and large snappers.

Figure 34-6. Parrotfish beak. Photos by Mark Priest.

Diversity of coral reef fishes

Coral reefs offer a vast array of different types of possible fish prey items. Therefore, there are varieties of coral reef fish species well adapted to make use of each of these ready food resources. For example, the herbivorous parrotfish have evolved large, beak-like mouths (***Figure 34-6***) perfectly adapted to scrape microalgae from the surfaces of dead coral colonies. In contrast, the herbivorous surgeonfish have small mouths with numerous small teeth adapted for cutting and eating macro-algae. The major families of coral reef fish can be arranged by feeding strategy, with four major groups recognized: herbivores, planktivores, benthic carnivores, and piscivores.

Herbivores

Herbivores play a key role in maintaining coral reef health by removing algae through their feeding activities. These herbivores are common members of reef fish assemblages throughout the Indo-Pacific region.

- **Parrotfish** are the largest and most colorful of coral reef herbivores. They are named for their brilliant hues and beak-like mouths.
- **Surgeonfish** are the mid-size models of herbivorous coral fishes. The name "surgeonfish" comes from the retractable

scalpel-like spines at the base of each side of the tail, used as defensive weapons. Bluespine unicornfish (*Naso unicornis*) are macroalgal browsing surgeonfish (***Figure 34-7***).

Figure 34-7. Bluespine Unicornfish. Photo by Mark Priest.

- **Rabbitfish** have large, dark eyes and small, somewhat rabbit-like mouths, which gives them their name. Most species have either bright colors or a complex pattern.
- **Damselfish** are more sedentary than the wide-ranging parrotfish, surgeonfish, and rabbitfish. Small herbivorous damselfishes are territorial "farmers" that maintain and vigorously guard small patches of algae on the reef.

Planktivores

Planktivores are coral reef fishes that prey upon small animal plankton (zooplankton). There are many different types of planktivores, including:

1. **Open Water Plankton Feeders**: The daytime open-water plankton feeding coral reef fish consists of many diverse species, including damselfishes, wrasses, snappers, sea basses, and surgeonfishes.
2. **Benthic Planktivores**: A diverse group of small daytime plankton feeders (e.g., jawfish) avoid the dangers of open-water hunting by remaining close to the safety of the reef or other nearby benthic habitats while capturing their tiny prey.
3. **Nocturnal Planktivores**: The daytime planktivores seek shelter within the reef at night and are replaced by night-time species adapted to low light conditions. These night hunters include cardinalfishes, squirrelfishes, and soldierfishes.

Benthic carnivores

Benthic Carnivores (***Figures 34-8,9,10***) describe fishes that prey on a variety of animals living on or near the sea floor. Some common daylight benthic carnivores that hunt and feed on or near the reef include the blennies, gobies, wrasses, and goatfishes. There are many types of benthic carnivores, including:

1. **Butterflyfishes** are among the most abundant and colourful of daytime reef benthic carnivores. Their forcep-like mouths armed with fine comb-like teeth serve them well in browsing on exposed coral polyp tentacles and other tiny reef invertebrates.
2. **Triggerfish** and their close relatives the filefishes, trunkfishes, and puffers have evolved to become skillful benthic carnivores, often feeding far from the shelter of the reef.
3. **Grunts and snappers** shelter on the reef by day and venture out only at night to feed in open sand and seagrass habitats.

Piscivores

Piscivores (***Figure 34-11***) are coral reef fish that prey mainly or entirely upon other fishes. There are three different basic hunting strategies employed by these predators.

1. **Pursuing Predators** are those that rely on speed to chase prey in open water. These fishes have streamlined bodies, and are capable of extremely fast attack speeds. Examples include the jacks, mackerels, and many sharks.

Figure 34-8. Butterflyfishes.

Figure 34-9 (*Above*). Triggerfish.

Figure 34-10 (*Left*). Grunts and Snappers.

2. **Stalking Predators** sneakily approach their prey before striking. Common coral reef fish employing this strategy include barracudas, needlefishes, and trumpetfishes. All have slender, elongated bodies that present a minimal head-on profile to prey.
3. **Ambush Predators** rely on disguise and stillness to hunt. They wait motionless for unsuspecting victims to stray into striking range. Common ambush piscivores include frogfishes, lizardfishes (***Figure 34-11, bottom left***), flatfishes, groupers, and scorpionfishes (***Figure 34-11, bottom right***).

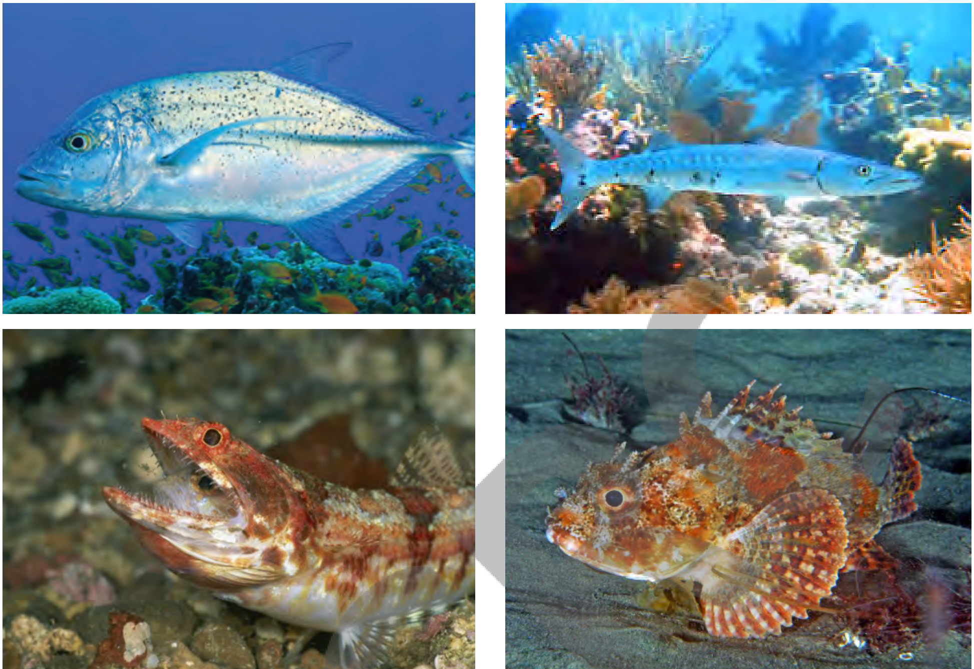
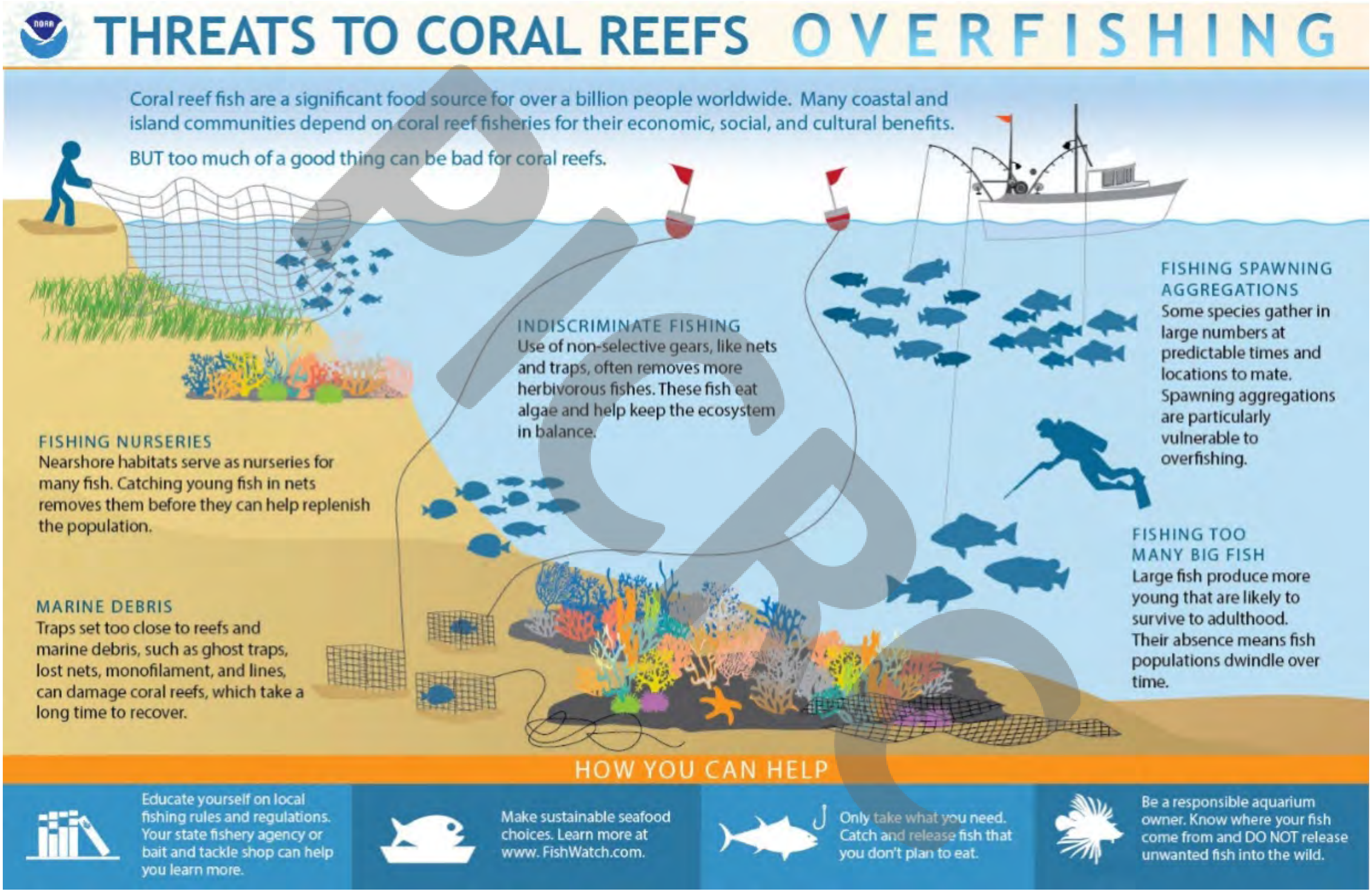


Figure 34-11. *Top left*: Pursuing Predator (Bluefin Trevally by Mark Priest). *Top right*: Stalking Predator. *Bottom left*: Lizardfish, an Ambush Predator. *Bottom right*: Scorpionfish, an Ambush Predator.

Coral reef fish exploitation and management

In addition to their ecological value in the oceans, more than one billion people around the world rely on reef fish as a source of food and income. However, despite their importance, coral reef fish are not always managed sustainably. Fishermen can sometimes rely too heavily on certain species, causing some reef fish to be severely overharvested (***Figure 34-12***), which can have negative consequences for reefs. Depletion of parrotfish and surgeonfish populations allows algae to grow unchecked, causing some coral reef ecosystems to change from a beautiful, complex seascape of corals to degraded,

Figure 34-12 (right page). Threats.
Source: http://oceanservice.noaa.gov/facts/coral-overfishing.html.


THREATS TO CORAL REEFS OVERFISHING
Coral reef fish are a significant food source for over a billion people worldwide. Many coastal and island communities depend on coral reef fisheries for their economic, social, and cultural benefits.
BUT too much of a good thing can be bad for coral reefs.
FISHING NURSERIES
Nearshore habitats serve as nurseries for many fish. Catching young fish in nets removes them before they can help replenish the population.
MARINE DEBRIS
Traps set too close to reefs and marine debris, such as ghost traps, lost nets, monofilament, and lines, can damage coral reefs, which take a long time to recover.
INDISCRIMINATE FISHING
Use of non-selective gears, like nets and traps, often removes more herbivorous fishes. These fish eat algae and help keep the ecosystem in balance.
FISHING SPAWNING AGGREGATIONS
Some species gather in large numbers at predictable times and locations to mate. Spawning aggregations are particularly vulnerable to overfishing.
FISHING TOO MANY BIG FISH
Large fish produce more young that are likely to survive to adulthood. Their absence means fish populations dwindle over time.
HOW YOU CAN HELP
Educate yourself on local fishing rules and regulations. Your state fishery agency or bait and tackle shop can help you learn more.
Make sustainable seafood choices. Learn more at www. FishWatch.com.
Only take what you need. Catch and release fish that you don't plan to eat.
Be a responsible aquarium owner. Know where your fish come from and DO NOT release unwanted fish into the wild.

empty fields of rubble and seaweed. More than 1,800 species of reef fish, 140 species of corals, and 500 species of other invertebrates are also collected for the aquarium trade. Although trade can be conducted sustainably, reef populations are often overexploited to supply the demand for these animals. For example, populations of clownfish and mandarinfish have been overexploited by heavy collection for the aquarium trade. This can lead to local extinctions, disrupted mating systems, and fewer fish on the reef.

Coral reef management is the process of modifying human activities to avoid damage to healthy coral reefs and to help damaged reefs recover. The key strategies used in reef protection include having community involvement to reduce stressors that damage reef health. One management technique is to create Marine Protected Areas (MPAs) that directly limit human activities such as fishing. Coral reefs are facing unprecedented threats from a combination of local (e.g., overfishing, pollution, coastal development) and global stressors (e.g., increasingly intense/frequent storms and climate change). At the same time, coral reefs are increasingly recognized as a vital source of food and income for many communities. Effective management of coral reefs has become an important focus for coastal communities, and a range of strategies are available to help protect reef biodiversity and facilitate sustainable use into the future.

Images Citation

Green, A.L. and D.R. Bellwood. 2009. Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience – A practical guide for coral reef managers in the Asia Pacific region. IUCN working group on Climate Change and Coral Reefs. IUCN, Gland, Switzerland. 70 pages.

Except where sourced, photos provided by the author.

Coral reef. Photo (right page) by Yubee Isaac.

CHAPTER 35

A PERSPECTIVE OF FISHERIES MANAGEMENT IN PALAU

Ann Hillmann Kitalong

Critical Thinking:

Why are fisheries so important to Palau?

Inshore fisheries

Palau has the highest diversity of fish in Micronesia with over 1,573 recorded species (www.fishbase.org). Fish consumption rates in Palau are higher than most of the Pacific (FAO, 2009). Fishing is a way of life for Palauans. For centuries, Palauans have managed their fisheries using traditional sustainable fishing practices and the no take law, *bul*, to protect marine stocks. A *bul* is declared by the chiefs when resources are limited. Today, many fisheries management tools are used that build upon the *bul* to ensure that Palau's fisheries remain healthy.

What are the most common reef fish harvested in Palau?

During 1976 to 1990, the ten most common species of fish commercially landed were the unicornfish (*Naso unicornis*), the humphead parrotfish (*Bolmetopon muricatum*), the snappers (*Lutjanus gibbus, Lutjanus ramak,* and *Lutjanus bohar*), the groupers (*Epinephelus* spp.), the pacific longnose parrotfish (*Hipposcarus longiceps*), the rabbitfishes (*Siganus fuscescens* and *S. lineatus*), and the emperor fish (*Lethrinus xanthochila*). Today there is a ban on the harvest of the humphead parrot (*B. muricatum*) and a closed season for rabbitfish (*S. fuscescens*), during its early spring spawning period.

Why does fish size matter?

There are strong indications that fishing catches have declined over time. For example, in 2002, 31% of fishers perceived that the inshore fishery was being over-harvested and communities perceived their catch was at least 3 times less than a decade ago (Bureau of Marine Resources, 2002). Kitalong (2011) found that the size and numbers of pre-spawning aggregations of *Siganus fuscescens* in Airai were smaller than 20 years ago. Prince et al. (2015) found that over 66% of the top food fish in the Northern Lagoon had a spawning potential ratio (SPR) less than 20%. If the spawning potential ratio is less than 20%, it suggests that there is not enough reproductive capacity for stock to increase and the numbers of fish will continue to decline if management is not imposed. Recently, Lindfield (2017) analyzed the size frequency of eight of the main species of fish through comparisons of historical catches from 1982- 1991 to recent market data from 2014-2015. These results showed that four of the main species of fish: keremlal (*Lutjanus gibbus*), mechur (*Lethrinus xanthochilus*), um (*Naso unicornis*), and erangel (*Naso lituratus*) continue to

Figure 35-1. Jeremy Prince measuring *Lutjanus gibbus* at Kayangel.

Figure 35-2. This immature *L. xanthochilus* was released in a catch and release fishing derby.

decline in size. Fishing pressure needs to be reduced so populations of these fish can rebound. The steady reduction in nearshore fisheries populations requires more size limits for more species and greater protection of fish spawning aggregation sites.

What are the fishermen concerned about?

Fishers' perceptions also provide an indication of the current state of Palau's reef fisheries and what can be done to better sustain it. Moore et al. (2015) interviewed 15 fishermen who perceived that the quantity of fish (73% of the fishermen) and the size of fish (80% of the fishermen) had decreased in the past five years. The fishermen's concerns were overfishing, habitat destruction and geophysical changes on the reef caused by storms and typhoons, the effects of climate change on coastal resources, and the effects of increased tourist numbers to reefs and fisheries. Suggestions for management included: more community awareness and outreach programs, increasing the number of species subject to temporal closures, and development of management measures to prevent the capture and/or sale of small (immature) fish.

How do we manage our inshore fishery?

Palau's fisheries management efforts in the past have been successful and make the quality of the fishery much better than it would be without these efforts. The introduction of minimum legal mesh sizes for gillnets and surround nets (*kesokes*) under the Marine Protection Act of 1994 has resulted in fewer small, immature fish being caught. This was highlighted by Moore et al. (2015), who compared the length of six top commercial reef fish species between 1990-1991 and 2014. More large-sized individuals of *Hipposcarus longiceps, Lethrinus obsoletus, Naso lituratus, Naso unicornis,* and *Siganus lineatus* were harvested in 2014 compared to 1990-1991.

The seasonal harvest closure of some fish species during their peak reproduction periods has also been successful. For example, Gouezo et al. (2015) observed significantly more groupers (up to 9 times more) within protected fish spawning aggregation sites than the reference sites. At two sites, the abundance of the grouper, *Epinephelus fuscoguttatus* (meteungerel'temekai) increased over time and there was a trend for increasing numbers of the grouper *Epinephelus polyphekadion* (ksau'temekai) at one of the sites. The Conservation and Community Investment Forum (2013) found that Marine Protected Areas (MPAs) under the Palau Protected Areas Network (PAN) serve as building blocks for nearshore fisheries and coastal marine resource management. However, they recommended that states incorporate larger fisheries management efforts around MPAs and the rest of their state waters including legal structures, enforcement, and a sustainable finance mechanism for nearshore fisheries.

Figure 35-3. *Lethrinus xanthochilus* caught in the northern reefs.

In recent years, there has been great demand for inshore fisheries resources. Tourism in Palau has increased


Figure 35-4. Emperor fish and snappers weighed in at the fish market in Koror.

from 6,000 visitors in 2002 to over 160,000 visitors in 2015 (http://pristineparadisepalau.com) with a subsequent increase in the number of restaurants, hotels, and tourism venues catering to guests. The tourism market consumes the majority of marine products, as seen by the increased prices and quick depletion of fish from the market each morning. This demand from the rise in seafood tourism increases fishing pressure and monetary rewards provide increased incentive for illegal activities by fishers. Birkeland (2017) recommended that Palau reserve reef fish for the local population and the tourist industry target the larger stocks of oceanic or pelagic fish.

