Human, climatic and oceanographic influences on the marine environment of Pohnpei, Federated States of Micronesia

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Abstract

Coral reefs and marine resources are culturally, as well as economically, vital to Pohnpei, situated in the Federated States of Micronesia (FSM). Farming and fishing are the main sources of livelihood for most Pohnpeian communities. Pohnpei has eleven Marine Protected Areas (MPAs) where nine are situated in the Pohnpei Island Lagoon and two MPAs on the outer low-lying atolls. Like many other Pacific Island countries Pohnpei is on the verge of creating more MPAs. However, the marine environment continues to be significantly threatened by human and natural influences. The recognised threats are yet to be methodically investigated.

This thesis used a combination of sediment, coral, fish, climatic, and oceanographic data, and focused on the Pohnpei Lagoon, examining a range of natural and human issues in the marine environment both at the local level (focusing on that within the Pohnpei Lagoon) and regional level (focusing on the western Pacific region).

Evidence from historical, archaeological, and modern experience has influenced various marine impacts that have altered the coastline and the marine environment of the Pohnpei Lagoon. Humans have greatly impacted on the coral diversity and fish populations in the Pohnpei Lagoon by over-fishing and contributing to accelerated sediment inputs. My study findings shows that that increased sea surface temperature (SST) caused by El Niño events is not the only cause of coral bleaching, but also cooling of SST, and other human factors. However, when corals bleach they recover by “symbiont shuffling”. This is an ingenious way in which corals host one or more varieties of their zooxanthelle (*Symbiodinium* symbiont clades) that are more tolerant of the stress caused by increased SST and human factors.

The recognised natural climatic variability, particularly the El Niño/Southern Oscillation (ENSO), may pose a significant threat to the Pohnpei Lagoon. El Niño events are associated with: a change in trade winds and stronger wind gusts attributed to typhoons; lower rainfall causing drought; a decrease in SST

attributed to cooling of the marine environment; increase of salinity in marine estuaries affecting development and recruitment of marine species communities; and a steep fall in sea level exposing corals to other elements. The various on-going human threats and El Niño-like conditions have caused giant clams *(Tridacna gigas)* to become extinct, have endangered herbivorous fish populations, and caused coral bleaching by cooling of SST.

Although high SSTs are normally blamed for coral bleaching, the last major bleaching event in Pohnpei (2002) was likely to be due to a reduction in salinity (freshwater runoff and lower sea level), and there has been strong recovery. However, decreasing water temperatures rather than increases of SSTs may contribute to coral bleaching in the Pohnpei Lagoon and the Micronesian region. The Micronesian region appears to have suffered relatively few episodes of regional coral bleaching events. This is due to the "Western Pacific Warm Pool" (WPWP) where sea surface temperatures exceed 29°C but also where various feedback mechanisms limit the maximum SSTs.

The management aims of Pohnpei's MPAs are to move forward, while still respecting traditional practices. However, a lack of scientific monitoring, technical support and funding restricts our understanding of human and natural influences on the existing MPAs and the Pohnpei Lagoon. With respect to our policy makers the findings of the present research have implications on the future work in Pohnpei's marine environment and for policy makers, to make more-informed decisions before establishing new MPAs.

My key recommendations were: 1.) Integrate coral and fish monitoring during and after El Niño events to understand El Niño effects on the Pohnpei environment. 2.) Undertake herbivorous fish investigation into their populations inside and outside the MPAs. 3.) Do not cut down vegetation along coastline areas, as it prevents erosion 4.) Investigate *Symbiodinium* coral clades in Pohnpei Lagoon and the outer low-lying atolls.

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Abbreviations

CSP	Conservation Society of Pohnpei
COT	Crown of Thorns
ENSO	El Niño and Southern Oscillations
EPA	Environmental Protection Agency
FSM	Federated States of Micronesia
MPA	Marine Protected Area
NOAA	National Oceanic and Atmospheric Administration
PICRC	Palau International Coral Reef Center
SOPAC	Pacific Islands Applied Geoscience Commission
SST	Sea Surface Temperatures
WPWP	Western Pacific Warm Pool

Chapter One: Introduction

1.1 Background

The Federated States of Micronesia (FSM) is comprised of 607 islands, and spread over more than a million square kilometres of the western Pacific within an east west chain of islands known as the Caroline Islands (Smith, 1992). FSM is comprised of four states, with an estimated population of about 107,000, according to the FSM 2000 census (Balick et al., 2009). Naming the four island states from east to west they are Kosrae, Pohnpei, Chuuk and Yap (Figure 1.1). FSM is located between the equator and 14° N latitude and between 135° E and 166° E longitude, (Smith, 1992) with each state having its own cultural identity, language, traditions, and history (Figure 1.2).

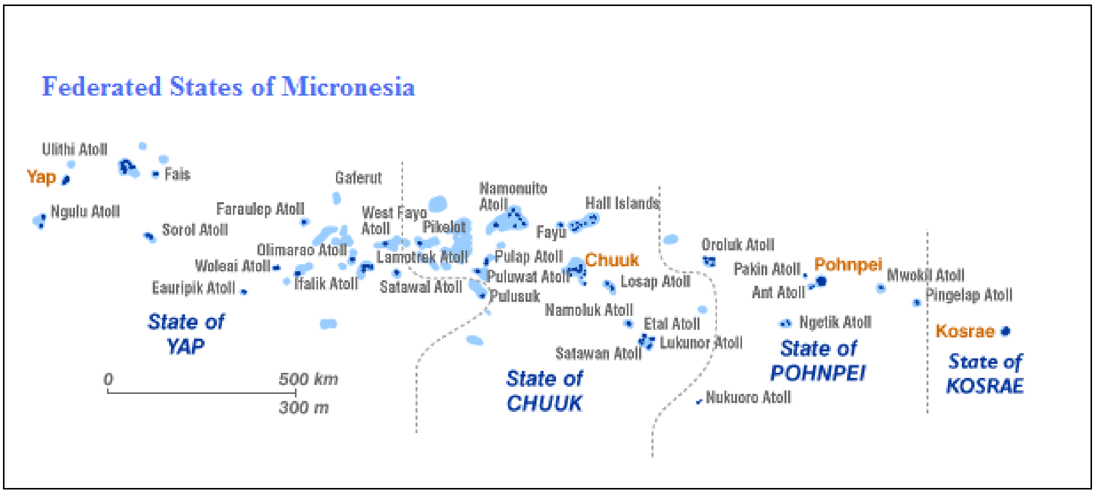


Figure 1.1: Map of the Federated State of Micronesia (FSM Visitors Board, 2009)

The FSM people are mostly of Micronesian descent: however, two outer low-lying atolls, Kapingamarangi and Nukuoro of Pohnpei State, are of Polynesian descent (Smith, 1992). Fishing and farming are the main sources of livelihood for the majority of the FSM's population, while others work in government sectors and private businesses.

Figure 1.2: Map of Oceania and Micronesia (FSM) (Oceania, 1995)

1.1.1 Government

FSM is a democratic constitutional federation of the four states (Smith, 1992). FSM gained independence from the United States of America (USA) in 1986, under the Compact of Free Association with USA. The FSM is responsible for its own internal and foreign affairs, while the USA governs security and defense matters of the FSM (Scott, 1993). Prior to the compact, FSM and other western Pacific regions were part of the United Nations Trust Territory of the Pacific Islands (TTPI) administered by the US in 1947. Before that FSM was under colonial rule by Spain, Germany, and Japan (Smith, 1992).

There are three types of government that operate in the FSM: National, State, and Municipal. The National government is headed by a President and Vice-President who is elected by fourteen senators of the FSM congress on popularity votes to represent the states. State government is headed by a Governor and Lieutenant Governor, with state legislatures who are also popularly elected by each state. Municipal governments are headed by a Mayor or Chief Magistrate who are popularly elected by municipal voters. The three governments are divided into executive, legislative and judicial branches. Traditional rule plays a major role in the governments.

1.1.2 Climate

FSM has a tropical oceanic climate that is warm and humid. Rainfall is extremely high on the high volcanic islands of Kosrae, Pohnpei and Chuuk (Smith, 1992). The region is affected by storms and typhoons that are generally more severe in the western islands, and by periods of drought and excessive rainfall associated with El Niño weather patterns.