Offshore finfish

Tuna is the primary pelagic finfish species group targeted for harvest by foreign vessels from Palau's Exclusive Economic Zone (EEZ). Species of tuna harvested include albacore (*Thunnus alalunga*), bigeye (*T. obesus*), yellowfish (*T. albacares*), skipjack (*Katsuwonus pelamis*), and northern bluefin (*T. macoyii*). Other pelagic fish taken in high amounts include blue marlin (*Makaira nigricans*), sailfish (*Istiophorus platypterus*), striped and black marlin, swordfish, and dolphin fish (*Coryphaena hippurus*). During 1990, five foreign fishing agreements allowed 487 vessels to participate in offshore fishing. Direct economic benefits to Palau were from license fees. In 1994 about 830.6 metric tonnes or 44% of the catch from Palau's EEZ was air freighted fresh to Japan for the sashimi market. The remainder of the catch was frozen and shipped to Taiwan for canning. No value-added processing occurred in Palau (Bureau of Oceanic Fishery Management, 2015).

Figure 35-5. Fisherman heading out from Ollei to the northern reefs.

How do we manage our offshore fishery?

The Bureau of Oceanic Fishery Management is responsible for research, fisheries statistics, and development of a domestic tuna fishery. Subsection 181 of RPPL 6-36 prohibits the use of any licensed foreign fishing vessel to fish for any shark, or any part of any such, or to remove the fins of or otherwise intentionally mutilate or injure any such shark. Tuna fishing in the Palau EEZ is dominated by the locally-based foreign longline fleet of Chinese Taipei and the offshore-based longline and purse seine fleet of Japan. In 2014, the total provisional longline catch in Palau waters was 4,181 metric tonnes. 79 longline vessels and 21 purse seiners were active in Palau waters (Bureau of Oceanic Fishery Management, 2015).

Palau's EEZ covers 616,031 km^2. Since the 1980s, Palau observers have been deployed on the locally-based foreign fleet to collect data on fishing gear and the size and species caught. Personnel training through regional programs was ongoing. Palau had one permanent observer and three seasonal observers. Dedicated fisheries port samplers were present at all times during offloading of longline vessels at port to collect data and information. Palau had the following offshore fishing agreements: Fisheries Bilateral Agreement between Palau and the Japan Fishing Association, Locally-Based Foreign Fleet of Chinese Taipei, US Multilateral Fisheries Treaty, the FSM Arrangement, and an agreement with Palau's wholly owned fishing entity which does not have active fishing vessels (Bureau of Oceanic Fishery Management, 2015).

Why is the National Marine Sanctuary so important to our fishery?

On October 22, 2015, the Palau National Marine Sanctuary Act (PNMS) was made into law. This *bul* was declared by the paramount chiefs of Palau (Rubekul Belau). All commercial fishing within 80% of Palau's EEZ (492,825 km^2) will be phased out by 2020. The Act eliminated the Asian long-line fleets. The purse seiners can only harvest free swimming schools of skipjack in the remaining 20% of Palau's EEZ because this fishery was deemed sustainable. Local and sustainable sportfishing for billfish, tuna, wahoo, mahi mahi, barracuda, and giant trevally is being promoted using nearshore Fish Aggregation Devices (FADs) (Bureau of Marine Resources, 2015).

Summary

Management tools that will continue to be successful include the traditional *bul*, size limits, gear restrictions, seasonal closures, protected areas, sanctuaries, education and awareness campaigns, laws banning unsustainable fishing practices, and observer programs. However, ongoing research and monitoring of the inshore and offshore fisheries is needed to determine the effectiveness of these management tools. A sustainable fishery requires effective management of the land, the sea, and people. A Japanese scientist, Mr. Yoji Kurata, now in his 90s helped manage fisheries in Palau before World War II. In February of 2017, I asked him what he considered the top action needed to sustain Palau's fisheries. He stated, *"Protect the reef. Many fish live in the reef, but the reef is connected to the land. One must value the sea and the land."* I asked *Obakradebkar* Clarence Kitalong, a local fisherman, the same question. He replied, *"Use the local traditional fishing methods only. Stop the large commercial long liners."*

Acknowledgements

I thank Dr. Steven Lindfield for reviewing this article.

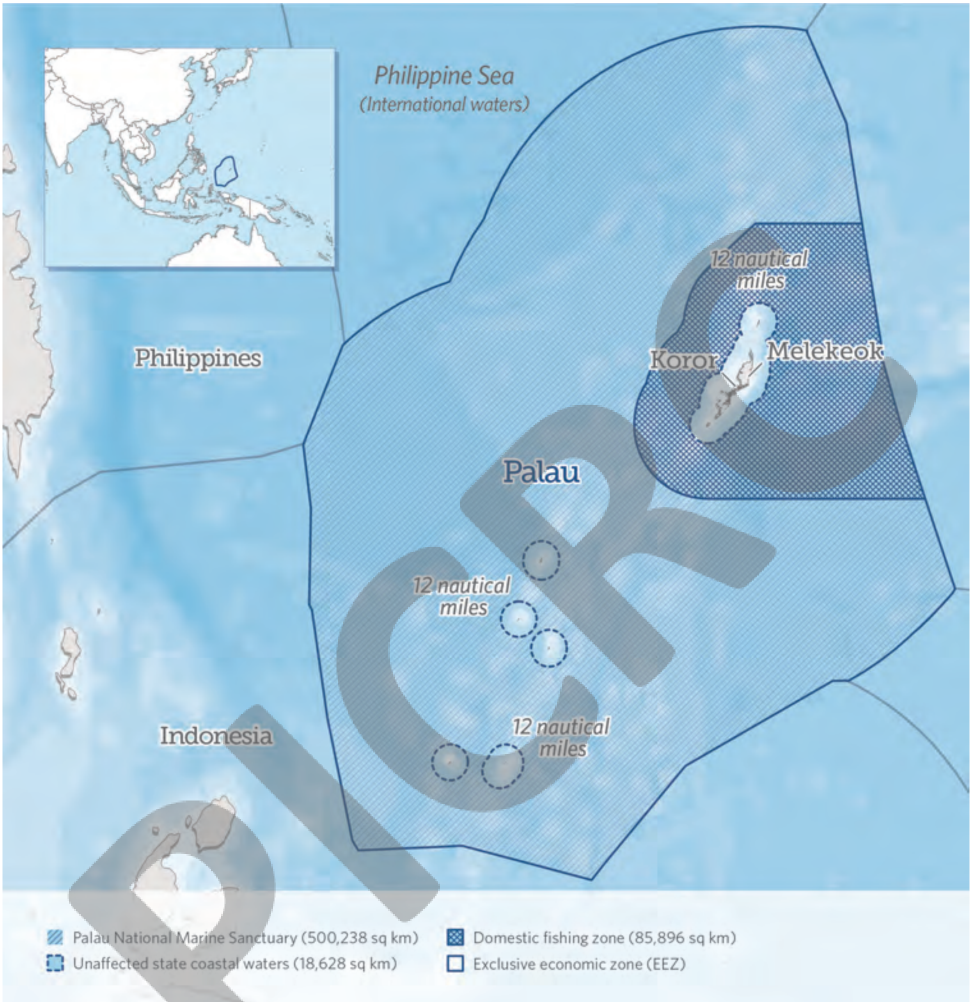


Figure 35-6. The Palau National Marine Sanctuary (PNMS). Source: Pew Charitable Trusts.

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Photos provided by Dr. Steven Lindfield.

Photo provided by PICRC.

PART 6
Nature and Humans

CHAPTER 36

EFFECTS OF CLIMATE CHANGE ON CORAL REEFS

Haruko Kurihara and Chuki Hongo

Critical Thinking:

What will happen to coral reefs and organisms if the ocean temperature increases?

When we use fuel and electrical appliances such as air conditioners or cars, we are discharging carbon dioxide (CO_2) into the atmosphere. Due to human activity, the percentage of carbon dioxide in the atmosphere has already increased from 280 ppm (parts per million) since the pre-industrial era (year 1860) to 404 ppm today. When carbon dioxide in the atmosphere increases, there are two main concerns in the ocean: rise of seawater temperature and ocean acidification (IPCC, 2014).

Carbon dioxide traps heat, causing an increase in the mean temperature (global warming). Due to global warming, by 2100 the seawater temperature in Palau is predicted to increase on average by 1.5 to 3°C degrees compared to the present average seawater temperature (28 ~ 29°C). What will happen to coral reefs if the ocean temperature increases?

First, many corals can start to bleach. When corals are exposed to temperatures ranging from 1 to 2°C degrees higher than the average maximum temperature that corals normally experience, corals start to lose the algae (zooxanthellae) that live within their tissue (Hoegh-Guldberg et al., 1999). When corals lose zooxanthellae, their tissue becomes transparent and looks white, which is the color of their calcium carbonate skeleton (***Figure 36-1***). Since corals receive

Figure 36-1. Bleached corals lose zooxanthellae and their tissue becomes transparent and looks white. Photo by Haruko Kurihara.

much of their nutrients from the zooxanthellae, if corals loose them for a long period of time, they will die. In 1998, the ocean seawater temperatures of Palau experienced higher than normal conditions for several weeks due to the El Niño Southern Oscillation (ENSO). ENSO is a natural phenomenon that transits between two phases, the warmer central and eastern equatorial Pacific seawater temperature phase (El Niño) and a cooler central and eastern equatorial Pacific seawater temperature phase (La Niña). During that period, it has been reported that 50-70% of the corals bleached in Palau (Bruno et al., 2001).

In addition to corals, many other organisms lost their zooxanthellae due to stress from the temperature rise, such as sea anemones (***Figure 36-2***), soft corals, giant clams, and the jellyfish including *Mastigias papua etpisoni*. Therefore, global warming can cause mass mortality of corals and many other organisms on coral reefs.

Global warming also causes sea level rise. When the seawater temperature rises, it causes the melting of ice sheets and shelves at higher latitudes, which expands seawater volume. The global average sea level is expected to increase by 0.44–0.74 meters by year 2100 (Church et al., 2013). During high tide, the coasts of Palau are at a high risk of flooding. Sea-level rise causes saltwater intrusion


Figure 36-2. Bleached sea anemone. Photo by Takuma Fujii.

of surface water and erosion at sandy beaches (***Figure 36-3***). Some low-lying islands such as Kayangel and Helen Reef in Hatohobei are particularly vulnerable to sea level rise.

Global warming is causing unprecedented extreme weather events such as a super typhoons. In 2012 and 2013, Palau was severely impacted by two sequential typhoons (Bopha and Haiyan). These super typhoons destroyed forest and reef habitats, damaged coastal infrastructure from the impact of storm surges, and seawater flooding resulted in major economic losses. The reef ecosystem in Palau was significantly damaged (Doropoulos et al., 2014; Gouezo et al., 2015): for example, many corals were overturned, dislodged, and buried. Many numerical simulations indicate there will be an increase in the maximum wind speed of typhoons due to global warming (Christensen et al., 2013). Thus, the coastal areas of Palau will face future risks from storm surges and flooding. Furthermore, future projections indicate that global warming will increase rainfall rates during typhoons (Christensen et al., 2013). High sediment discharge from the land to coral reefs occurs during periods of heavy rainfall, which can cause a reduction of coral reef resilience.

An increase in atmospheric carbon dioxide also causes ocean acidification. When atmospheric carbon dioxide increases, the carbon dioxide simultaneously dissolves into the seawater. Because carbon dioxide is a weak acid, it produces a proton and seawater become more acidic resulting in the decrease of seawater pH (***Figure 36-4***). The average seawater pH at Palau is now around 8.05. However due to the increase of carbon dioxide, by year 2050 it is expected that the seawater pH will decrease to around 7.98 and to 7.87 by year 2100. As the seawater become acidic, it is known that the ability of corals to build their calcium carbonate skeleton will decrease (Kleypas et al., 2006). This suggests that coral growth will slow down, including the formation of coral reefs and reef crests which protect us from high waves. All calcifiers that make calcium carbonate skeletons such as sea urchins, bivalves, gastropods, and crabs will be affected by ocean acidification (Kurihara et al., 2008).

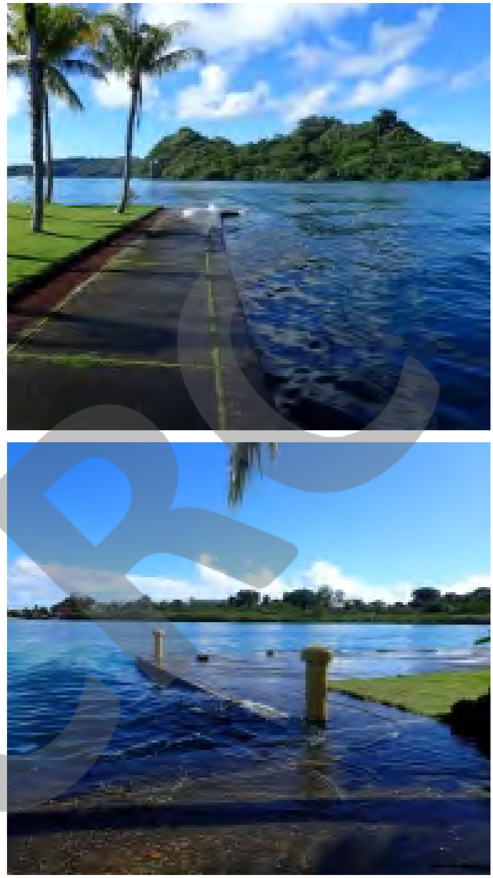

Figure 36-3. Sea level rise. Photos by Chuki Hongo.

Interestingly, when seawater pH decreases, coral reef fishes lose their ability to smell (Munday et al., 2009). Because many coral reef fish like clownfish are known to distinguish their "sea anemone house" by its smell, it is suggested that many coral reef fishes may get lost, and be unable to find their own anemone house in the future (***Figure 36-5***). Recently it was found that in some places like Nikko

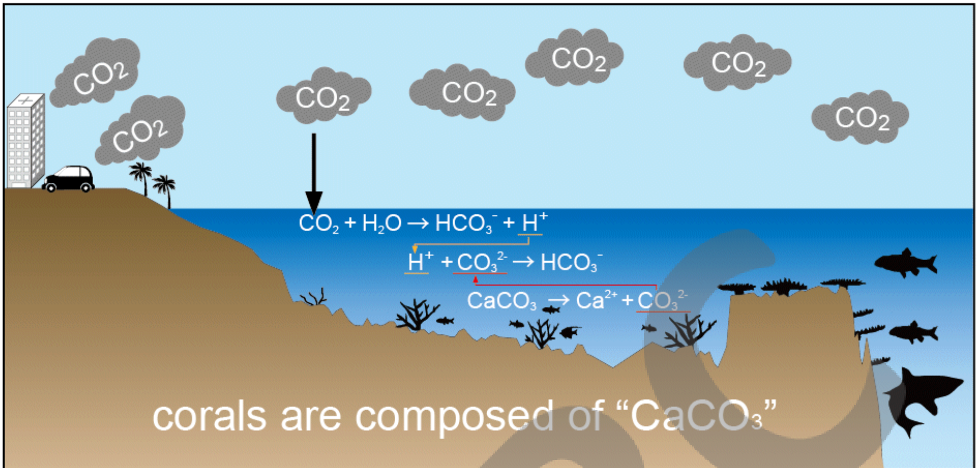

Figure 36-4. Increased atmospheric CO_2 causes ocean acidification. When CO_2 dissolves into seawater, it produces a proton (H+) and seawater become more acidic. As the ocean acidifies, the ability of corals and other calcifiers to build their calcium carbonate ($CaCO_3$) skeletons decreases.

Bay in Palau, the seawater pH is already at the low values that are predicted to occur by the end of this century. However Nikko Bay has high coral coverage and a diverse coral community (Barkley et al., 2015; Golbuu et al., 2016), suggesting that Nikko Bay has naturally resilient reef communities. Further studies evaluating the resilience of the corals in this bay are underway and may have global significance.

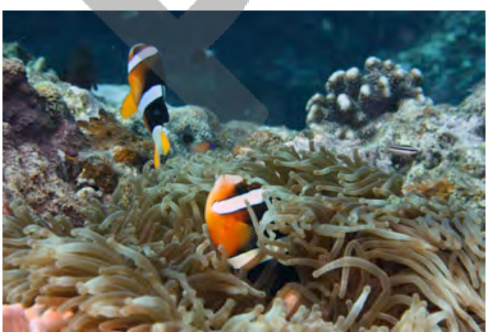

Figure 36-5. Sea anemone hosting Clownfish. Photo by Haruko Kurihara.

Climate change causing accelerated rates of global warming and ocean acidification threatens coral reef ecosystems which provide ecosystem services for us such as protection from typhoons (*Figure 36-6*), food sources, and recreation. So what can we do? Most importantly, we need to reduce

Figure 36-6. Coral reef barrier at Siaes, Palau. Photo by Haruko Kurihara.

the causes of climate change, which is the amount of carbon dioxide that is discharged into the atmosphere. Additionally, recent studies demonstrate that the coral resilience to stresses such as temperature or pH can change according to their health. When corals are less stressed they are more resilient to impacts of climate change (Doney 2010). Therefore, any effort to keep the ocean clean and healthy can help to protect coral reefs in Palau from the impacts of climate change.

More Critical Thinking:

1. ***What will happen to coral reefs and organisms if the sea level rises?***
2. ***What will happen to coral reefs and organisms if the ocean become acidic?***

Graphic provided by the authors.

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CHAPTER 37

CORAL BLEACHING

Takashi Nakamura

Critical Thinking:

What may determine coral bleaching?

Mechanisms

Corals flourish around Palau but they are facing increasing pressures. Persistent high water temperatures threaten the resident biota of coral reefs resulting in **coral bleaching** (***Figure 37-1***) (Hoegh-Guldberg and Smith 1989). Bleaching occurs when zooxanthellae density in coral tissues declines and/or photosynthetic pigment (e.g., of chlorophylls) concentrations in the remaining algal cells become too low. The reduction in the quality and quantity of symbiotic zooxanthellae results in the loss of color causing the white-colored skeletons to be seen through the transparent tissue (***Figure 37-2***).

Figure 37-1. Bleached corals in Sekisei Lagoon, Okinawa (2016). Photo by T. Nakamura.

Figure 37-2. Bleaching viewed from the branch of a colony. Bleaching process: pigments within zooxanthellae are degraded by excessive light energy, damaged zooxanthellae are expelled from the coral hosts (and/or digested within coral tissue), corals bleach. Drawn by T. Nakamura.

In Palau, water temperature generally rises during May and June. When cloud cover is less than normal, more sunlight reaches the sea surface and warms the waters above average temperatures. Under these circumstances, solar radiation often increases the water temperatures to above 30°C in July and August, which may induce a coral bleaching phenomena. Moderately intense storms can reduce sea temperatures rapidly through wind-driven mixing. Coral bleaching tends to occur in years with persistent days of calm seas and sunny weather.

The photosynthetic machinery of primary producers (e.g., cyanobacteria, algae, and plants) is able to absorb only a finite number of photons (particles of light). Excessive irradiance may cause damage to the photosystems (a series of proteins arrayed on the chloroplast membranes). When corals and their symbiotic zooxanthellae are exposed to excessive light, a component of the chloroplast (the D1 protein) deforms, causing a shutdown of photosynthesis that prevents irreversible damage to other components of the light-absorbing apparatus. This process of **photoinhibition** operates like a breaker fuse in an electrical circuit that prevents system overload (Takahashi et al., 2004). D1 proteins are immediately regenerated when suitable light levels are restored. Actually, such disruption and regeneration of these **breaker fuses** allow zooxanthellae to maintain optimal photosynthesis with minimal risk of irreversible damage under dynamic light conditions in coral reef environments. However, a high water temperature sometimes alters this finely balanced mechanism (Takahashi et al., 2004).