1.1.3 Marine resources

The marine resources are the FSM's largest resource, of which tuna fisheries constitute the most important commercial species in the FSM (Smith, 1992). The FSM Exclusive Economic Zone (EEZ) spans over 2,590,000 km^2. The EEZ is an area of the ocean that is owned by the state for economic purposes, scientific research and environmental protection (United Nations Division for Ocean Affairs and Law of the Sea, 2009). The zone starts from the reef edge to 370 km from the coast or beyond. However, with such vast ocean area and valuable resources FSM lacks full understanding of its marine resource wealth. The rich biota is not fully documented and little is known about the deep environment (Department of Economic Affairs, 2007). Meanwhile, inshore marine resources from the coastline to the barrier reef have been the main source of livelihood for most of FSM's population. FSM's marine resources are of vital cultural and economic value. FSM has some of the world's most diverse coral reef systems (Raynor et al., 2004). However, Micronesia, as elsewhere in the Pacific Islands, is undergoing rapid changes and population growth which affect the marine resources (Holthus, 1986).

1.2 Research: Pohnpei

1.2.1 Location

Pohnpei is located in the Eastern Caroline Islands and is situated 756 km north of the equator in the western Pacific Ocean (US Army Corps of Engineers, 1986). Ponape, which means "upon a stone alter", is the original ancient name of the island (Panholzer & Mauricio, 2004). The capital of the FSM is Palikir, located on the island of Pohnpei (Figure 1.3).

Figure 1.3: Pohnpei Island overlooking the northern lagoon (FSM National Biodiversity Strategy and Action Plan, 2003)

1.2.2 Pohnpei Island and outer low-lying atolls

Pohnpei proper is divided into 5 districts that are distributed around the coastal areas of the island (Figure 1.4): Nett, U, Madolenihmw, Kitti, and Sokehs. The urban centre of Kolonia is the main city centre and has about 7,000 people. While the total population of Pohnpei Island is about 40,000, around 31,540 people reside on or around coastal areas of the main island of Pohnpei (Office of Planning and Statistics, 1996). The majority of the population are subsistence farmers and fisherpersons (McKenzie & Rasheed, 2005).

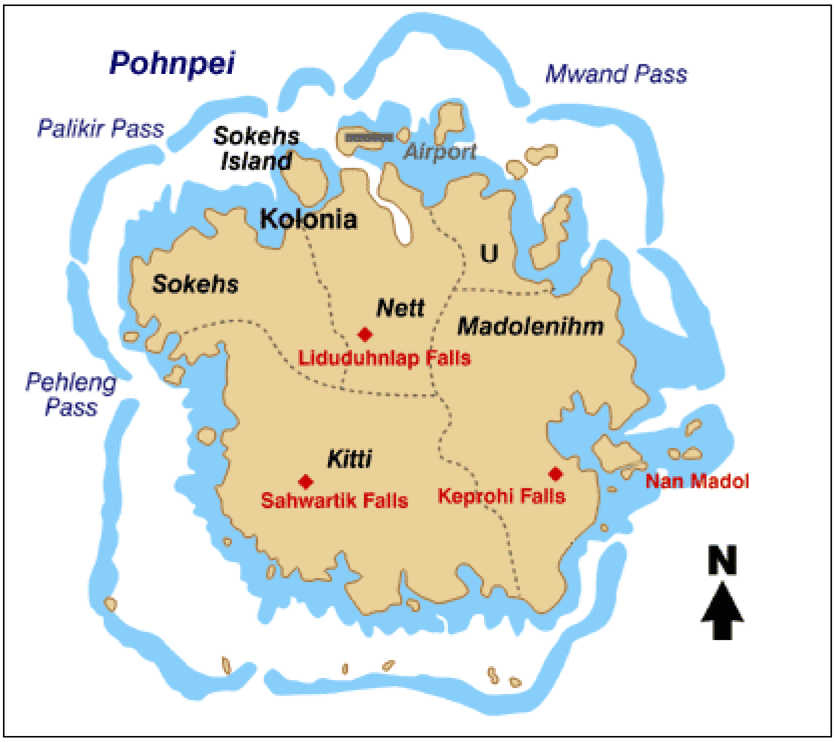


Figure 1.4: Pohnpei map showing 5 municipalities (Department of Economic Affairs, 2002)

Pohnpei Lagoon has about twenty five coral islets (Balick et al., 2009) with nine outer low-lying atolls: And (aka Ant), Pakin (Figure 1.5), Mwokil, Pingelap, Ngatik, Nukuoro, Kapingamarangi, Oroluk, and Minto Reef. The people on outer low-lying atolls speak their own distinct dialect. For example the languages follow the name of the atolls: Mwokilese, Pingelapese, Ngatikese, and so forth, except on And, which speaks the same Pohnpeian Language as the main island of Pohnpei; or Oroluk which is inhabited by Kapingamarangi people, and Minto Reef, which is only a submerged reef without human populations. And Atoll is privately owned by the Nanpei family (McKenzie & Rasheed, 2005).

Figure 1.5: Pakin Atoll, outer low-lying island of Pohnpei (Raynor et al., 2004)

1.2.3 Pohnpei climate

Pohnpei, being close to the equator halfway between Hawaii and Australia (McKenzie & Rasheed, 2005), receives a high amount of rainfall and sun hours. It is also considered to be one of the wettest places on earth with April and May being the wettest periods (National Oceanic and Atmospheric Administration, 1983). Annual rainfall approaches or exceeds about 5m on the coast (McKenzie & Rasheed, 2005) and over 8m in higher elevation areas (Rhodes et al., 2007). More than forty streams and rivers (Balick et al., 2009) drain into the mangrove forest and barrier reef around the Pohnpei Lagoon. Rainfall is heavy and frequent with about 300 hundred rain days per year (Butler, 1997). The average daily temperature is 27 °C and there is little seasonal or even hourly variation. However there does tend to be an increase in humidity from May through October (McKenzie & Rasheed, 2005). From the months of November through June, the climate of Pohnpei is mostly influenced by the northeasterly trade winds. By April, the trade winds typically diminish in strength and by July the trade winds give way to lighter and variable winds of the doldrums (National Oceanographic and Atmosphere Administration, 1983). July through November the island is influenced by the Intertropical Convergence Zone (ICZ), which brings southeasterly winds and tropical disturbances creating very humid months (National Oceanic and Atmospheric Administration, 1983). The tidal range on Pohnpei has a 0.7 m mean and 1.0 m diurnal range (McKenzie & Rasheed, 2005).

However, the changing ocean and weather patterns are not the same every month and are changing every year on the land and at sea (National Oceanic and Atmospheric Administration, 1983; Raynor, 1991; Baynham, 1994; Pohnpei Surf Club, 2009; Buden, D. & Raynor, B., personal communication, November 15, 2009).

1.2.4 Marine ecosystem

Pohnpei is a high volcanic island that covers 344 km^2 which include islets and mangrove forests (Balick et al., 2009). It is roughly circular and a deeply dissected volcanic dome (US Army Corps of Engineer, 1986). The oldest lava dates to over 5 million years B.P (Balick et al., 2009). Pohnpei Island is surrounded by a full fringing, lagoon and barrier reef system except along the southeast coast which also has a wide fringing reef platform that extends out towards the barrier reef and open lagoon. The well developed lagoon features a wide diversity of productive and relatively intact natural habitats, including mangrove forests, seagrass beds, fringing reef flats, reef passages, islets, and the barrier reef (US Army Corps of Engineers, 1986).

1.2.4.1 Mangrove forests

Figure1.6: Mangrove forest with local fishermen (Photo by Naiten Bradley Phillip Jr.)

1.2.4.2 Seagrass beds

Seagrass beds are also common near the mangrove forests and on the inshore fringing reef flats that surround the island and coral islets (Figure 1.7). The inshore fringing reef has terrigenous sediments, while calcareous sand and rubble deposits are dominant in the open reef flats that support sea grass beds (US Army Corps of Engineers, 1986).

Figure 1.7: Seagrass meadows in a shallow sub-tidal area (McKenzie & Rasheed, 2005)

There are three species (*Cymodocea rotundata, Enhalus acoroides,* and *Thalassia hemprichii*) around Pohnpei and two species (*Cymodocia rotundata* and *Thalassia hemprichii*) at And Atoll (McKenzie & Rasheed, 2005). Like the mangroves, sea grasses are also important sediment traps and nursery areas for juvenile fish. The seagrass beds are also home for jelly fish, sea cucumbers, and bivalve molluscs (US Army Corps of Engineers, 1986). Seagrass beds are also known to be turtle feeding grounds.

1.2.4.3 Fringing reefs

The main fringing reef varies in size, but is approximately 50 m in width reaching numerous patch reefs and extends 1-2 kilometres into the lagoon (US Army Corps of Engineers, 1986). At the fringing reef edge lies a zone of solid reef rock and coral islets (Figure 1.8). The highest coral cover is located at water depths of 3-5 m on the fringing reef slope, where massive coral colonies and boulders can be found. Below these depths coral cover drops off. ‘Reef holes’ are present at various fringing reef areas, known by local fishermen to be the migration paths and spawning grounds for herbivorous fish. The main fringing reef reaches about 6 kilometers in width along the north side of the island and is surrounded by the Pohnpei Lagoon (US Army Corps of Engineers, 1986).