When corals remain bleached for prolonged periods of time, they become stressed from energy deficiencies due to the reduction in energy transfer from the zooxanthellae (***Figure 37-3***). Although the remaining zooxanthellae in the bodies of bleached corals may sometimes recover to their original densities when environmental conditions change, the polyps have already been weakened by the nutrient deficiencies, and they readily succumb to disease. Growth rates of corals also decline after a bleaching event, even when the colonies have returned to their original pigmentation.

Current research through coral stress experiments revealed differential thermal stress impacts on the corals when stress-sensitive

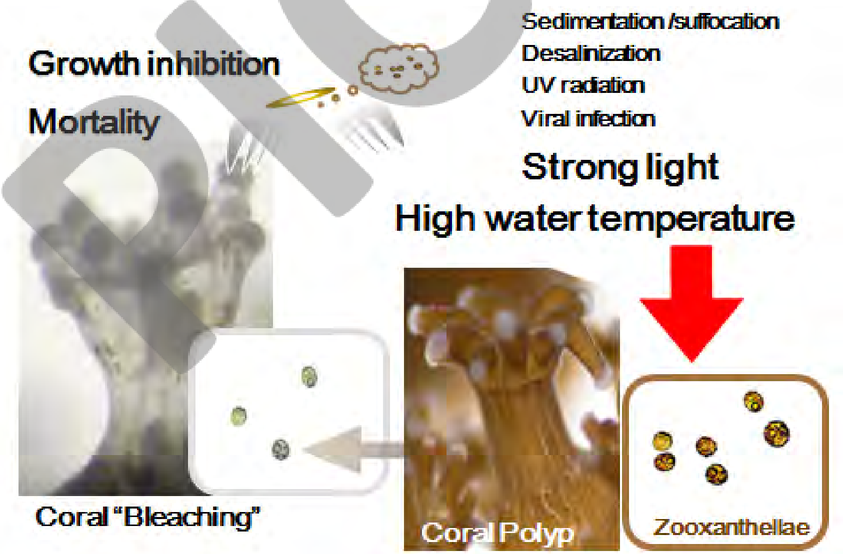

Figure 37-3. Potential environmental stress factors for symbiosis between coral and zooxanthellae. Mass scale bleaching is often a result of light-induced stress responses in many symbiotic zooxanthellae exposed to high water temperature due to global warming (Hoegh-Guldberg and Smith, 1998, Takahashi et al. 2004). Drawn by T. Nakamura.

corals, such as branching coral (e.g., *Acropora* spp.) and ginger coral (*Stylophora* spp.), are exposed to excessive light to induce photoinhibition, and then allowed to recover under a range of temperatures. Recovery of photosynthesis in these coral species is markedly slowed by temperatures exceeding 30°C, but this effect is often not apparent in stress-tolerant corals (e.g., *Pavona* spp.) (Takahashi et al., 2004). Thus, thermal sensitivity during recovery from excessive insolation is likely a key determinant of relative bleaching sensitivity in corals. It is still under debate whether it is either the host and/or the symbiotic algae that is responsible for the variation of tolerance (Yuyama et al., 2016). In addition, such a stress response is found to be easily amplified by the lack of water circulation (Nakamura et al., 2005; Nakamura and Yamasaki, 2013), increased sedimentation, and over-nitrification.

In the century of global warming, we have had increased frequencies of extreme weather conditions and ocean warming that is causing mass bleaching events around the world. The struggle of coral survival around our islands indicates that the modern marine environment is becoming unsuitable for many corals. Coral reefs may not last long as they are now if we continue to expose them to additional local stresses such as overfishing and pollution from sedimentation and waste.

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CHAPTER 38

THE IMPACTS OF TYPHOONS ON CORAL REEFS IN PALAU

Marine Gouezo

Critical Thinking:

How do typhoons form?
How do corals recover after typhoons?

Climate change is forcing unpredictable weather patterns and may alter the trajectories and strength of tropical storms or typhoons (IPCC, 2013). Typhoons, cyclones, and hurricanes are all the same weather phenomenon but have different names depending upon the region in which they form. Hurricanes form in the Atlantic Ocean,

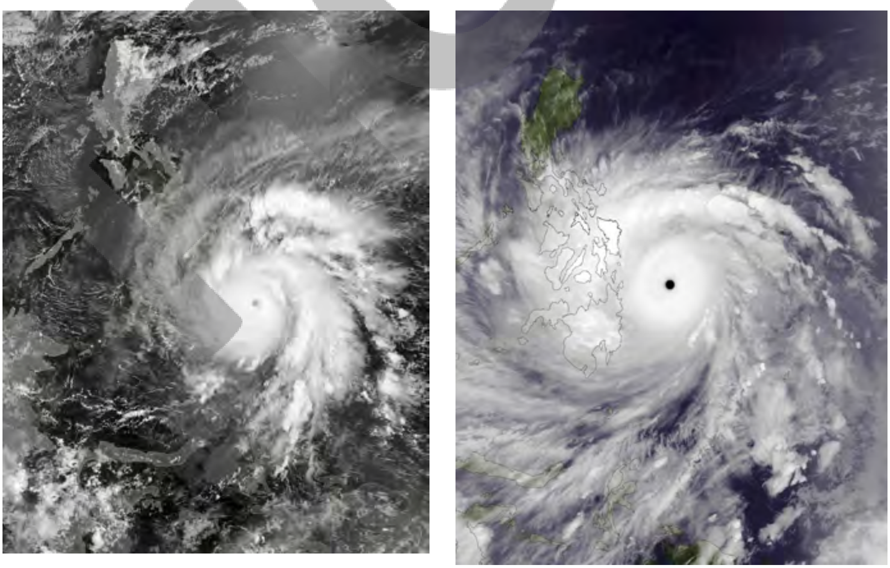

Figure 38-1: Satellite view of typhoon Bopha (left; Source: NASA/Wikimedia) and Haiyan (right; Source: Wikipedia).

cyclones form in the Indian and South Pacific Oceans and typhoons form in the North-West Pacific Ocean – where Palau is located. For a typhoon to form, it needs the right weather conditions, a warm tropical ocean, high levels of humidity, and light wind conditions. If these weather conditions persist, it will create a mass of air rotating inward to a low atmospheric pressure area, counter clockwise in the Northern hemisphere. The wind speed around the low-pressure area increases as the typhoon moves over warmer ocean and more humid conditions. The maximum wind speed is around the low-pressure area, called the **eye** of the typhoon. Many countries have different scales to measure the strength of a typhoon but they are all based on the maximum wind gusts. The Saffir-Simpson scale is one of the scales that uses rating from 1 to 5 to estimate the potential damages from typhoons. Super typhoons are category 5 storms (on the Saffir-Simpson scale) and lead to very destructive winds with gusts of more than 280 km/h (175 miles/h) and create waves up to 15 m (50ft)!

Why have typhoons been so destructive in Palau?

Typhoon occurrence in Palau is uncommon because Palau is located close to the equator, about 7 degrees North. Typhoons, more generally, form 10 degrees North and above the tropical zone. Since the availability of meteorological data records in the 1950s, five typhoons have hit Palau (***Figure 38-2***).

The two most recent super typhoons, Bopha (2012) and Haiyan (2013), were stronger than the three previous typhoons. Super Typhoon Bopha had a central pressure of 920 to 930 millibar (atmospheric pressure unit), maximum north eastern winds reaching 250 km/h (155 miles/h), and breaking waves up to 8.7 m high (Chu et al., 2012; Windguru, 2015)! Typhoon Haiyan had a lower central pressure than Bopha (906 mbar), maximum sustained winds reaching 290 km/h (178 miles/h), and breaking waves up to 8.6 m high (Chu et al., 2012; Windguru, 2015)! Eastern exposed reefs received more damage because the storms came from the East.

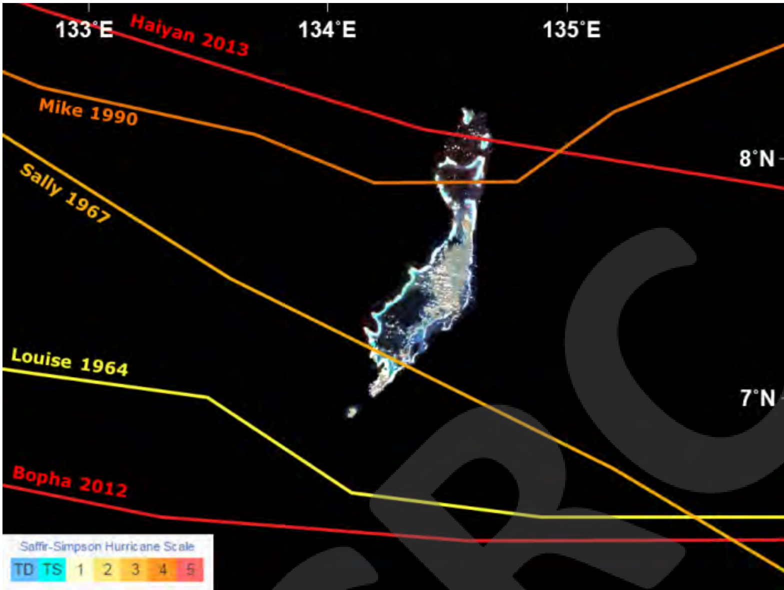

Figure 38-2: The trajectories of the 5 typhoons that have hit Palau since 1950s. Note that the two last were the strongest on the scale. Source: Created by Marine Gouezo.

The wave energy created by typhoons is huge and especially destructive to coral reef communities. In other Pacific Islands, such as Guam or Okinawa in Japan, the coral reefs have morphologies that are stout and strong and can resist large waves impacts (Yamano et al., 2003). In contrast, coral reef morphologies in low latitude islands like Palau have more fragile colonies (van Woesik et al., 1991; Harmelin-Vivien, 1994) because typhoon impacts are infrequent. In 2012 and 2013, within a twelve-month period, both typhoons destroyed most of the eastern barrier reefs (Gouezo et al., 2015). Typhoon Bopha had a high impact on the southeastern coral reefs while Haiyan had a high impact on the northeastern coral reefs (***Figure 38-3***).

Some sites on the eastern barrier reef, such as Ngerchong Island, lost all their corals. ***Figure 38-4*** shows the reef before and after super typhoon Bopha. The reef prior to the typhoon (***Figure 38-4, left***) supported high coral coverage and high diversity while the reef after the typhoon (***Figure 38-4, right***) is covered with rocks and rubble.

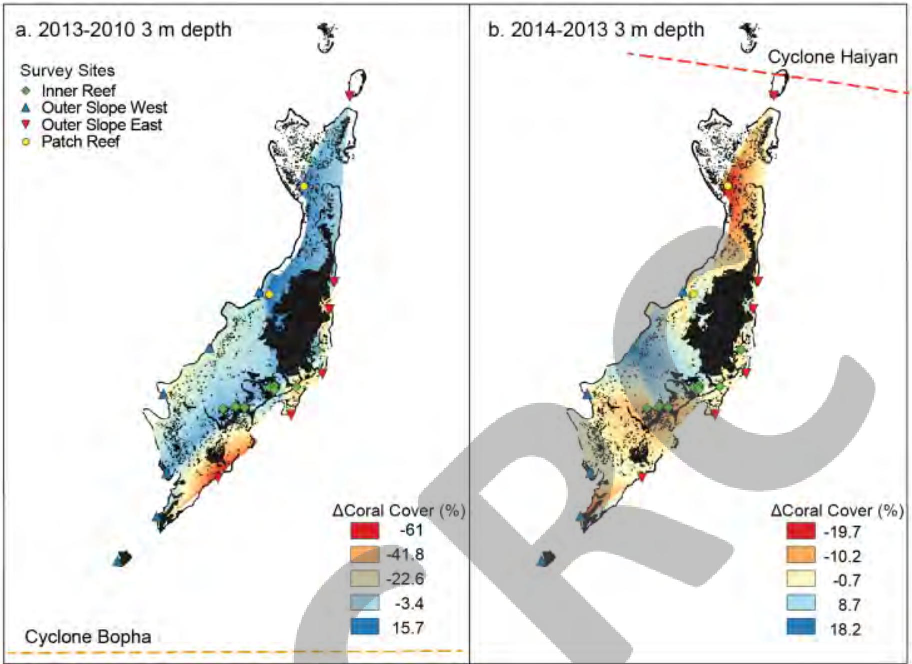

Figure 38-3: Map shows the change in coral cover at 3 m depth after the occurrence of typhoons Bopha (left) and Haiyan (right). Source: Gouezo et al., 2015.

What have we learned from the damage caused by typhoons?

Now researchers have a better idea of the spatial impacts of both typhoons on Palau's coral reefs. Researchers are now focused on understanding the recovery rate of these reefs. Other studies have shown that reefs can take decades to fully recover from typhoons (Harmelin-Vivien, 1994; Connell, 1997; Hughes and Connell, 1999). The recovery process of a coral reef is long and complex as it involves several variables such as the loss of reef structure, coral larvae replenishment, coral recruitment, coral reef growth, and many bio-physical variables (e.g. fish biomass, wave exposure) that may influence these processes. As global climate change predictions for Palau include an increase in ocean temperatures and tropical storm severity (Knutson et al., 2010; IPCC, 2013), a deeper understanding of spatial and temporal scales of coral reef recovery is essential to mitigate climate impacts through coral reef management strategies that effectively protect our reefs.

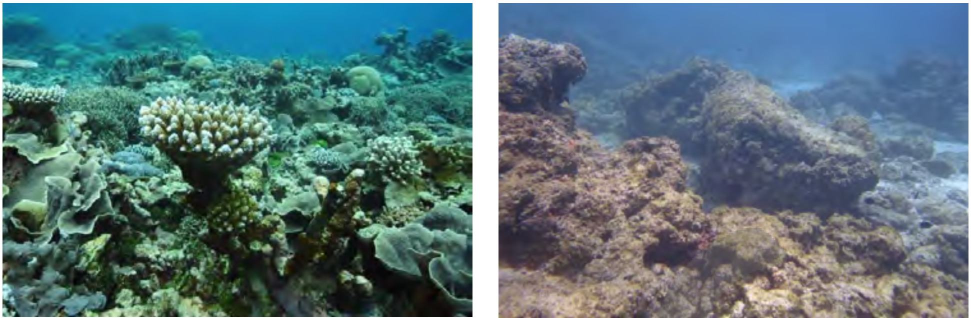

Figure 38-4: Underwater photos of the reef located at PICRC monitoring site in Ngerchong reef, before the typhoon in 2010 (left) and 2015 (right). Source: PICRC.

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CHAPTER 39

WATERSHEDS AND LIVING WITH NATURE

Akiko Iida

Critical Thinking:

Why is a watershed important for us? How does a watershed sustain life?

This painting is of a traditional Palauan village in the early 20th century drawn by the Palauan painter, Ado Imetuker (***Figure 39-1***). The two yellow buildings located on the hilltop are *bai*, traditional meeting houses for leaders. The other houses are connected by stone paths that extend from the *bai*. In the center of the painting there is a taro patch with a stream flowing into it from a river. Looking at the surrounding environment, you can see hills behind the village, a shallow sea, and a river that connects the ridge to the reef. A **watershed** is an area of land that drains all of the rainfall and streams from land into the ocean. This painting clearly shows a watershed and the Palauan way of life within it.

Why is a watershed important for us? How does a watershed sustain life? A watershed is an area of land that drains all of the terrestrial rainfall and streams into the ocean. ***Figure 39-2*** shows cross-section of the watershed from the ridge to the reef on Babeldaob Island, Palau's biggest island, and the various benefits it provides. Watersheds in Palau can be classified into four zones based on socio-ecological characteristics (***Figure 39-2***):

1. Lowland forest and savanna zone located upstream
2. Village and agroforestry zone located downstream
3. Mangrove forest zone in the intertidal flat, and
4. Coastal zone.

Figure 39-1. Traditional Palauan village in the early 20th century. Painting by Ado Imetuker provided by the Bureau of Arts and Culture.

The technical term for benefits from nature is **ecosystem services**, which are categorized into four groups: provisioning service (PS), such as the production of food and water; regulating service (RS), such as the control of climate and the prevention of natural disasters; habitat or supporting service (HS), such as the provision of habitats for species; and cultural service (CS), such as spiritual and recreational benefits.

The lowland forest and savanna zone located upstream accounts for more than 80% of the island. The lowland forest and savanna zone provides water for our daily life, and residents collect useful plants and wood from (PS). It is an important habitat for birds and insects (HS), and the forest prevents soil erosion and retains soil fertility (RS). In recent years, Palau's lowland forests, savannas, and waterfalls have attracted tourists for recreational activities such as hiking and bird watching (CS).

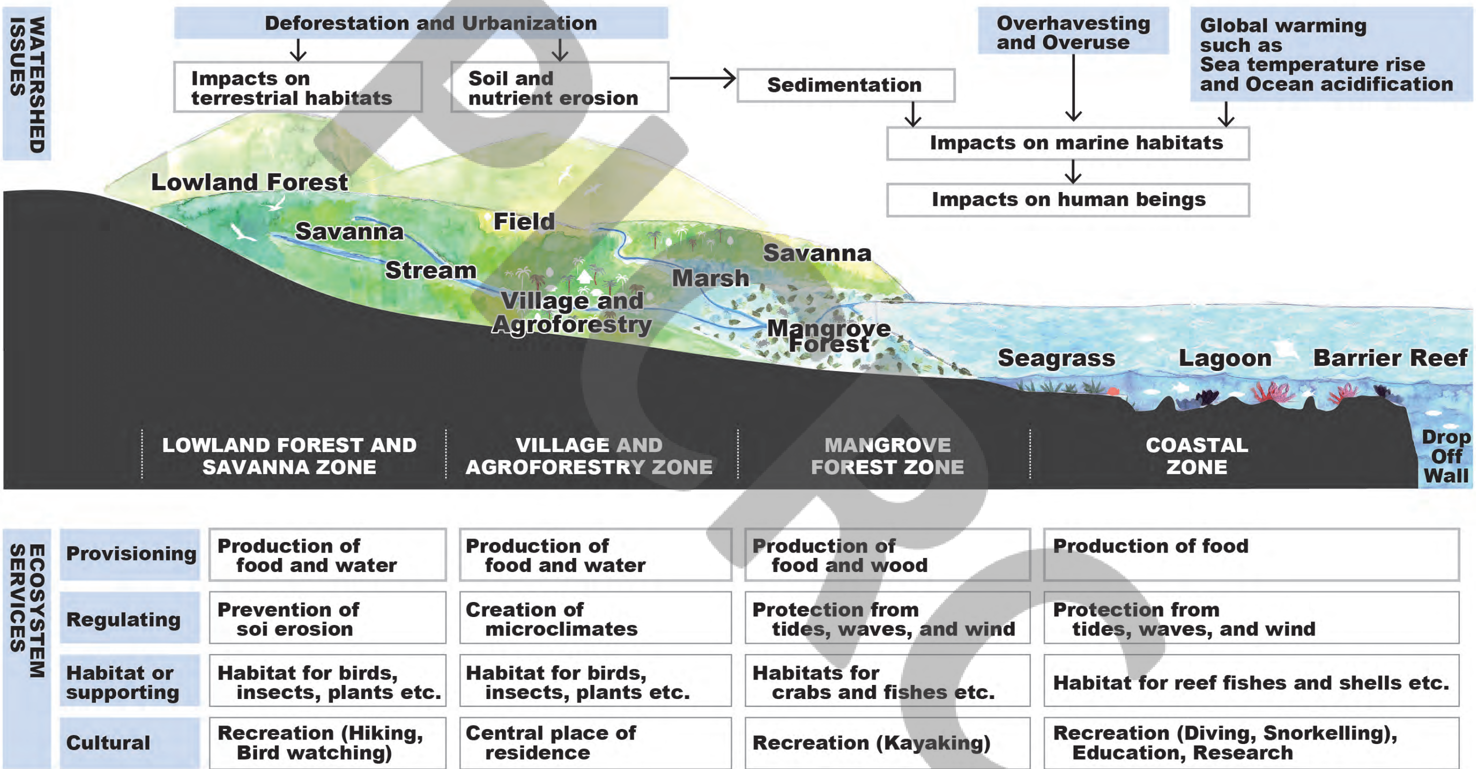

Figure 39-2. Watershed and ecosystem services as seen in a cross-section of a watershed. Graphic provided by A. Iida.

People live in the village and agroforestry zone located downstream. Various types of fruits, vegetables, taro, and other useful plants are planted and cultivated through agroforestry based on environmental conditions such as water, soil, slope, and sunshine. Domestic animals are raised around homes (PS). Many kinds of birds and insects also live close to homes (HS). Planted trees create cool microclimates that protect houses from the strong sunshine of the tropics and also act as windbreakers (RS).

Mangroves grow in the intertidal flat downstream where seawater comes in and out according to high and low tides. The mangrove forest has a buffering effect from the tides, waves, and wind (RS). Mangrove trees are used as building materials because the wood is strong and tolerant to tides (PS). The interlacing roots of mangroves are suitable habitats for crabs and small fishes (HS), and provide seafood resources for residents (PS). Nature experiences, such as kayaking in the mangrove forest, are also popular tourist activities (CS).

The coastal zone has an abundant supply of a large variety of reef fishes, shells, sea cucumbers, etc. (HS), and Palauans depend on these seafood resources (PS). Barrier reefs are a living breakwater and protect the shore from strong tides, waves, and winds. Thanks to the barrier reefs and mangrove forests, the inland environment is kept safe and intact. The colorful coral reefs and other amazing creatures in the sea attract foreign tourists and researchers, providing a place for recreation, education, and academic research.

Nature and human life in the watersheds are interlinked with each other. Human impact in one particular place will produce indirect effects in other places. For example, if there is a development, such as the construction of a road or subdivision and/or deforestation upstream, it would affect not only the terrestrial habitat but also the marine habitat. Once soil and nutrient erosion occurs at the development site, sediment-laden waters would drain into the mangrove forest and the coastal zones through the river. Other pressing marine resource issues, such as overharvesting and overuse by residents and tourists, as well

Figure 39-3. Clockwise from top left: lowland forest, savanna, mangrove forest, and coral reefs. (Photographs by A. Iida).

as the rise in sea temperature and ocean acidification due to global warming, have impacts on ecosystems with negative consequences for humans through the degradation or loss of ecosystem services. The well-being and health of residents depends on a clean and healthy watershed and environment.

The watershed in Palau is composed of four socio-ecological zones: the upland forest and savanna located upstream; the village and agroforestry located downstream; the mangrove forest in the intertidal flat; and the coastal zone. The benefits from these types of environments (known as ecosystem services) sustain our lives in various ways.

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CHAPTER 40

OUR LIVELIHOOD DEPENDS ON NATURE

Naito Soaladaob

Critical Thinking:

How do our lives depend on nature?

Plants are used in our lives in many ways

In Palau, the five main types of plant habitats are ***oreomel*** (forest), ***ked*** (savanna), ***delomeklochel*** (wetland), ***keburs*** (mangrove), and ***chelebacheb*** (rock islands). A variety of plant species can be found within these habitats. A long time ago, Palauans were hunters/gatherers and were more likely to harvest or collect plants from within these habitats for use at home, hence not removing them and planting them in different habitats. The knowledge of identifying plants and their usage was limited to certain community members, mainly the hunters, healers, and builders. ***See table at end of chapter***.

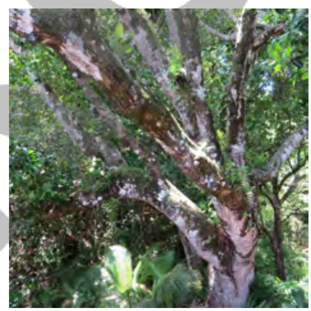

Figure 40-1. Top to bottom: Btaches, Dudekelbisech, Dui.

Common plant species in Palau used as food or toys

Plants commonly used for food include fruit from trees such as ***meduu, lius, iedel, bobai, riamel, rebotel, chedebsachl, kidel, bekbedengel a meradel*** (a variety of Citrus

Figure 40-2. Top to bottom: Esel, Rebotel, Dort.

tree species), and root crops such as ***kukau***, ***brak*** and ***bisech***. Introduced plants that are now part of the Palauan diet are root crops (***diokang***, ***telngot***, and ***emutii***), ***kangkum***, ***bata***, ***tuu***, ***ongor***, and ***titimel***. Children's toys such as kites were either made from ***llel a meduu*** (breadfruit leaf) or ***mengchongch*** (betelnut sheath). ***Urur*** fruits were used to make ***ebis*** (tops).

Common plants used for building structures or materials

Several types of wood are preferred when building homes and ***bai*** which include ***ukall***, ***rebotel***, ***lius***, ***dort***, ***btaches***, and ***beokl***. Mangrove trees such as ***mekekad***, ***biut***, ***urur***, ***tebechel***, ***teuechel***, and ***buuk*** were also used as building materials. *Esel* (bamboo) were frequently used when building a bai, houses, or kitchen areas.

Several plant species also have important medicinal value

Knowledge and skill associated with medicinal plant identification and application was limited to only a few within a clan. As is practiced throughout Palau's history, protecting a clan's secret such as medicinal recipes or fishing techniques was a survival method. It was only passed on between close family members and never disclosed publicly.

Many plants have ceremonial purposes

Another common usage of plants was during festivities; they were used for traditional wear and as decorations. ***Mur*** (feast) where ***klechedaol*** (community festivities) were held at ***bai rar cheldebechel*** (community bai, mens' meeting house). Normally the facility was not decorated with anything except for adornments that were used during dances. Women performers used plant materials, such as ***cheriut*** (grass skirts) made of ***chermall*** and flowers as decorations. Others used sticks made of ***chermall*** plants while dancing. Male performers used ***meolt*** (young coconut leaves) for decorations and used ***biskang*** (spear) made from ***lild*** and ***raod*** (mangrove root) or betelnut trunks and ***brotech*** (war club made from hard wood such as ***dort***) in their dances.

Plants have important significance at customary events such as the first birth ceremony, with the rituals of ***omesurch, omengat, ngasech,*** or ***mo-tuobed*** still practiced in Palau. Upon giving birth to her first-born child, a woman is traditionally instructed to complete the ***omesurch*** (hot bath) ritual which is dependent on her clan's status. The herbal hot bath is comprised of many different types of herbal medicinal plants that differ within each clan (***See Chapter 41***). After the final day of the hot bath ritual, the new mother then goes through the herbal steam bath for the ***omengat*** ritual, which takes place early in

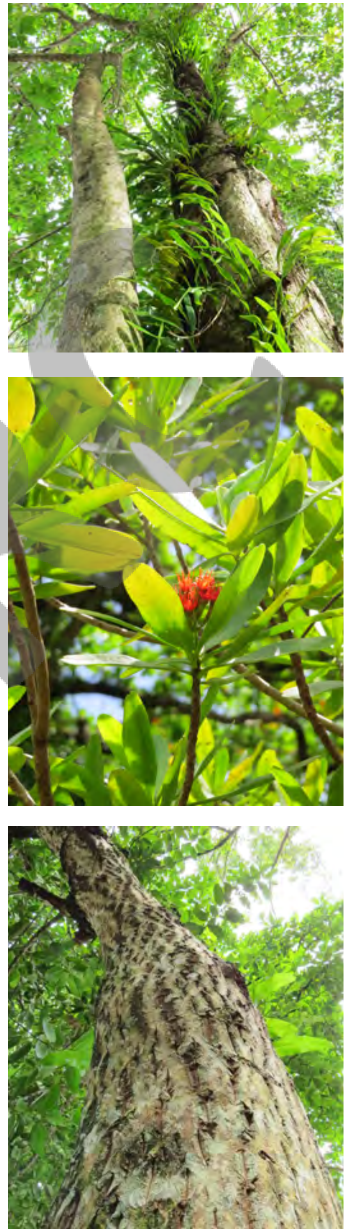

Figure 40-3. Top to bottom: Beokl, Mekekad, Btaches.


Figure 40-4. Meduu and Meduu leaves.

the morning. A ***bliukel*** is a small steam hut built with bamboo where the new mother will go to for a final steam bath from a pot of the hot herbal medicinal concoction. Finally, the new mother is adorned with her clan's ***besiich*** (decorations) and presented to her husband's family, in what is called the ***mo-tuobed*** or ***ngasech*** ceremony. The ***ngasech*** ceremony however, is only practiced in the state of Angaur, and is only for the first clans of the 4 villages of Angaur (with some exceptions). Adornments may include flowers, plant parts, feathers, body oil made of turmeric and coconut oil, and Palauan money around her neck. A ***ulitech*** (mat woven from coconut leaves) is used as a pathway for the woman when she comes out to be viewed by the husband's family.

Specific plant materials are used during traditional bestowing or taking of ***dui*** (title) at funerals to signify lineage, clan, or societal status. Obtaining or removing chiefly titles in Palau for male and female title holders is conducted in ceremonies using an assortment of fresh plant materials such as ***dudekelbisech*** and ***meolt*** needed to assemble the ceremonial ***dui*** (a symbol of power). The ***dui*** is used only at funerals to transfer or take the title from the deceased before burial. This ceremonial ***dui*** is then kept until such time that another

Figure 40-5. Taro Garden, and holding dui.

person is to be considered for the title. Village Chiefs at times would impose traditional moratoriums or ***bul*** to protect species or areas. A sign made of woven coconut fronds with flowers was usually displayed to announce the moratorium.

Certain plants are used for tools and building materials

Ingenious instruments, tools, or equipment for hunting, fishing, tending gardens, and building different types of canoes were made from a variety of plant materials.

For hunters, the most common tool was a ***boes*** (blow gun) which is made of ***lild*** and ***raod*** (root of ***tebechel***) which would be the tip of the dart. This tip was dipped in poison made from plant species such as ***bduul***. ***Sikerou*** is a method of trapping birds using a net made of ***suld*** (coconut fiber). A flowering tree is a sign that birds will soon start gathering to eat the fruit of the tree and so the hunters would lie in wait on an ***elumel*** which is a specially constructed platform built high up in the trees. When a bird lands around their platform then they use the net to capture them.

In the past, Palauan fisherman used fishing materials such as a ***ruul*** made of ***demailei*** fronds to gather, fence in, or guide fish to one area and capture them using a fish trap or spear. Fish traps were made from either bamboo, or ***tebechel*** roots, or ***cheritem*** branches (or a combination of them) and tied together using ***kerangel*** or ***ochaoel*** *(Combretum tetrolophum)* vines. Spears were made of ***lild*** and betelnut trunks which were sturdy and allowed for multiple use. Baskets woven from coconut leaves were used to gather invertebrates such as sea cucumbers and clams during low tide.

While work in the ***mesei*** (taro patch) consisted mostly of using the hand to turn over the soil and plant, there were other techniques employing the use of plant materials to ensure the survival of the plants. For instance, banana leaves and other plant leaves were placed around individual taro plants to prevent growth of unwanted grass. Some of these plant leaves were also used as fertilizers when the soil was being prepared for planting. Sticks, taken from strong trees in nearby areas, were used to make waterways between taro patches and also to dig holes in ***dechel*** (shallow taro patches which are drier than ***mesei***, ***see Chapter 6***). Taro is harvested and placed in woven baskets made of coconut leaves. Sometimes women who tend their taro patches would take the large leaves of the ***brak*** plant and use them as hats to avoid direct sunlight. The same ***brak*** leaves are also placed in the bottom of large pots when boiling taro to keep the taro from sticking to the bottom of the pot, and also placed on top of the taro beneath the lid to keep moisture in the pot. It was taboo to plant anything that was red in color or had red flowers such as ***kerdeu*** or ***kesuk*** near or around the home as these plants were considered ***delemelel a elid*** (bad spirits plants). Most taro patches were a distance from the home unlike today where gardens of introduced vegetables such as ***kangkum***, ***emutii***, ***kiuri***, and ***diokang***, and fruit trees such as ***kemim*** are seen planted in one's backyard.

Palauans relied heavily on water transportation to go from place to place, to move heavy materials, and also to fish for their livelihoods. Building ***mlai ra daob*** (canoes) became an important skill but often took years because of limited tools. Common tools used in building a canoe are the ***ebakl*** (adze) and a ***kubiang*** (gouge). The handle was made of strong wood, such as ***ermall*** or ***btaches*** while the head or blade was made of a sharpened clam shell. Using the ***ebakl***, different canoes were made from trees, such as ***btaches, meduu,*** or ***ukall***. ***Blacheos*** was used for the ***desomel*** (outrigger) while ***rriu*** was used to make the ***besos*** (paddle). In addition, coconut husk fibers were used to make ***kerreel*** (fishing line). The sail of the canoe was made of ***such***. Different types of canoes included ***kaeb*** for ***klaidesachel*** (competition), ***kabekel*** for ***mekemad*** (war), ***berotong*** for ***omenged*** (fishing), and ***omuadel*** (fishing). There are two types of ***brer*** (bamboo rafts) as well. The smaller ***brer*** was made from tying together bamboo poles with ***suld el kerreel*** (coconut fiber rope) or ***kerangel*** (strong vine) used for ***omenged*** (fishing). The bigger ***brer*** called ***olechutel***, was used for transporting things between places.

Other noteworthy plants uses

Another noteworthy use of plants was the use of plants in the pastime of chewing betelnut. Chewing of betelnut consisted of ***buuch, kebui,*** and ***aus*** (lime powder made from ashes of burnt corals) assembled together and placed in one's mouth for chewing, most similar to the chewing of tobacco. This was only done by elders and not young people. It was improper for young people to ask elders for betelnut. For ***rubak*** (men), when conducting meetings in a ***bai*** and a conflict arose or there was no consensus, the ***rubak*** would stop, fix their betelnut, and chew. This was a way to relax; and to think before they got back together to resolve the issue. For ***mechas*** (women), when work in the taro patch became cumbersome or tiring, they retreated to a shaded area, took out their ***tet*** (woven basket) of betelnut, fixed their betelnut, and chewed to relieve stress before they continued their work. In the community, chewing betelnut could also be viewed as a way to socialize, to share, and to interact with other elders. Young people who wanted to imitate the act of chewing betelnut usually combined ***kairs*** (fruit of ***rriu***) and ***meolt*** to chew. This combination did not need the aus but did produce red sputum similar in color to the chewing of betelnut with ***kebui*** and ***aus***.

Plants important to our livelihoods in Palau		
Palauan Name	**Common Name**	**Scientific Name**
bata	avocado	*Persea americana*
bduul	fish poison tree, box fruit tree	*Barringtonia asiatica*
bekbedengel a meradel	variety of Citrus trees	*Citrus* spp.
beokl	New Guinea teak	*Vitex cofassus*
bisech	wild taro	*Alocasia macrorrhizos*
biut	tagal	*Ceriops tagal*
blacheos		*Gmelina palawensis*
bobai	papaya	*Carica papaya*
brak	giant taro	*Cyrtosperma merkusii*
btaches	Alexandrian laurel ball tree	*Calophyllum inophyllum*
buuch	betelnut	*Areca catechu*
buuk		*Pandanus kanehirae*
chedebsachel	watery rose apple, water apple	*Syzygium aqueum*
demailei	Sagisi palm	*Heterospathe elata* Scheff. var. *palauensis*
diokang	cassava, tapioca	*Manihot esculenta*
dort	Ipil, iron wood	*Intsia bijuga*
dudekelbisech		*Colocasia or Alocasia*
emutii	sweet potato	*Ipomoea batatas*
ermall	native hibiscus, sea hibiscus	*Hibiscus tiliaceus*
esel	bamboo	*Bambusa vulgaris*
iedel	mango	*Mangifera indica*
kangkum	water spinach	*Ipomoea aquatica*
kebui	betel, betel vine, betel pep-per	*Piper betle f. densum*
kemim	star fruit	*Averrhoa carambola*
kerangel		*Loeseneriella macrantha*
kerdeu	flame of the woods	*Ixora casei*
kesuk	garden croton	*Codiaeum variegatum*

Plants important to our livelihoods in Palau		
Palauan Name	**Common Name**	**Scientific Name**
kidel	Malay apple	*Syzygium malaccense*
kiuri	cucumber	*Cucumis sativus*
kukau	taro	*Colocasia esculenta*
lild		*Schizostachyum lima*
lius	coconut	*Cocos nucifera*
meduu	breadfruit	*Artocarpus altilis*
mekekad	red flower black mangrove	*Lumnitzera littorea*
ongor, ongolngebard	pineapple	*Ananas comosus*
ongorraked	screwpine	*Pandanus tectorius*
rebotel	Java apple, rose apple, wax apple	*Syzygium samarangense*
riamel	football fruit	*Pangium edule*
rriu	mangrove trumpet tree, tui	*Dolichandrone spathacea*
such		*Pandanus* spp.
tebechel	loop-root mangrove	*Rhizophora mucronata*
telngot	yam	*Dioscorea alata*
titimel	wild mango	*Spondias pinnata*
touechel	nipa palm, mangrove palm	*Nypa fruticans*
tuu	banana	*Musa* spp.
ukall	monkeypod	*Serianthes kanehirae*
urur	mangrove apple	*Sonneratia alba*

Photos provided by the author.

CHAPTER 41

WHERE DO MEDICINAL HERBS GROW?

Akiko Iida

Critical Thinking:

Do you know a secret place where medicinal herbs grow?

Medicinal herbs have been used for various occasions in Palau. For instance, *Omesurech* is an important ritual for a young mother (***Figure 41-1***). After giving birth for the first time, in order to heal herself the new mother bathes in steam from a herbal hot bath, in which many kinds of herbs are boiled and stirred. In addition, Palauans use medicinal herbs in their daily life to treat headaches, constipation, and scrapes. A hundred different types of medicinal herbs and their usages were recorded in a paper written in 1940 before the start of modern medical treatment in hospitals in Palau by Masayoshi Okabe who had studied local Palauan medicines. Medicinal herbs have been very important for life in the islands. Each clan or family has particular places to collect the medicinal herbs and particular knowledge about their usages. These places and knowledge are usually kept secret; however, several typical cases are described in this article.

A large variety of medicinal herbs are planted near houses. For example, *Phaleria nisidai (Delal a kar, Ongael)* (***Figure 41-2***), also called "mother of medicine," is planted in home gardens and neighborhood forests, and even grows wild in limestone and volcanic forests. There are many other herbs planted in home gardens and neighborhood forests, such as turmeric ginger, *Curcuma longa (Telab, Kesol)*, the steam of which is mixed with coconut oil and put on a young mother's

Figure 41-1. Pictures from the herbal hot bath, *Omesurech*. Upper left: Family member of a young mother collecting medicinal herbs for Omesurech. Upper right: Medicinal herbs such as the flower of Pandanus and pitcher plant. Lower left: Medicinal herbs for final hot bath boiled in a big pan. Lower right: A young mother standing in front of her family and relatives in a birth ceremony (*Omengat*). Photos by A. Iida.

body in the herbal hot bath. The lemon tree, *Citrus hystrix (Debechel)*, lemongrass, *Cymbopogon citratus (Keskus)*, and the ylang-ylang tree, *Cananga odorata (Irang Irang)*, are also common herbs planted near houses and used in the herbal hot bath.