Figure 1.8: Reef passage between barrier reef and numerous patch reefs (Photo by Ron Vave, 2006)

1.2.4.4 Pohnpei Lagoon

The lagoon is about 181 km^2 (Balick et al., 2009), enclosed by a barrier reef located about 3 kilometers offshore (Holthus, 1986) with high coral growth and diversity. Occasionally, dogtooth tuna can be found near passes, while dolphins are typically seen entering and leaving the lagoon through numerous reef passes. There are about 15 deep passes that are steep with scoured reef walls and little coral cover in some areas of the lagoon (US Army Corps of Engineers, 1986). These passes are rich in fish communities, ranging from reef to pelagic species. Grey reef sharks are mainly abundant in the reef passes. Large aggregations of carnivorous and herbivorous fishes are present in all of the passes. Sand and rubble cover the reef flats of the lagoon with coral growth and fish diversity occurring on the reef slopes at water depths of 5-10 meters. Below 10 meters sand and rubble dominate (US Army Corps of Engineers, 1986).

The lagoon hosts some 25 coral islets (Balick et al., 2009) with their own fringing and patch reef (US Army Corps of Engineers, 1986). The patch reefs are enclosed secondary lagoons that are extensions of fringing and barrier reefs supporting moderate coral growth of various sizes and shapes. The coral islets are covered by white sandy beaches and coral rubble. The vegetation on the coral islets consists of plants that are resilient to salt spray. There are white sandy beaches on some of the smaller islets located on the barrier reefs that encircle the Pohnpei Lagoon. The beaches also comprise a number of shrubs, herbs, vines, and grasses. Some of the sandy beaches are used as turtle nesting grounds on some of the coral islets. Hermit crabs are easily spotted wandering on the white sandy beaches, whereas coconut crab, (*Birgus latro*), are common on the inner forested areas of the coral islets. Numerous species of seabirds, about 26, are common migrants that feed and nest on these coral atolls. The Pacific reef heron (*Egretta sacra*) is a common resident and is seen in most shallow coastal areas (US Army Corps of Engineers, 1986).

1.2.4.5 Barrier reef

On the barrier reef (Figure 1.8), giant clams (*Hippopus hippopus*), trochus, sea stars and sea cucumbers can generally be found. In sandy areas near the reef crest cowries and sea cucumbers are common. On the reef slope and reef flat areas, byssally-attached giant clams (*Tridacna maxima*) occur with coral eating Crown-of-thorns (COTs) starfish (*Acanthaster planci*). In the surf zone, sea cucumber (*Actinopyga nilolticus*) stick tightly to the reef pavement and massive coral boulders host numerous lobsters. The solid reef rock pavement and terrace walls slip deeply into the wave zone. Green sea turtles (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys mbricate*) can be found resting under large coral boulders or swimming alongside the barrier reef walls. Down the ocean slope, trochus can be sighted again, with flat corals spreading wide in the crystal clear waters. The leeward side of Pohnpei has steep sea walls, while the windward side has less distinct terrace and slopes. There is high coral diversity at water depth of 15 meters at numerous sites on the outside barrier reef regions (Turak & De Vantier, 2005).

Along the margins and slopes of fringing, patch and barrier reefs (Figure 1.9), coral development and diversity and fish abundance increase. These habitats of the Pohnpei Lagoon support a remarkable abundance of marine life, including more than 650 species of fish and 350 species of coral (Allen, 2005; Turak & De Vantier, 2005). The nearly 350 species of reef-building (hermatypic) corals are in 61 genera from 14 scleractinian families; however, several genera, such as *Montipora*, *Acropora*, and *Alveoprora* may be undescribed (Turak & De Vantier, 2005). Some marine species are on the International Union for Conservation of Nature (IUCN) red-listed species, such as Green, Olive Ridley, and hawksbill turtles, and the giant clam (Seacology, 2004). The IUCN red list is the world's inventory of global conservation status for all plants, animal species and regions of the world, an authoritative guide for the status of biological diversity (International Union for Conservation of Nature, 2009).