Many kinds of medicinal herbs also grow in the savanna. Not many people go to the savanna in daily life, but it is a rich repository of herbs. When the species of herbs used for an herbal hot bath was surveyed in Airai in 2010, half of the total herbs (altogether 12 species), were gathered in the savanna. For example, the pitcher

Figure 41-2. Fruit and leaves of *Phaleria nisidai (Delal a kar, Ongael)*. Photo by A. Iida.

plant, *Nepenthes mirabilis (Meliik)*, the vine, *Cassytha filiformis (Techellel a chull)*, *Phyllanthus palauensis (Dudurs)*, *Melastoma malabathricum (Matakui)*, and the *Pandanus tectorius* tree *(Ongor)* are common savanna species that are used in the herbal hot bath. Surprisingly, many savanna plants are native species, and some of them are endemic to Palau, such as *Dudurs* and several Pandanus species. The savanna is a culturally important habitat for Palauan herbal plants.

Medicinal plants also grow in the forest. The oil extracted from the nuts of the *Calophyllum inophyllum (Btaches)* tree, which grows as coastal vegetation, is frequently used to treat bruises and scrapes. The leaves of the wax apple tree, *Syzygium samarangense (Rebotel)*,which grows in limestone and volcanic forests, are used not only as an herb for the hot bath itself, but also as a special broom to splash the hot water onto the mother's body.

Unique medicinal herbs, such as the small plants *Limnophila fragrans (Ulekelakel)* and *Ceratopteris thalictroides (Tiela uek)*, grow in taro patches. The taro patch is irrigated and cultivated, keeping the surface of the soil wet and light. This environment is a suitable habitat for these small plants. If the cultivation is stopped, tall grass will grow thickly and the taro patch will become a marsh. Then, the *Ulekelakel* and *Tiela uek* that like wet and light conditions could not grow anymore. On one hand, the plants heal people with their medicinal effect; on the other hand, people maintain the plants' habitat.

In Palau, medicinal herbs grow in various kinds of environments, such as home gardens, neighborhood forests, savannas, volcanic forests, limestone forests, and taro patches. Some of them live in a symbiotic relationship with human beings. Medicinal herbs reflect the intimate relationship between nature and humans.

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CHAPTER 42

DEVELOPMENT OF MANGROVE CRAB AQUACULTURE PRODUCTION IN PALAU

Miguel Delos Santos

Critical Thinking:

How can aquaculture help improve the wild population of mangrove crabs in Palau?

The mangrove crabs *Scylla serrata,* also called the mud crabs, are highly valued seafood species that are widely distributed throughout the Pacific. However, in most countries in Asia and the Pacific Islands, these crabs are becoming scarce due to years of overharvesting to satisfy continually increasing demands from tourism and population growth. In Palau, mangrove crabs are considered indigenous and are widely caught from the mangrove areas for local consumption (Colin, 2009; Ewel et al., 2009). Due to increasing demand, the market price for mangrove crabs has risen in recent years to as high as $18 per pound (Lee, 2015, CTSA Regional e-notes). The price of mangrove crabs in the local market is expected to increase further because the supply is becoming more limited. Their high price and demand has created interest in mangrove crab aquaculture.

Since 1998, the Palau government has made an effort to strictly regulate the fishing of mangrove crabs by banning their exportation, and allowing people to catch only crabs with a carapace length of more than 6 inches (DMR and SPC, 1998). In addition, the development of mangrove crab farming is essential to meet the demand of local consumers.

Figure 42-1. Example of mangrove crab farm in Palau using a net enclosure inside the mangrove area.

In 2006, attempts to grow imported mangrove crab juveniles that came from the Philippines were done in netted pen enclosures inside mangrove areas (***Figure 42-1***). Some farmers also tried stocking the juveniles or undersized mangrove crabs caught by fishermen inside the netted pen for further grow-out and fattening; however, continuous production was hampered due to limited supply of the locally sourced crablets.

To address the diminishing stock of mangrove crabs in the wild and to support the growing interest in developing an aquaculture production for this highly important seafood commodity, the Palau Community College (PCC) initiated a project to develop a seed production technique and grow-out system for mangrove crabs. This project started in 2009 and was continued with additional funding support from the Land Grant Program of the College of Micronesia (COM-Land Grant) and the Center for Tropical and Subtropical Aquaculture (CTSA).

A series of larval rearing and nursery trials to produce the mangrove crab juveniles was conducted at PCC hatchery located at Ngermetengel, Ngeremlengui State (***Figure 42-2***). Reliable hatchery and nursery techniques to produce these crablets were established in 2012. Since then, more individuals have become interested in mangrove crab farming.

Figure 42-2. Larval rearing and nursery tanks for mangrove crabs at the PCC Hatchery.

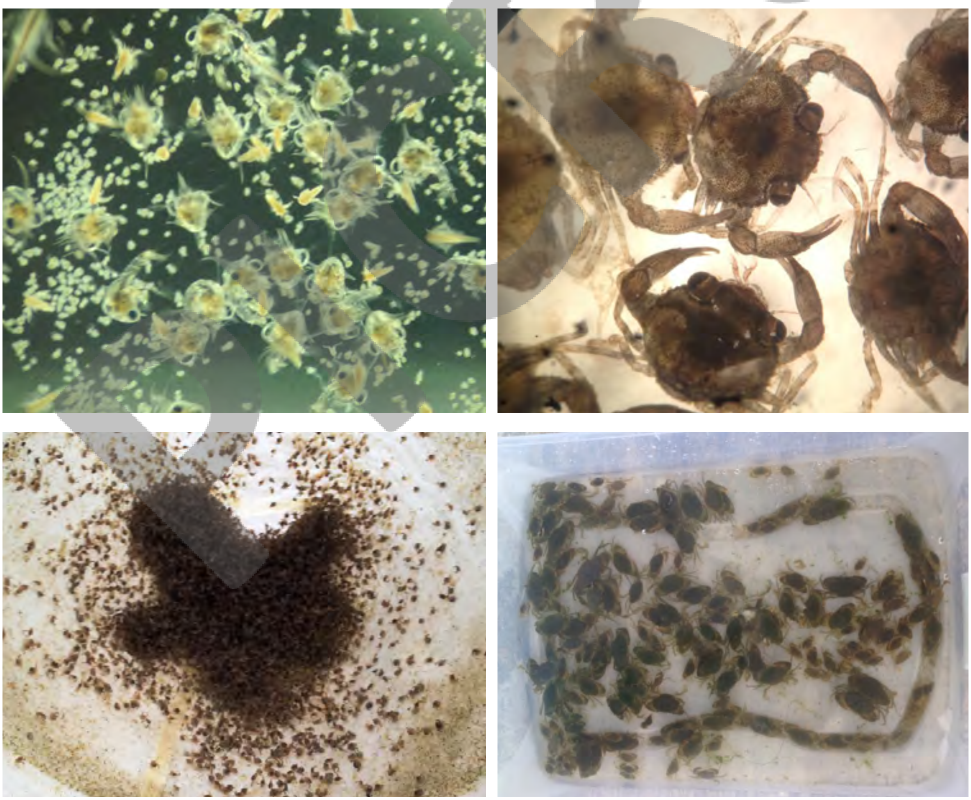

Figure 42-3. Photos of the mangrove crab larvae and the hatchery produced crablets.

Since 2012, about of 356,200 pieces of five weeks old crablets (0.2 inch carapace length) have been released to four mangrove areas in Palau and a total of 16,000 crablets with sizes that ranged between 0.35 to 3 inch carapace length were given to local farmers for grow-out trials in their ponds, crab pens inside mangroves, and crab cages (***Figure 42-3*** and ***Figure 42-4***).

Figure 42-4. Releasing the hatchery produced crablets to mangrove areas.

The success in establishing a seed production technique for mangrove crabs in Palau was a turning point in the development of sustainable mangrove crab farming not only in the country but also throughout the Micronesian region. Currently, the seed production techniques are being demonstrated at the PCC Hatchery and the crablets that were produced were given for free to the farmers who wanted to try growing mangrove crabs in their respective areas (***Figure 42-5***).

Figure 42-5. Some of the beneficiaries of PCC hatchery produced mangrove crab seeds.

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Photos provided by the author.

CHAPTER 43

ECOSYSTEM SERVICES OF CORAL REEFS & BENEFITS FROM NATURE

Makoto Tsuchiya and James D. Reimer

Critical Thinking:

Why are coral reefs important?

Why is nature important? This is a very important and big question, but it is not so easy to answer. We receive many benefits from nature, which we call ecosystem services. If we think about ecosystem services we can come to a better understanding of this question. Let's think about the coral reef ecosystem as an example.

What is an ecosystem?

A variety of animals and plants live in the natural world. Air surrounds these creatures, as well as water, soil, and so on. This is the environment. An ecosystem is defined as a system composed of a community of living organisms in conjunction with the non-living components of their environment. Coral reefs, forests, rivers, and lakes are examples of different ecosystems (***See Chapter 15*** and ***Figures 15-1*** and ***15-2***).

Coral reef ecosystem services and benefits

- We live by taking fish and shellfish from reefs (***Figure 43-1***).
- We are protected from strong waves by the natural breakwater of coral reefs (***Figure 43-2***).
- We enjoy diving and fishing (***Figure 43-3***).
- Coral reefs have become a place of study for children (***Figure 43-4***).
- Coral reef organisms warn us of changes in the global environment (***see Chapter 36 and 37***).

In order to receive these benefits, coral reefs must be healthy and people need have a better understanding of corals and coral reefs (***see Chapters 32 to 34***), including:

- More about the coral reef ecosystem.
- What kind of creatures are corals?
- What creatures are living in coral reefs?

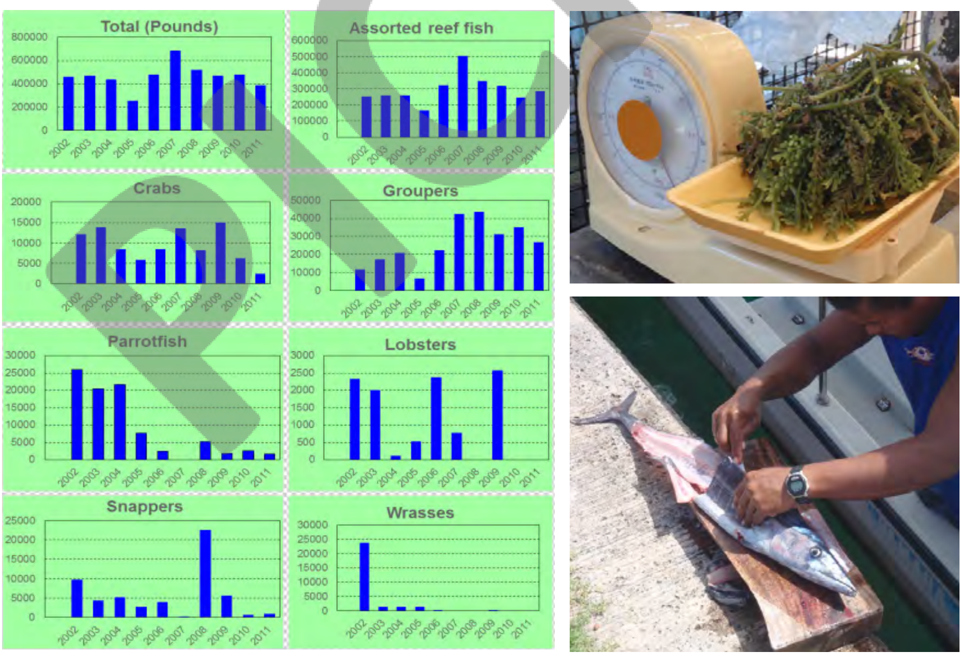

Figure 43-1. Changes in fish catch in Palau. We receive many foods from coral reefs.

Understanding the importance of nature means considering the ecosystem services received from it. Ecosystem services can be distinguished into four categories including provisioning, regulating, cultural, and supporting services. Supporting services are the basis for the services of the other three categories according to the Millennium Ecosystem Assessment (MA) (***see Chapter 44***).

Figure 43-2. Coral reef is protecting our lives as a breakwater.

The value of nature

There is a way to represent ecosystem services and natural values with a monetary value (***see Chapter 44***). This is calculated by estimating the value of the uses or products enabled by the natural resource. For example, how many fish can be caught in a year and how much money are they worth? How much would it cost to replace lost shoreline protection services by building an artificial breakwater around Babeldaob Island? If we can measure or estimate the sales or budgets associated

Figure 43-3. Diving is an important activity for tourists in Palau.

Figure 43-4. Interpreters tell interesting stories about coral reef organisms.

with reef products and uses, we can determine their monetary value and the value of coral reefs.

Large numbers of tourists visit Palau every year (***see Chapter 46***). This is evidence that people recognize the value of Palau's nature. The money they spend here and even the cost of their travel can be used to evaluate the monetary value of Palau's reefs.

The Contingent Valuation Method (CVM) is used to estimate economic values of nature. CVM involves directly asking people, usually through a written survey, how much they would be willing to pay for specific environmental services like:

- How much are you willing to pay to help conserve this beautiful coral reef?
- How much are you willing to pay to help conserve Napoleon fish in Palau?

Payment for ecosystem (or environmental) services

Far too often, ecosystem services and the value of nature are ignored when setting prices for reef products and uses, such as tours. This has contributed to the overuse and overexploitation of coral reefs. New thinking is that ecosystem services and benefits from nature should be explicitly considered when setting prices, called Payment for Ecosystem Services (PES) (***see Chapter 44***).

Palau has been forward thinking about PES. The Green Fee established in 2009 is a way of "charging" visitors to Palau for the ecosystem services they receive. Green fees are "paid back" to the environment in the form of conservation activities and support for sustainable management at sites in Palau's Protected Areas Network (PAN).

Let's think about other ecosystems:

Mangrove forests surround Palau. The shallow ocean has lush seagrasses. Think with your friends or family about what ecosystem services and benefits we receive from these ecosystems.

Photos provided by the authors.

CHAPTER 44

ECONOMIC EVALUATION AND APPROACH FOR ECOSYSTEM CONSERVATION

Yoko Fujita

Critical Thinking:
How can we measure the importance of nature?

Relationships between ecosystems and human well-being

People in small islands like Palau have been living very closely with nature and utilizing the natural environment for eons. Oceans provide seafood and fish as an essential daily food. Forests give us important materials: timber, as well as contribute to clean air and water. They also can be sites for recreation and healing, and sometimes mitigate damage from natural disasters. Nature is the foundation of our life and economy, not only on small islands, but also for other regions and continents. Life as we know it would not exist without nature. Could humans survive without soil, water, sunlight, and other living creatures on Earth? The answer is obvious. We, human beings, are supported by the plentiful natural environment on the planet Earth. Why, however, is this indispensable nature spoiled by our human conveniences in the modern world? We will consider the values of nature in this chapter.

Our system of life exists because of the exquisite balance and linkages among the sun, air, soil, water, and living things. We call this our **Ecosystem**, and the expanse of various flora and fauna in this system is **Biodiversity**. Ecosystems and biodiversity provide

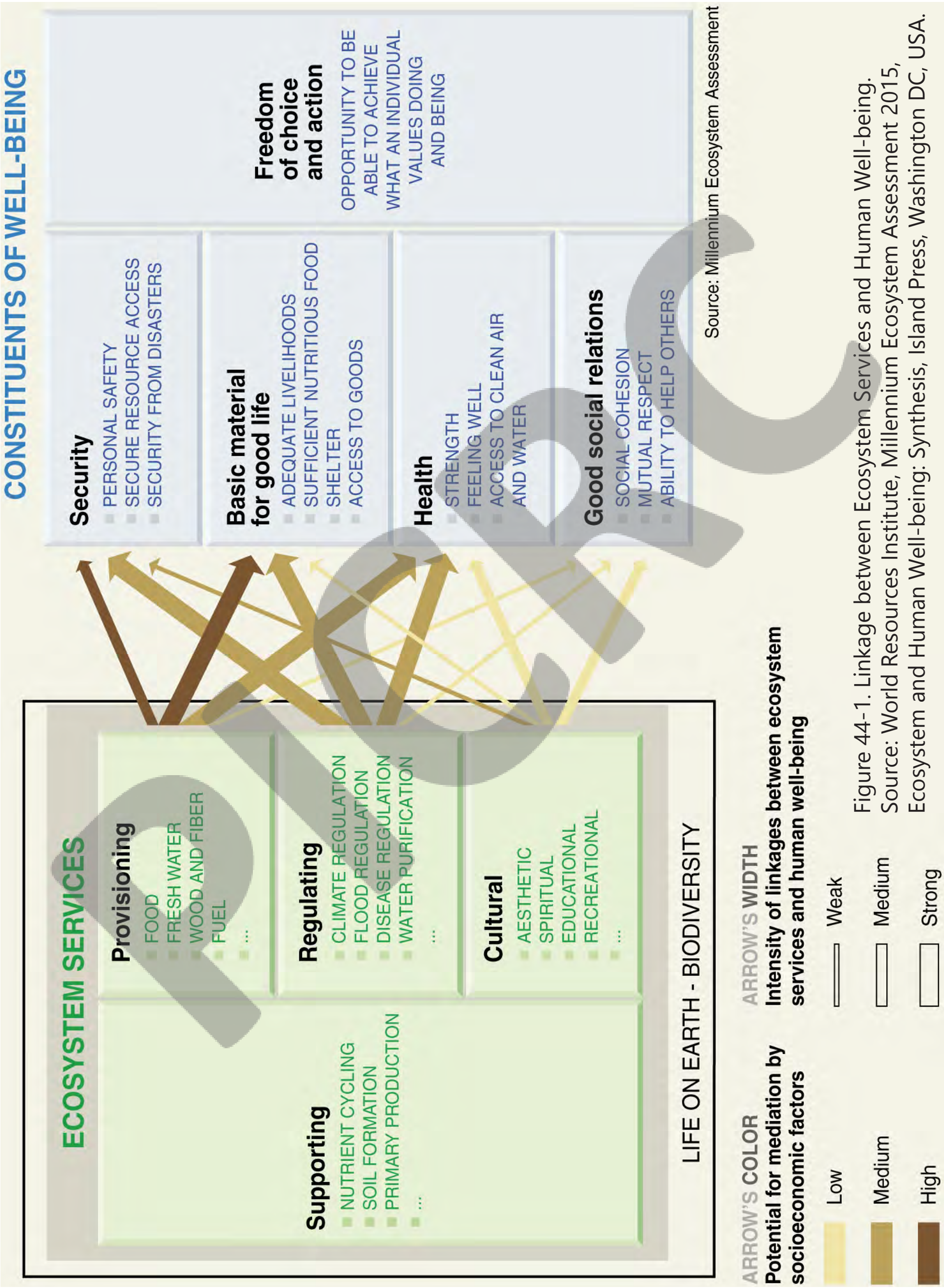

Figure 44-1. Linkage between Ecosystem Services and Human Well-being. Source: World Resources Institute, Millennium Ecosystem Assessment 2015, Ecosystem and Human Well-being: Synthesis, Island Press, Washington DC, USA.

humans with many material and immaterial benefits. The functions of nature that provides these benefits are **Ecosystem Services**. Our daily life and economic activities, without exception, are supported by ecosystem services.

The United Nations led the **Millennium Ecosystem Assessment**, a global research project to clarify the relationship between ecosystems and human society, especially by considering the consequences of ecosystem change on the well-being of human beings. The report was released in 2005 and shared widely across the world in order to contribute to conservation or restoration of ecosystems and to the sustainable utilization of ecosystem services. ***Figure 44-1*** appeared in the report, and shows the various relationships between ecosystem services and human well-being. We can see that ecosystems have four kinds of functions: **Supporting, Providing, Regulating,** and **Cultural services** - that provide various benefits to human beings. If the natural environment is ruined, we never receive these ecosystem services and lose their benefits. Ecosystem conservation is extremely important not only to protect lives, but also to maintain and improve upon the great worth or value that nature holds for human beings.

Why is Environmental Economics an important discipline?

Environmental Economics is a specific field of Economics that considers the reasons, results, and solutions of environmental issues from the viewpoint of economic systems. Often people doubt the links between the environment and the economy. Yet it is clear that economic activities/development and environmental conservation are in a close trade-off relationship.

To start, all environmental problems are caused by our economic activities. This is true not only at the industrial level, but also because individual citizens put pressure on the environment through the extraction of goods, energy consumption, transportation, and so on. Therefore, in order to solve environmental problems, we need to reconsider our present economic systems that ignore and injure the natural environment.


Figure 44-2. Fishing has economic value.


Figure 44-3. Coconuts, important resources.

Because economic growth is important to our livelihoods, we need to have ways of convincing people to change their current economic systems, which often requires thinking long-term and big picture.

Assume, for example, that there is a development plan to fill a coastal area of reef in order to build something—e.g. a hotel or road, etc.—for vitalizing the local economy. It is easy to show clearly how much monetary profit the project will generate through the construction costs, expected number of employees, annual productivity, rents paid, jobs created, and other economic ripple effects. These monetary benefits can be strong reason that local people support such an economic project.

On the other hand, the ecosystem and cultural services lost from the destruction of nature, or the benefits lost from missed nature conservation opportunities, are more difficult to ascertain. Non-market values are not estimated easily, because they are not given any market price. We can say, for example, "Coral reefs are very important for us," or "Palauan nature is extremely precious." Since these are not concrete indicators, however, we cannot compare economic profits and nature conservation to know which holds more value. Generally speaking, humans prefer to have specific numbers over abstract concepts when they have to make decisions. This is one reason why economic projects are promoted as priorities, without consideration of nature and ecosystem services.

Economic evaluation of ecosystem values

Environmental economists have been developing various methods to estimate values of nature in monetary terms, so that people better understand its worth to human society, and are able to compare the profits of economic development and the benefits of nature and natural conservation on the same stage.

Consider the four kinds of ecosystem services (***Figure 44-1***). The economic value of **Provisioning functions** is evaluated by the prices of the materials, uses, or resources provided by nature. If a reef fishing site is destroyed, we would lose a certain monetary value provided by the coral reefs. The economic loss caused by its destruction can be estimated by the trading price of fish and seafood that would otherwise have come from the intact site (***Figure 44-2***). We can do the same estimation for lost forest functions after land development (e.g. lost income from coconuts (***Figure 44-3***)).

Regarding **Regulating functions**, there is an evaluation method named "replacement cost method" that evaluates the ecosystem value by the cost of its replaceable technologies. For instance, coral reefs are natural breakwaters that protect the shore from wave damage. Because technologies exist for the construction of submerged breakwaters that can model these natural functions, we can estimate the value of the natural breakwater by estimating the construction and maintenance costs of a man-made breakwater (***Figure 44-4***).

Figure 44-4. Reef crest breaking waves.

Figure 44-5. It is difficult to express the value of scenery.

Figure 44-6. These kayakers have shown "Willingness to Pay."

It is comparatively difficult to express the value of **Cultural services** in monetary terms. Nature's functions of healing effect, educational location, beauty of natural scenery, and biodiversity are not currently priced by market trade (***Figures* 44-5** and ***44-6***). Furthermore, they mostly cannot be replaced with other market goods or facilities. How can we evaluate them in that case? There is an economic indicator called "willingness to pay" which can be determined through questionnaires and surveys. How much people are willing to pay for something is an indication of how much monetary value they place on it. In Environmental Economics, we apply this idea to estimate the value of the natural environment. In a survey, researchers ask respondents questions like "How much are you willing to pay for conservation of coral reefs in the Rock Islands?" The stated amount expresses how much the respondents care about or value the coral reefs and their conservation. We can estimate the total value of coral reefs by aggregating the willingness to pay by target populations. The name of this method is Contingent Valuation Method (CVM). There are many other economic evaluation methods not described here.

It must be noted that there are many people who disagree with the evaluation of nature in terms of amounts of money. Protecting the natural environment, biodiversity, and ecosystems should be considered spiritual and indispensable. However, history has shown that most people are unwilling to protect nature over economic development without awareness of exactly how important nature is to their own lives and livelihoods.

Economic Approach in Convention on Biological Diversity

According to the Millennium Ecosystem Assessment, the rate of extinction of species on Earth has risen a thousand times in the past 100 years. For instance, 20% of coral reefs vanished and another 20% deteriorated within several decades during the 20th century. 35% of mangroves in the world have already disappeared, and fishery resources and genetic resources have been rapidly diminishing, too. Due to the degradation of biodiversity, about 60% of ecosystem services have been getting worse or are not able to be used sustainably.

In order to solve these problems, the Convention on Biological Diversity (CBD) was adopted at the United Nation Conference on Environment and Development (UNCED) held in 1998 at Rio de Janeiro in Brazil. The goals of the CBD include: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

In 2010, the 10th Conference of the Parties to the CBD was held in Nagoya, Japan. 13,000 representatives from 179 countries met to discuss biodiversity conservation. After repeated discussions by the member countries of the CBD, it was recognized that economic approaches were required in order to accomplish the goals of the CBD. One of these important approaches was determined to be "Payment for Ecosystem Services (PES)." PES is a scheme to establish a system so that beneficiaries of ecosystem services pay fair amounts of money for those services, according to their way and level of their utility. For instance, if forest around a river in the upper part of a watershed is maintained in a healthy condition at a large scale, people downstream can receive environmental benefits in the form of plentiful clean water. Without PES (and associated rules and laws), those downstream users generally would not be charged for the costs of maintaining that forest. On the other hand, people in the upper watershed have to invest time, effort, and money into maintaining the condition of the forest. It is clear that such an unfair situation impedes sustainable management and is more likely to lead to overuse (e.g. such as wasting water downstream). Payment for ecosystem services is needed at the source of those services. The providers of services are not able to continue appropriate management without a financial basis to do so. PES requires that beneficiaries have to pay appropriately for the ecosystem management costs.

Conclusion

We, human beings, have developed societies that receive and benefit from the various material and immaterial wealth of nature on Earth. We also must pay the cost of those benefits. Only human beings can protect the nature of this planet. In order to coexist with the precious nature and to realize our sustainable and peaceful future, we need to fully and rightly understand the values of nature and be willing to pay for protecting, creating, and improving ecosystem services: those indispensable sources of human welfare.

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Photos provided by the author.

CHAPTER 45

JELLYFISH LAKE – ONGEIM'L TKETAU

Sharon Patris and Gerda Ucharm

Critical Thinking:

What are marine lakes?
Why is Jellyfish Lake unique?
What are threats to Jellyfish Lake?

Palau has over 57 marine lakes, with a diverse suite concentrated in the Rock Islands Southern Lagoon of Koror State, a UNESCO World Heritage site. A **marine lake** is a body of seawater completely surrounded by land. Marine lakes come in different shapes and sizes, and retain some connection to the ocean through tunnels, fissures, and crevices in the porous limestone islands (also known as rock islands). Jellyfish Lake (Ongeim'l Tketau) is an isolated lake with an indirect connection to the ocean. Through time and in isolation, the populations of marine organisms found in Jellyfish Lake have evolved, making this lake unique and different from the ocean and other marine lakes.

Jellyfish Lake has a surface area of 60,000 square meters and a maximum depth of 30 meters. Because of its indirect connections to the ocean and the surrounding high ridges of the limestone island, there is very little mixing in the water column of Jellyfish Lake, making it a stratified lake. A **stratified lake** has separate "layers" in the water column; these layers are separated by a difference in density, a result of temperature and **salinity** differences (***Figure 45-1***). Salinity is a measurement of the salt content in water. In Jellyfish Lake, the top layer is oxygenated, warmer, and less saline. With increasing depth, oxygen and temperature decrease while salinity increases. At 13-15 meters, there is a pink layer of bacteria and below that there is no light or oxygen. Instead, the bottom layer is filled with poisonous dissolved hydrogen sulfide gas (***Box 1***).

Box 1. Hydrogen sufide (H_2S) is a colorless gas that can smell like rotton eggs. Hydrogen sulfide is in the lake water as a by-product of decomposition of living materials at the bottom of the lake. The pink layer of purple bacteria found right above the **anoxic** (or no oxygen) layer utilizes the hydrogren sulfide, instead of oxygen, for photosynthesis. While bacteria can make use of the hydrogen sulfide, humans can die of exposure to high concentrations as the gas will attach to red blood cells, restricting the transportation of oxygen to body tissues. Because of the toxicity of hydrogen sulfide, no scuba diving is allowed in Jellyfish Lake.

The Golden Jellyfish

Jellyfish Lake is well known for the millions of golden jellyfish, scientifically known as *Mastigias papua etpisoni* (***Figure 45-2***). This jellyfish is a subspecies of *Mastigias papua*, its ancestor that lives in coves around Koror

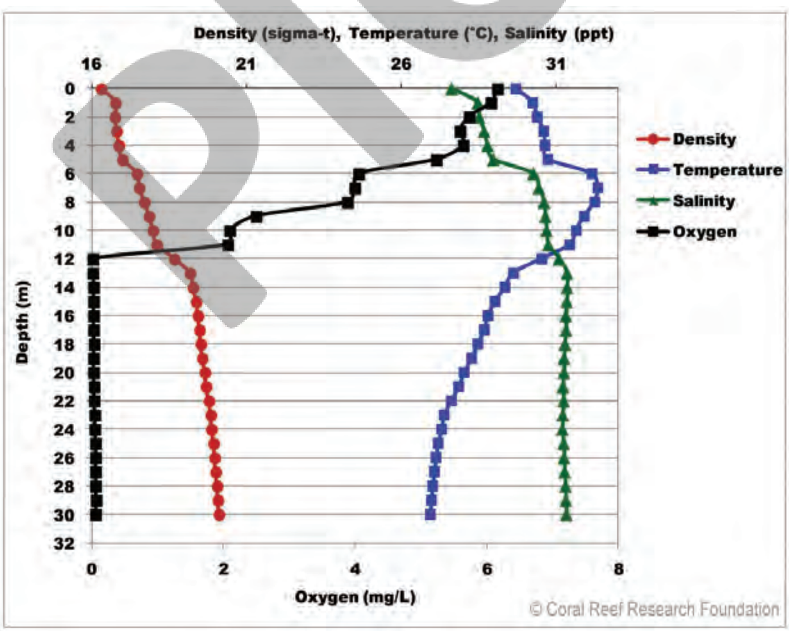

Figure 45-1. Vertical profile of Jellyfish Lake water column shows that with increasing depth, temperature and oxygen decrease, while salinity and density increases.

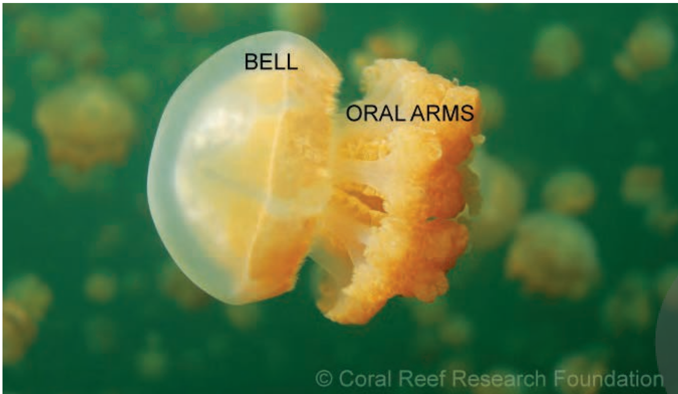

Figure 45-2. *Mastigias papua etpisoni* gets its golden color from zooxanthellae. The umbrella-shaped bell of the jellyfish pulsates to move around, and oral arms have stinging cells used to capture zooplankton for food.

(*Box 2*). This subspecies is unique to Jellyfish Lake and found nowhere else in the world. The golden jellyfish gets its golden color from **zooxanthellae**, which are symbiotic dinoflagellates or micro-algae that live in the jellyfish tissue. Zooxanthellae provide nutrients to the golden jellyfish through photosynthesis, while the golden jellyfish provides shelter and exposure to sunlight for the zooxanthellae. Despite this beneficial relationship, jellyfish still have a need to feed on **zooplankton**, which are tiny mid-water animals. Like their ancestors, the lake jellyfish do have a mild sting and use stinging cells located on their oral arms to catch their prey.

Box 2. Where did the golden jellyfish in the lake come from?

The marine lakes, including Jellyfish Lake, formed 10-15,000 years ago as sea level rose after the last glacial, or ice age, maximum. As the sea level rose, water entered depressions found in the rock islands through tunnels and cracks. Marine organisms in the lagoon entered with the water and settled and colonized these depressions that became marine lakes. The golden jellyfish entered Jellyfish Lake, and with time and isolation, they evolved to look and behave differently than their ancestor in the lagoon.

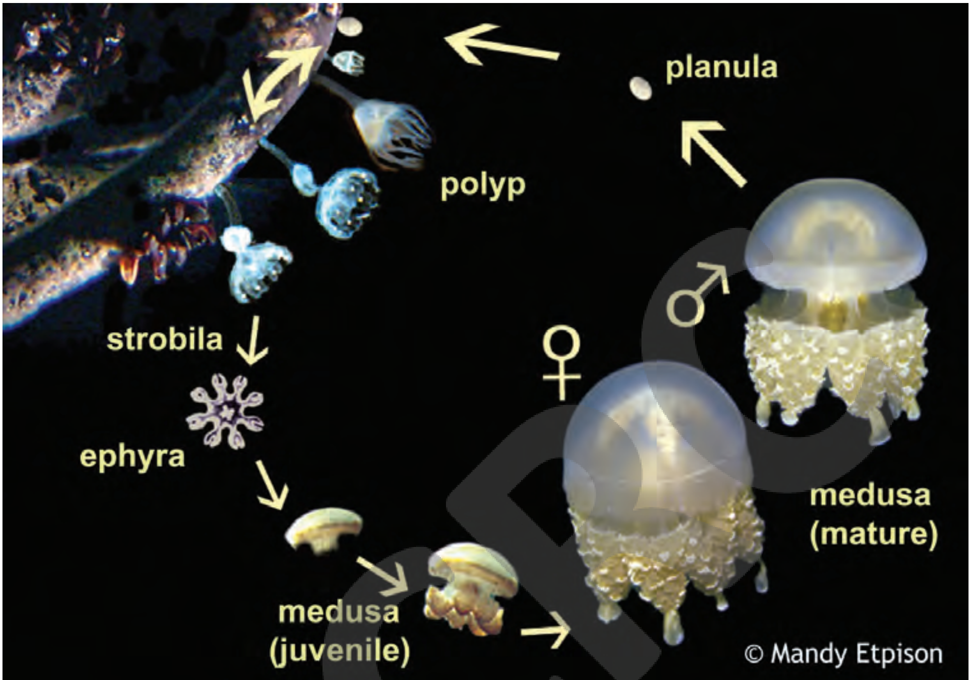

Figure 45-3. The life cycle of jellyfish has two alternating stages: polyp and medusa. Adult medusae (female and male) reproduce sexually, producing planula larvae. Planulae will swim to the sides of the lake where they will settle, attach to the bottom and grow into polyps. Polyps will then produce tiny jellyfish, or ephyrae, which will grow into adult medusae.

The golden jellyfish has an interesting life cycle with two main alternating life stages—the medusa and polyp (***Figure 45-3***). The medusa form is what people see when swimming in Jellyfish Lake, while the polyp form is **benthic**, ~1-2 mm in size, living on the sides of the lake attached to the bottom. Adult medusae (male and female) reproduce sexually, producing planula larvae. Planulae will swim to the sides of the lake where they will settle, attach to the bottom, and grow into polyps. Polyps will then produce tiny jellyfish, or ephyrae, which will grow into adult medusae.

The golden jellyfish in Jellyfish Lake migrate in a unique pattern that is not seen in any other lake. These jellyfish will actively swim towards the east shoreline as the sun rises in the morning, stopping at the shadow line formed by the surrounding rock island and trees.

Figure 45-4. The white sea anemone, *Entacmaea medusivora*, is a native species to Jellyfish Lake that eats the golden jellyfish. Figure © Coral Reef Research Foundation.

As the sun passes overhead around noon, the jellyfish turn and swim towards the west shoreline. Here they stop once more at the shadow line and wait for the sun to rise again the next morning. It is hypothesized that these golden jellyfish swim in this particular pattern to avoid the real edge of the lake where their only natural predator, *Entacmaea medusivora* (or medusa-eater), a white sea anemone, lives (***Figure 45-4***).

Threats to Jellyfish Lake

There are both natural and anthropogenic (human-induced) threats to Jellyfish Lake. Natural threats include climate variability such as the **El Niño Southern Oscillation (ENSO)**, or **El Niño** and **La Niña**. ENSO is a natural phenomenon where there is a change in wind patterns and ocean temperatures, usually accompanied by a shift in atmospheric pressure. El Niño is when warm water pools at the central to eastern Pacific, while La Niña is when cold water pools at the central to eastern Pacific. In Palau, which is located in the western Pacific, cooler than normal water temperatures are recorded during El Niño, and warmer than normal water temperatures are recorded during La Niña.

ENSO events can affect Jellyfish Lake and the jellyfish population. The jellyfish population disappeared twice in the past 20

Figure 45-5. *Exaiptasia pallida* is a non-native sea anemone that was introduced into the lake, probably by visitors. This invasive sea anemone has brown tentacles with a white stalk, and can be found throughout the lake, growing on mangrove roots and hard substrates. Figure © Coral Reef Research Foundation.

years, and both disappearances were correlated to strong El Niño/La Niña events. Drought conditions during strong El Niño events, followed by an increase in sea temperatures during La Niña events, can have an impact on lake conditions, leading to a disappearance of jellyfish. However, the jellyfish in the lake have shown resilience, returning to the lake in about 8-9 months after each disappearance.

Anthropogenic threats are derived from human activities, and visitors can have an impact on Jellyfish Lake through their actions and behaviors. One particular anthropogenic threat to the lake is the introduction of non-native species. **Non-native species** are species that do not occur naturally in a particular place. Most non-native species are introduced through human activities, such as shipping and recreational activities. Once introduced, non-native species have the potential to become invasive, overtaking space and other vital resources.

In the early 2000s, a brown sea anemone, *Exaiptasia pallida*, and two of its symbiotic zooxanthellae were introduced to Jellyfish Lake. These sea anemones have brown tentacles with a white stalk, and are well known aquarium pests that are difficult to control and eradicate. The *Exaiptasia* anemone has spread throughout the lake, dominating mangrove roots and hard substrates (***Figure 45-5***), changing the aesthetics of the lake. Only time will tell the full impact of these introduced and invasive species.

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Photos and graphics provided by the authors.