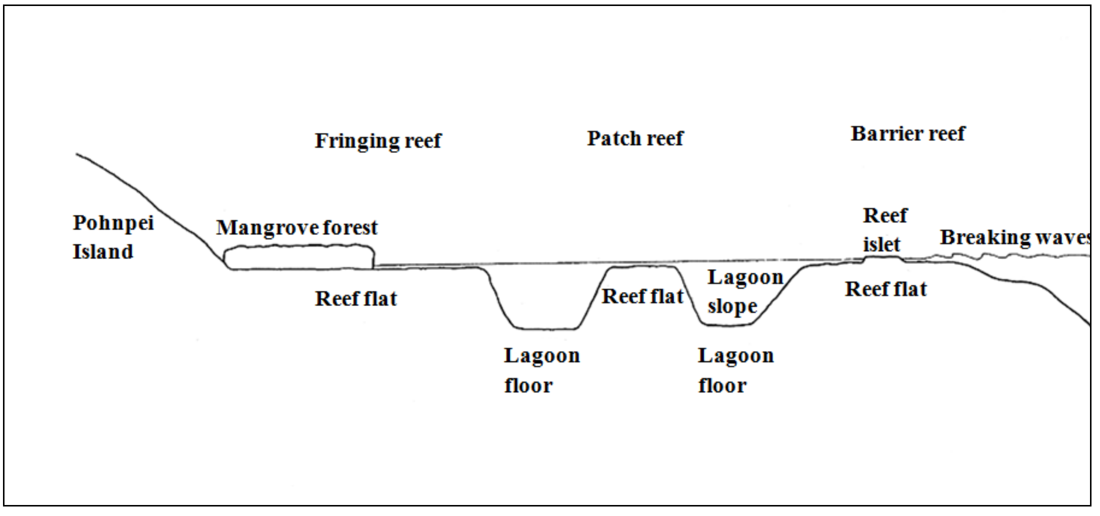
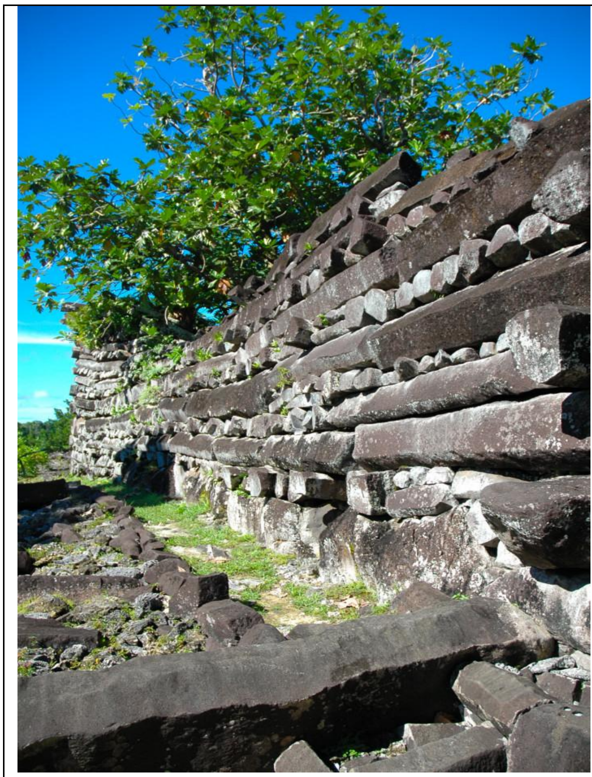


Figure 1.9: cross section of Pohnpei reef system, illustrating three basic reef types; fringing, patch, and barrier reef (US Army Corps of Engineers, 1986)

1.3 Historical human impact on the Pohnpei Lagoon

1.3.1 Nan Madol



Pohnpei has been archaeologically documented to have been inhabited for about 2,000-2,500 years or longer (O'Connell, 1972). The historical records of Pohnpei date from early to mid 1800s. Hezel and Hezel (1983) believed Pohnpei was inhabited earlier than the mid 1800s as evidenced by Nan Madol, a sophisticated megalithic coastal structure built as early as 800-900 A.D. and completed by the 1600-1700s (Figure 1.10).