CHAPTER 46

TOURISM IN PALAU

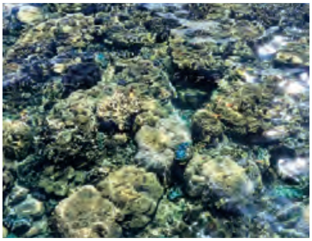
Kaoruko Miyakuni

Critical Thinking:

How can we enjoy Palau?

Palau is an island nation known for its pristine marine and terrestrial environment and its unique island culture. Palau is an archipelago of great natural diversity with more than 400 coral species and 1,400 reef fish species (TNC, 2017). Palau gained attention for its designation of the Rock Islands Southern Lagoon (RISL) as a World Heritage Site (for both natural and cultural significance) in 2012. Palau's policies to protect its natural environment, such as the Shark Sanctuary (2005), Palau National Marine Sanctuary (PNMS), Protected Areas Network (PAN), and Green Fee, and many conservation areas have caught the attention of the world. Tourists around the world come to enjoy various ecotourism activities on land and sea.

Palau has been one of the most admired destinations "for scuba diving in the world, as captured by the underwater photography of Douglas Faulkner in the 1970s" (Kitalong, 2013). The famous diving



spots are in the RISL, including Blue Corner, Blue Hole, Big Drop-off, and Turtle Cove to name a few. The strong current at Peleliu Corner over the reef off the northern tip of Peleliu excites many experienced divers, who come to see spawning aggregations of fish. Shark City, Ulong Channel, and Siaes Tunnel in the western barrier reef of the Southern Lagoon also attract divers with various iconic fish such as Sharks, Napoleon Wrasse, and Manta Rays as well as Hawksbill and Green turtles (Kitalong, 2013).

Snorkeling provides great opportunities for tourists to experience Palau's marine diversity. Palau's water is so clear that even novice snorkelers can see various corals and abundant tropical fish including anemonefish, gobies, cardinalfish, wrasses, parrotfish, groupers, triggerfish, and more. Jellyfish Lake, a marine lake with non-stinging Jellyfish, provides a magical experience of swimming with Jellyfish.

Besides scuba diving and snorkeling, Palau offers various unique marine tourism activities. Visitors enjoy swimming in Milky Way. At the bottom of the Milky Way, there is a white clay known to be good for the skin. Tourists enjoy putting the clay on their bodies as if they are painted white. There are many peculiar island formations to see and narrow sand pathways that are exposed (such as Long



Beach) at low tide. Tourists enjoy sea kayaking and beach barbeques on designated Rock Islands. In downtown Koror, tourists can learn about the ocean environment at the Palau International Coral Reef Center.

Across from Malakal, there is a unique facility where guests can learn about the life history of dolphins and experience feeding and swimming with dolphins.

Tourism opportunities do not end with the ocean environment and Palau is full of exciting destinations on land. Tourists visit the Ngardmau "Taki" Waterfall for hiking, trekking, and swimming. In Ngarchelong State, the northern part of Babeldaob Island, there is a heritage site called Badrulchau Stone Monoliths. In Airai and Koror, Yapese Stone Money can be found. The Yapese were great carvers of stone. How they were able to carve stones weighing more than a ton and transport them to Yap remains a great mystery.

In Airai, Koror, Melekeok, and Aimeliik, there are traditional meeting houses called *Bai* with traditional Palauan architectural features. Tour companies are developing ecotourism experiences on land including taro harvesting, coconut preparation, and guided tours about local plants.

Throughout Babeldaob, there are remnants of World War II such as buildings used for bauxite mining, war tanks, artillery, memorials, and airplanes (some sunk in the ocean). On Peleliu Island, where one of the fiercest battles between the Japanese and Americans was

fought, there are many remnants. Although these heritage sites have not been fully equipped with tourism service facilities, there are various tours to experience these heritage sites.

Visiting the Belau National Museum, Etpison Museum, and Palau Aquarium allows tourists to learn about the beauty of Palau's nature and culture. Walking around the downtown eating Palauan food and various international food (American, Chinese, Thai, Korean, Japanese, Indian, and Italian, among others) is one of the most popular activities.

Tourists have been coming to Palau since the 1970s. The majority of tourists have been Japanese, Taiwanese, and Korean. The number of tourists increased drastically to nearly 170,000 in 2015 due to an influx of tourists from China. However, the number of tourists decreased in 2016 due to the closing of Jellyfish Lake (caused by a decline in the jellyfish population due to high temperatures) and goverment intervention to reduce the number of charter flights.

Tourists bring many good things to Palau. Tourism brings money to Palau (50% of Palau's total revenues come from tourism) (IMF, 2014). Tourism employs local residents. Palau's economy can benefit from the increase in tourists: because of tourism, infrastructure has been improved (such as roads, buildings, and water/sewer systems). Tourism allows for friendship and creates opportunities for cultural exchange. Because of tourism, local art and crafts (such as Storyboards) continue to flourish due to the demand for souvenirs.

Number of tourists in Palau, 2000-2016.

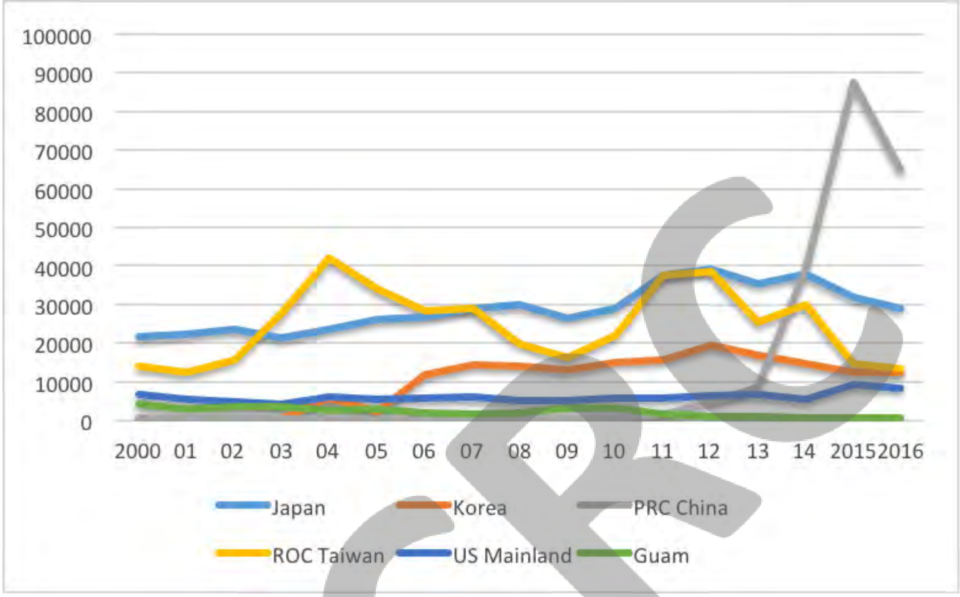


Figure 46-1. Number of tourists. Source: Created by K. Miyakuni with data provided by the Palau Tourism Authority.

Green fees that tourists pay protect natural resources. So, tourism can be good for Palau.

However, because of tourism, downtown Koror has become noisy, trash has increased, and at times there have been water shortages. In this way, increased tourism creates a burden on the local infrastructure. The price of housing has increased, and many local residents now struggle to find affordable homes.

Some unskilled and uneducated divers and snorkelers sometimes break corals and cause harm to fish. Tourists have increased the demand and price for mangrove crabs and reef fish, making it harder for local residents to afford them. If tour guides do not offer proper guidance on protecting Palau's natural and cultural heritage, then tourists can damage the very things they came to see. So, tourism can also have negative impacts on Palau.

Tourism in Palau is promising and local residents gain many things from tourism. In order to keep the tourism industry going and bringing benefits to Palau, the negative impacts from tourism must be addressed, reduced, and monitored.

All photos by Kaoruko Miyakuni.

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Chapter 47

THE CONSERVATION OF NATURE

Ann Hillmann Kitalong

Critical Thinking:
How do we conserve nature in Palau?

What is conservation?

Conservation is defined as the careful preservation and protection of something; especially planned management of a natural resource to prevent exploitation, destruction, or neglect such as **water conservation** and **wildlife conservation**. A second definition is the preservation of a physical quantity during transformations or reactions (https://www.merriam-webster.com/dictionary/conservation).

What is nature?

Nature is defined in several ways: (1) the physical world and everything in it (such as plants, animals, mountains, oceans, stars, etc.) that is not made by people; (2) the **natural** forces that control what happens in the world; (3) the way that a person or animal behaves; and (4) the character or personality of a person or animal (https://www.merriam-webster.com/dictionary/nature).

How do we conserve nature in Palau?

The traditional way to conserve nature in Palau is to take only what you need at the right time and right place. The elders teach the youth about the life cycles of organisms, their temporal patterns, and the right time to harvest. Harvest methods, such as fish traps, are designed to capture what is needed and to release what is too small. Fishermen know where mature organisms feed, breed, and move. They use that knowledge to capture what is needed to feed their families, communities, and guests. Women plant and harvest during certain lunar phases and months of the year. Women fertilize plants with natural compost, regulate water flow, and control pests. This knowledge is passed down to each generation. Each step is well planned. Communities work together to maintain the resources on land and in the sea. All parts of a fish are eaten or cooked to make a fish paste. All parts of the taro plant are used as food or compost. In the past, it was common to have a compost pile near a home as food was organic and recycled. There was no waste.

Taro Farm. Photo by Ann Hillmann Kitalong.

Mangrove channels are cleared for passage and dug when sediment accumulates. Cut trees are used for construction or firewood. Only mature trees of a certain size are harvested for construction. Saplings of young trees are snapped if they expand into seagrass meadows as each habitat is critical for the life cycles of different organisms. Women take the leaves of mangrove trees to push into the mud with their feet along the mangrove edge to help aerate the soil and provide loose mud for mangrove clams to grow. Giant clams are protected near shore to serve as food during stormy weather when it is too rough to go to sea. Children learn the value of the resources and how the sea is connected to the land. When certain flowers bloom or fruit, they know the clams and fish are ripe. Children learn what wild plants have edible fruits such as the purple berries of *matakui*. They learn what leaves to use if they cut themselves. Healers teach their young apprentices the chants and the plants for different types of illnesses. There is a belief that spirits dwell in the forests and the sea and these spirits are to be asked and honored for the resources they provide.

Mangroves and Mangrove Channel. Photo by Ann Hillmann Kitalong.

The traditional *bul* or temporary ban is a way to regulate harvests of resources. When the village chiefs observe that a resource is declining, they set a bul or law to reduce the harvest until such a time that the resources become plentiful. Our leaders use the same principle to set laws and regulations such as the Marine Protection Act (1997) and Palau National Marine Sanctuary (2015) to protect the resources. The Protected Areas Network (2003) helps conserve our forests, mangroves, and near shore reefs and lagoons.

The ancient terraces or pyramids of the Pacific are massive earthworks that created geopolitical boundaries that were used for agriculture and defense. Archaeologists believe that sediments from these earthworks washed downslope and formed the soils for the swamp forests and mangroves along the coastline today. Modern, large infrastructure and development projects, such as construction of the National Highway on Babeldaob, result in major earthmoving. Today these projects follow strict regulations set by the Environmental Quality Protection Board (EQPB) to control sediments from flowing into our freshwater streams and sea.

Respect of nature is a core concept in Palauan culture; respect one another and the environment with its resources. Villages are designed in such a way to enable people to live with nature. Community activities are intertwined with the environment around them. People walk the paths and learn the names of each property and its history. They know where trees grow such as coconuts, mango, papaya, and banana. They know whom to ask permission to have access to fruits to eat, or Nypa palm or coconuts fronds for weaving or thatch roofs. They learn to share their resources with the elderly, the children, and the families in need. The concept is "we" not "I," children learn at an early age on that their actions are a reflection upon their family and clan.

Village Path. Photo by Ann Hillmann Kitalong.

During times of conflict, high population growth, and development, the balance between natural conservation and human needs can be disrupted. Leaders must weigh their decisions to sustain resources for the future. Land use planning is critical to ensure that fertile soils are reserved for farming and that watersheds are protected to keep waters clean and pure. Good planning ensures that the forests, mangroves, taro gardens, and reefs remain intact as demands for more infrastructure increase. The challenge to the leadership is to ensure that nature is not disrupted and critical habitats are conserved for food, shelter, and recreation for future generations.

How can I conserve nature?

Learn all you can about Palau's rich heritage, the villages of our ancestors, the cycles of nature, and how to sustainably use these resources. Talk with the elders, and ask questions. You will be surprised at how much they can teach you. Listen and learn about the way the elders conserve the land and the sea and its rich bounty. Then, you too will be a good steward of Palau's land and sea.

> *"Abundant and beautiful nature is our treasure. In order to share the treasure with many people on the planet, and our descendants, it is important that young people are interested in nature. For that, they can gain a deeper interest when they are observing the shape, color, behavior, or reproduction of very common plant and animal species even in the school garden, the roadside, or the seashore. From these observations, we believe that they can recognize the importance of nature."*
>
> \- Makoto Tsuchiya, 2017

> *"Mengereomel*. Palau is very small and its resources and beauty can be wiped out if you don't conserve and protect nature."*
>
> \- *Obakradebkar* Clarence Kitalong, 2017

There is no place on earth like Palau. It has rich and diverse habitats that are resilient to climate change. We can conserve Palau's natural realm by learning and using traditional methods and new technologies to best manage it. The core underlying principle is to respect nature and each other as our ancestors did and we do today.

* Mengereomel means to conserve and protect nature.

Glossary	
acclimatized	become accustomed to a new climate or new conditions; adjust
acidic	having the properties of an acid, or containing acid; having a pH below 7
algae	a simple, non-flowering, and typically aquatic plant of a large assemblage that includes the seaweeds and many single-celled forms; Algae contain chlorophyll but lack true stems, roots, leaves, and vascular tissue
anthropogenic	threats are derived from human activities, and visitors can have an impact through their actions and behaviors
aquaculture	the rearing of aquatic animals or the cultivation of aquatic plants for food
asexual reproduction	reproduction (as cell division, spore formation, fission, or budding) without union of individuals or gametes
autotrophic	produce or synthesize their own organic compounds without relying on the consumption of other organisms
benthic	the flora and fauna found on the bottom; or the bottom sediments of a sea or lake
biodiversity	various flora and fauna within an ecosystem; or (biological diversity) means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems
bioturbation	the burrowing activities that modify the biogeochemical characteristics of the sediments, interstitial water, and water column
bivalve	an aquatic mollusk which has a compressed body enclosed within a hinged shell, such as oysters, mussels, and scallops
broadcast spawning	animals release their eggs and sperm into the water, where fertilization occurs externally
brooding	fertilization that occurs inside the maternal polyp
budding	the outgrowth of a part of body region leading to a separation from the original organism into two individuals
buttress	a projecting portion; a source of defense or support; increase the strength of or justification for; reinforce
carapace	the hard upper shell of a tortoise, crustacean, or arachnid
carnivore	predator that feeds primarily on passing zooplankton, as well as those that feed upon other animal members of the coral reef community; organisms that derive their energy and nutrient requirement from flesh or animal tissue
climate change	a change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.

conservation	careful preservation and protection of something; preservation of a physical quantity during transformations or reactions
consumer	organisms that eat other organisms for energy to grow and reproduce
contingent valuation method	method used to estimate economic values of nature
coral reef management	the process of modifying human activities to avoid damage to healthy coral reefs and to help damaged reefs recover
corals	colonial organisms made of many small polyps that secrete a calcium carbonate skeleton
decomposer	organisms (e.g. bacteria, worms, centipede, fungi) that break down organic materials such as dead trees or animal carcasses
desiccation	removing moisture from (something), typically in order to preserve it
detritus	organic matter produced by the decomposition of organisms; waste or debris of any kind
ecosystem	balance and linkages among the sun, air, soil, water, and all living organisms
ecosystem services	functions of an ecosystem; benefits from nature
ecotourism	responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education
endemic	a species that is native and restricted to a certain country or area; for example, a species found only in Palau
environment	the surroundings or conditions in which a person, animal, or plant lives or operates; the natural world, as a whole or in a particular geographical area, especially as affected by human activity
epiphyte	a plant that grows on another plant, especially one that is not parasitic, such as the numerous ferns, bromeliads, air plants, and orchids growing on tree trunks in tropical rainforests
estuary	the tidal mouth of a large river, where the tide meets the stream
fertilizer	a chemical or natural substance added to soil or land to increase its fertility
fission	when an organism splits into two separate organisms; division or splitting into two or more parts; reproduction by means of a cell or organism dividing into two or more new cells or organisms
fragmentation	the breaking of the body into two parts with subsequent regeneration
fruit	the sweet and fleshy product of a tree or other plant that contains seed and can be eaten as food; the seed-bearing structure of a plant
functional diversity	many biological functions that occur in different species on an ecosystems
genetic diversity	in the same species, different individuals may have phenotypic intra-species variation, different shapes, or different colors (diversity within species)

global warming	a gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, CFCs, and other pollutants
gonochoristic	only have one sex (male or female)
hatchery	an installation or building in which the hatching of fish or poultry eggs is artificially controlled for commercial purposes
herbivore	organism that only eat vegetation, such as grasses, fruits, leaves, vegetables, roots, and bulbs; derive their energy and nutrient requirement from plants
hermaphroditic	have both male and female gametes developing in either the same polyp or in different polyps within the same colony
inflorescence	the complete flower head of a plant including stems, stalks, bracts, and flowers; the arrangement of the flowers on a plant; the process of flowering
irradiance	the flux of radiant energy per unit area (normal to the direction of flow of radiant energy through a medium); the fact of shining brightly
keystone cultural species	a species that plays a critical role in the way of life
lagoon	a stretch of saltwater separated from the sea by a low sandbank or coral reef
landscape diversity	different ecosystems have different scenery; e.g. coral reefs, mangrove forests, and beaches are different types of ecosystems that are common in Palau
mangrove	forests that consist of trees, shrubs, herbs, vines, and ferns growing in coastal regions of inner parts of a bay or brackish zone that can tolerate freshwater and saline environments; sometimes called mangal
manure	solid waste from farm animals that is used to make soil better for growing plants
marine Lake	a body of seawater completely surrounded by land
migratory	moving from one place to another
nature	(1) the physical world and everything in it (such as plants, animals, mountains, oceans, stars, etc.) that is not made by people; (2) the natural forces that control what happens in the world; (3) the way that a person or animal behaves; and (4) the character or personality of a person or animal
non-native species	species that do not occur naturally in a particular place
obligate	restricted to a particular condition of life, as certain organisms that can survive only in the absence of oxygen; by necessity
offshore	situated at sea some distance from the shore
oligotrophic	(especially of a lake) relatively poor in plant nutrients and containing abundant oxygen in the deeper parts; low productivity waters

omnivore	organisms that derive their energy and nutrient requirements from both plants and animal origin
parthenogenesis	a process that an egg develops into a complete individual without being fertilized.
pelagic	relating to the open sea; inhabiting the upper layers of the open sea
photoinhibition	the inhibition of photosynthesis caused by protein damage due to high levels of light
photosynthesis	the process by which green plants and some other organisms use sunlight to synthesize nutrients from carbon dioxide and water; in plants it generally involves the green pigment chlorophyll and generates oxygen as a by-product.
piscivore	an organism that feeds mainly or entirely upon other fishes
planktivore	organism that feeds upon plankton
planula	a free-swimming coelenterate larva with a flattened, ciliated, solid body; Planktonic larvae; small larva
pneumatophore	a specialized root that grows upwards out of the water or mud to reach the air and obtain oxygen for the root systems of trees that live in swampy or tidal habitats
polyp	a solitary or colonial sedentary form of a coelenterate such as a sea anemone, typically having a columnar body with the mouth uppermost surrounded by a ring of tentacles; in some species, polyps are a phase in the life cycle which alternates with a medusoid phase
producer	plant or organism that can photosynthesize (produce chemical energy from sunlight energy) are at the base of the food chain; higher plants and algae utilize energy directly from the sun and create their own glucose through photosynthesis
propagate	breed specimens of (a plant or animal) by natural processes from the parent stock
propagules	a vegetative structure that can become detached from a plant and give rise to a new plant, e.g. a bud, sucker, or spore; seedlings
pulmonate	a mollusk of the group Pulmonata, which includes the land snails and slugs and many freshwater snails
reproduction	the production of offspring by a sexual or asexual process
rhizome	a continuously growing horizontal underground stem which puts out lateral shoots and adventitious roots at intervals
scute	a thickened horny or bony plate on a turtle's shell
seagrass	a grass-like plant that lives in or close to the sea
seaweed	large algae growing in the sea or on rocks below the high-water mark
sediment	matter that settles to the bottom of a liquid; dregs; a particulate matter that is carried by water or wind and deposited on the surface of the land or the seabed, and may in time become consolidated into rock.

sexual reproduction	two individuals, male and female, produce offspring that have genetic characteristics from both parents
spawning	Release or deposit of eggs; produce or generate a large number of eggs
spawning synchrony	both male and female gametes must be released at a specific time during fertilization
stocks	a supply or quantity of something accumulated or available for future use
stratified lake	has separate "layers" in the water column; these layers are separated by a difference in density, a result of temperature, and salinity differences.
substrate	an underlying substance or layer; the surface or material on or from which an organism lives, grows, or obtains nourishment
symbiosis	interaction between two different organisms living in close physical association, typically to the advantage of both; a mutually beneficial relationship between different organisms
taxonomy	biological categorization of various organisms; the branch of science concerned with classification, especially of organisms; systematics
terrestrial	of or on dry land; relating to earth; living or growing on or in the ground
viviparity	bringing forth live young which have developed inside the body of the parent; reproducing from buds which form plantlets while still attached to the parent plant, or from seeds which germinate within the fruit.
watershed	an area or ridge of land that separates waters flowing to different rivers, basins, or seas; an area or region drained by a river, river system, or other body of water
zooplankton	plankton consisting of small animals and the immature stages of larger animals; tiny mid-water animals
zooxanthellae	a yellowish-brown symbiotic dinoflagellate present in large numbers in the cytoplasm of many marine invertebrates; symbiotic dinoflagellate or micro-algae that live in the jellyfish tissue

*Scientific, Common, and Palauan Names

Although this table is listed by genera, the index also includes page numbers for references of the common or Palauan names. There is a long and rich history associated with how creatures are named. First developed in the 1700s, scientific names consist of two-part Latin names that are unique for every single species. Scientific names help us classify living creatures by group, and thus understand their relationship to each other (e.g. species that are in the same genus are most closely related to each other). Scientific names are a way to standardize the name of a species, so that people from all over the world can communicate with each other and know that they are refering to the exact same species. Common names are not unique and vary widely with language, region, use, and even appearance. Palauan names vary widely by location, use, clan, size, and even season. Palauan names are an important form of **Traditional Knowledge**, and often passed down through clans from generation to generation. In many ways, Palauan names represent both a living creature, as well as the diversity and rich history of the Palauan culture and its links to nature.

Index of Genera and Species *(*see footnote on page 280)*

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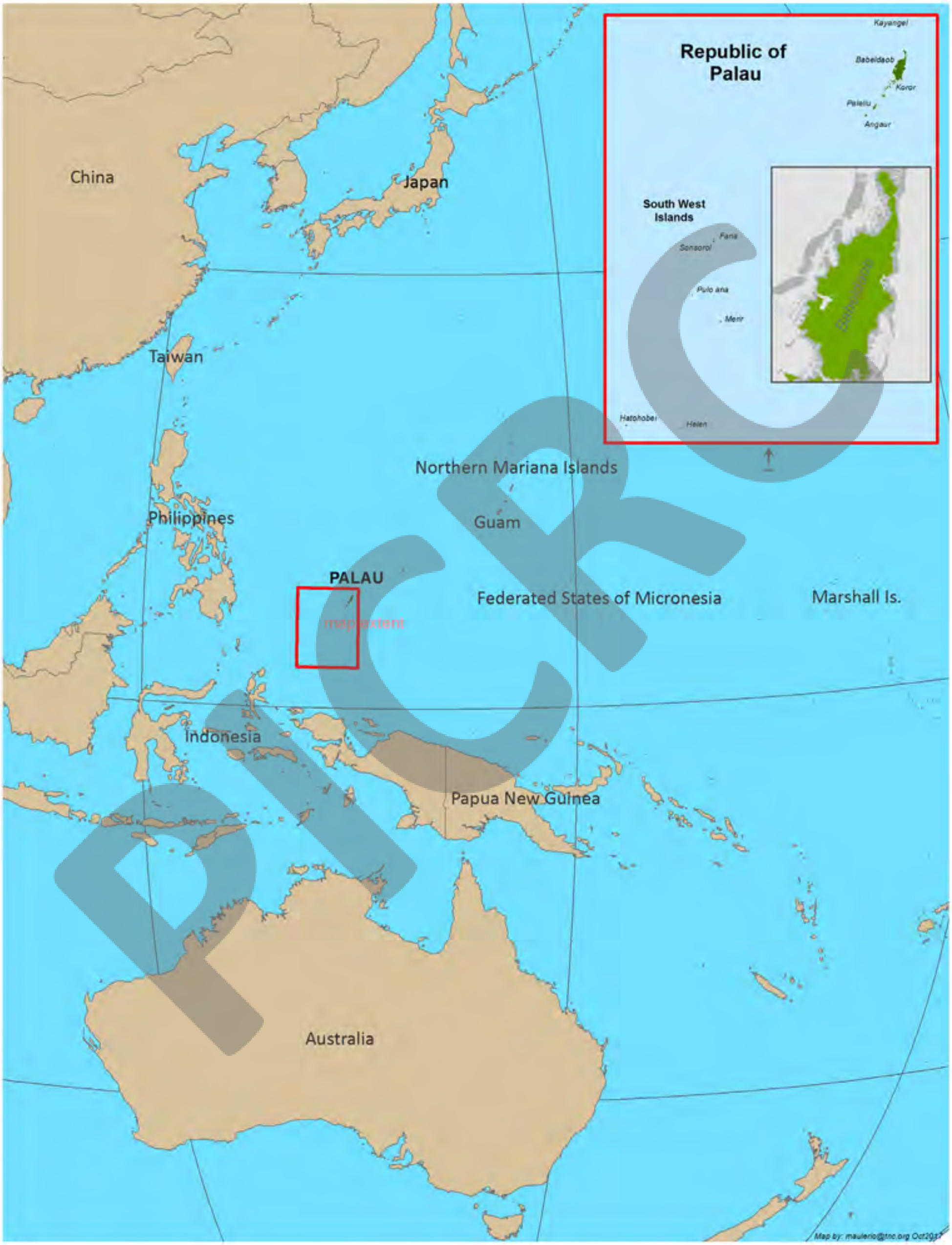
Soaladaob, Kiblas	United Nations Joint Presence (GEF-SGP), Koror, Palau	Chapter 5
Soaladaob, Naito	Belau National Museum	Chapter 40
Tellei, Patrick U.	Palau Community College	Preface
Tsuchiya, Makoto	University of the Ryukyus	Introduction, Chapters 1, 2, 3, 4, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 24, 25, 27, 28, 29, 30, 43
Ucharm, Gerda	Coral Reef Research Foundation	Chapter 45
Victor, Steven	The Nature Conservancy, Palau Field Office	Chapter 5
Yalap, Yalap	Palau Conservation Society	Chapter 26

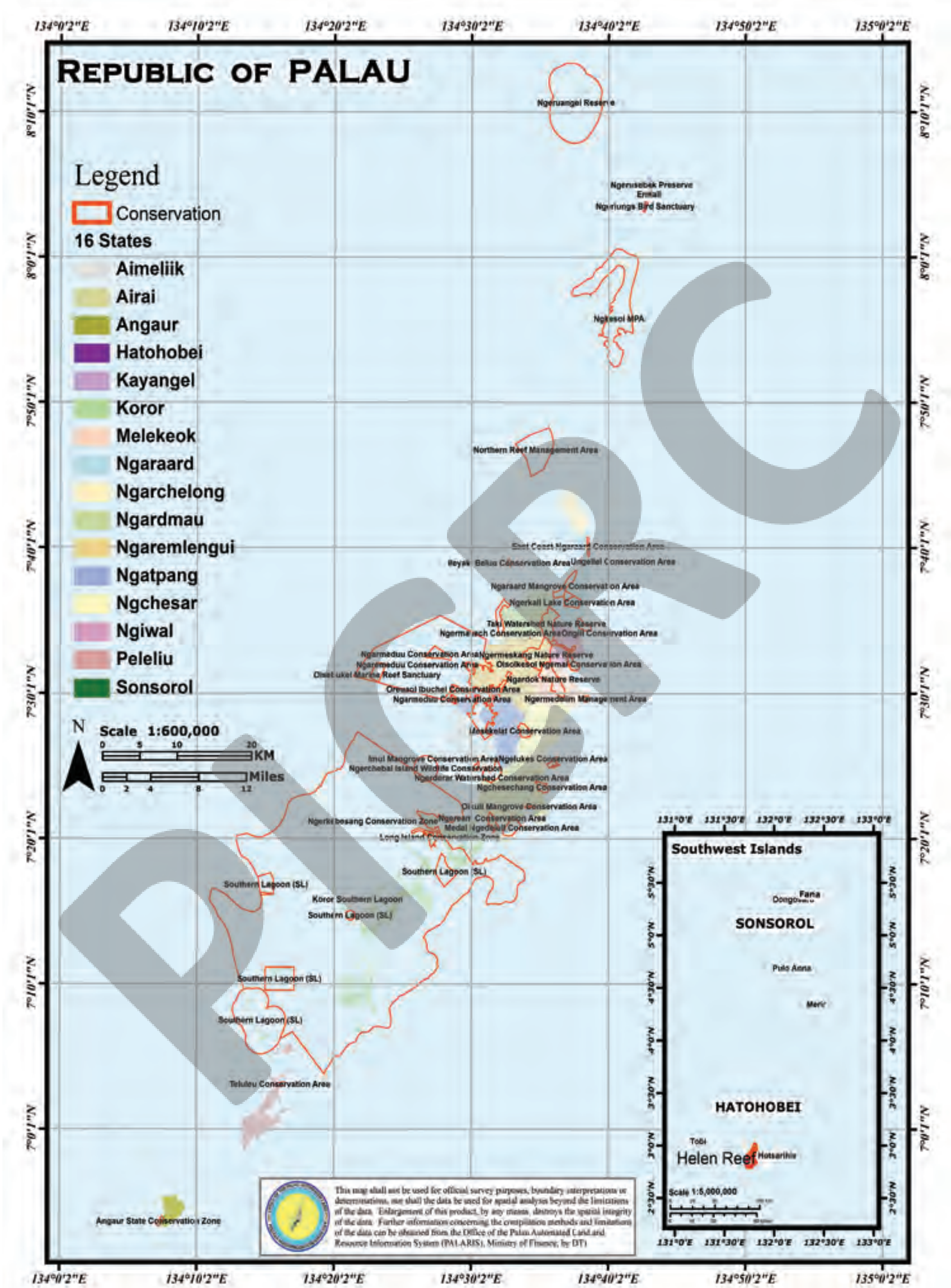
Acknowledgements

The editors would like to express sincere gratitude to the following persons for the review of chapter drafts and/or assisting in the compilation of this book:

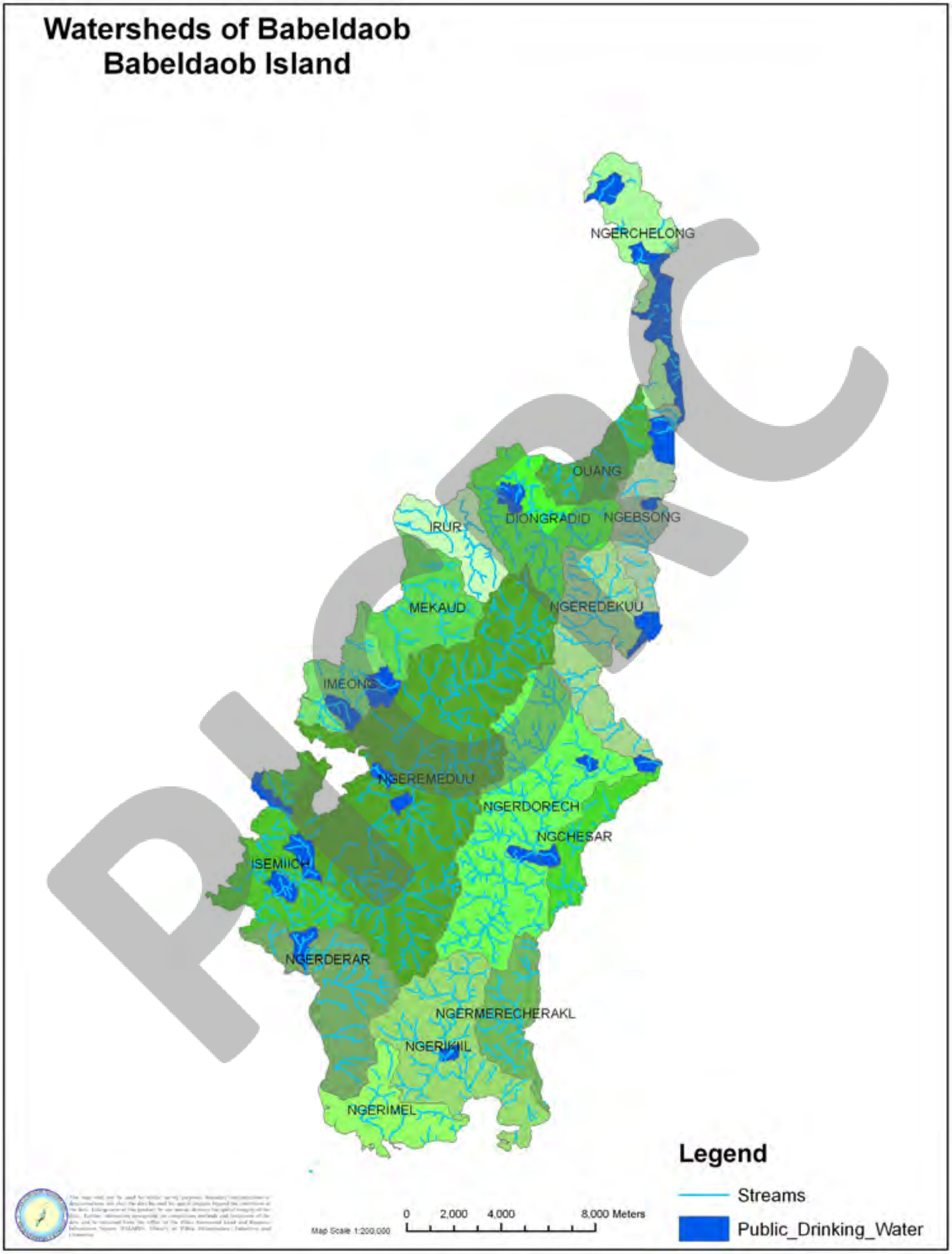
Lori Colin
Mikki Dochez
Sholeh Hanser
Randa Jonathan
Ines Kintoki
Seiji Nakaya
Sherry Ngirmeriil
Dawnette Olsudong
Anna Parker
Lynn Polloi
Marianne Temaungil



Palau location. Produced by The Nature Conservancy.



Geophysical boundaries of Palau. Produced by the Palau Automated Land and Information System (PALARIS).



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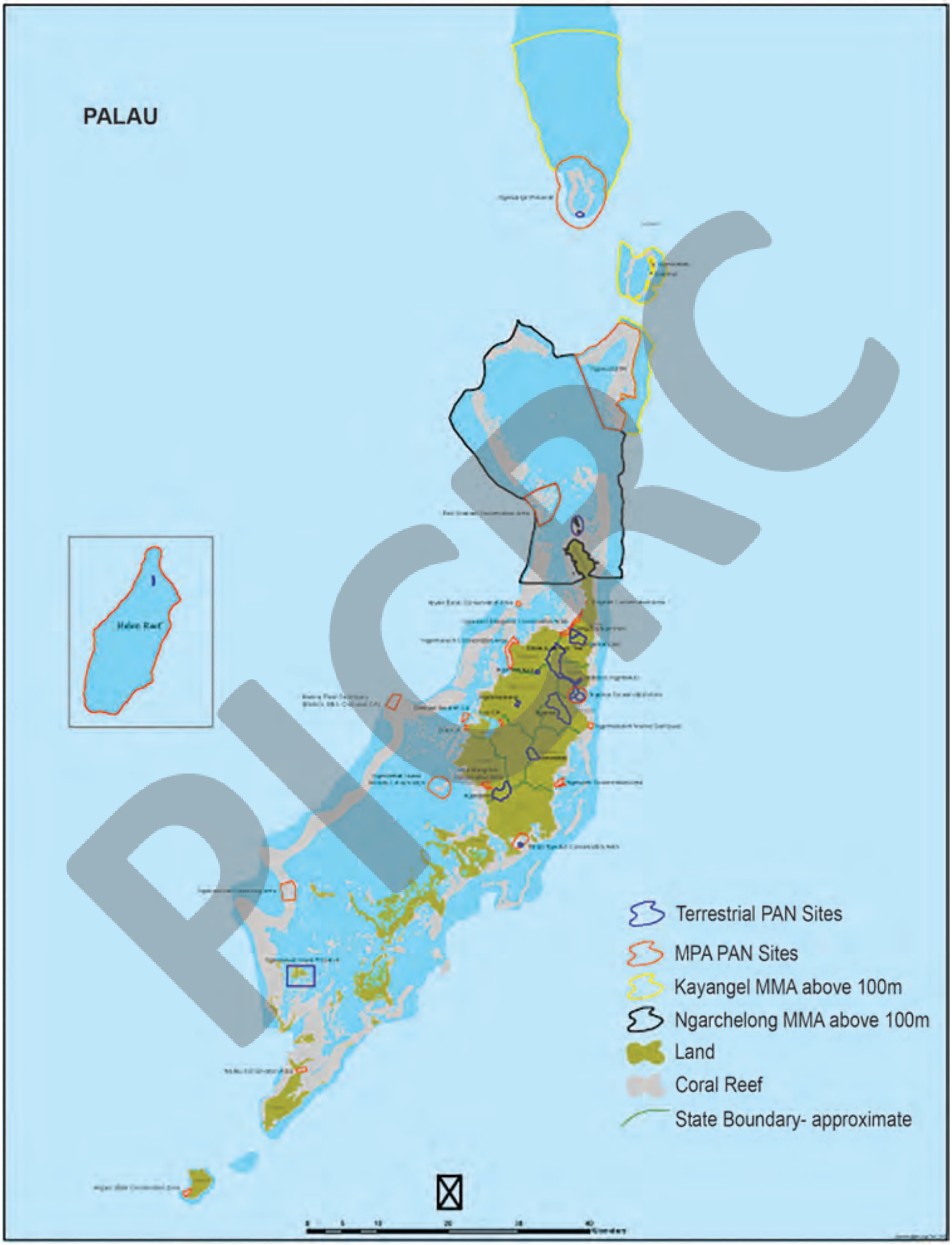

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