Figure 1.10: Basalt stones in Nan Madol (Photo by Ron Vave, 2006)

Nan Madol consists of nearly one hundred artificial islets constructed from huge basalt boulders, some weighing 15 to 30 tons. Corals are used to fill open spaces between the basalt boulders. There are several ponds within the interior of some of the islets used as holding areas for sea turtles and marine molluscs (*Anadara antiquota*). The Nan Madol complex is located in Madolenihmw municipality and sits on a fringing reef area extending out to the barrier reef on the east coast of Pohnpei. Other artificial basalt islets smaller in size and shape are also found at U and Kitti on the fringing reefs. Quarry sites of basalt stones are said to be in Kitti and Sokehs municipalities some 100 kilometers away. The technology and engineering practices used to construct Nan Madol are unknown (O'Connell, 1972). Clearly, there was extensive reef disturbance, and Nan Madol city is evidence of this.

1.3.2 Fish traps and mangrove channel tugging

There is also evidence of intensive human labour in the form of fish traps made from basalt stones and coral rubble, in a serpentine shaped layout found on lagoonal areas and at the edge of mangrove forests around Pohnpei Island (US Army Corps of Engineers, 1986). Fish traps catch reef fish during their spawning runs or during their daily migrations, with the tidal currents from deep water coral reef holes to the shoreline and mangrove forests. Hand tugged canoe channels are also commonly found as evidence of human alterations of the mangrove forest. It has been suggested that the use of this 'serpentine' pattern might have been a method for ensuring that channels did not get heavy sediment build-up, which would therefore require their deepening.

1.3.3 Foreign rule

Early in the 19th century, under the Spanish rule from 1886-1899, the introduction of trade by the western whalers and Christian missionaries created a drastic depopulation of Pohnpeians by foreign infectious diseases. The loss of population by infectious disease and conversion to Christian lifestyle led to some loss of traditional beliefs and lore (O'Connell, 1972). In the 20th century the population steadily grew with the successions of foreign rule, goods, medicines and development by the Germans (1899-1914), Japanese (1914-1945) and then the Americans (1945-present) (US Army Corps of Engineers, 1986).

1.3.4 Pacific War

The Pacific War between the Japanese and the Americans left remnants of warfare on the terrestrial and lagoonal areas. Numerous Japanese concrete structures are spread around the reef flat areas and one islet (Lenger Island) used to host an airport runway extending out into the water. Some reef holes might be confused with bomb craters on reef areas near Lenger, created by US war planes during World War II raids. Anchor chains from US warships were left wrapped around a mangrove tree patch on a fringing reef area of Lenger Island (fishermen personal communication, July 10, 2009). The Pacific War remnants are now part of tourist attractions for the Lenger Island community.

1.3.5 Modernization

Pohnpei has the largest share of the rich biodiversity in the FSM and also shares similar and a growing number of threats with all the other island states (Raynor et al., 2004). Pohnpei is the melting pot of the FSM, where various people from throughout the FSM and other races reside. Western influence is evident with modernization of the people's traditional lifestyles through the introduction of a cash economy. This has resulted in communities that depend locally on seafood for their protein buying cheap canned meats (tuna, corn beef) and frozen meat (hot dogs, turkey tails) imported from developed countries (King, 2007). The increased cost of living, increased development, and urbanization are potentially fuelling the loss of marine biodiversity, especially in Pohnpei's coastal marine area. The loss of marine biodiversity by modernization is attributed to dredging, sedimentation, over-fishing, Crown-of-thorns (COT) starfish outbreaks, pollution, mari-culture and aquaculture of marine species. Later chapters will have greater emphasis on the human impacts of the Pohnpei lagoon.

1.3.6 Climatic conditions

Today, the increased threat of global warming and climate change needs to be taken into account along with human threats. A better understanding of the link between both natural stress and human impacts on the marine resource conditions and their significance to locals' livelihood need to be investigated. The ENSO phenomenon may influence hardships that will follow current human activities and environmental conditions in Pohnpei, if humans continue in this un-sustainable path. Every few years the pressure systems in the Pacific reverse and this causes El Niño events, such as the one in 1997/98 causing worldwide coral bleaching events (King, 2007). A detailed explanation of ocean and weather conditions with on-going human threats will be discussed in Chapter 2.

1.4 Traditional knowledge and marine practices

1.4.1 Traditional marine species and practices

The traditional knowledge, practices and innovations are still practiced within Pohnpei. Numerous aspects of traditional knowledge and practices are still used in the areas of fishing, farming, navigation, healing, dancing, chanting, food preparation, construction, initiation rites and others (Pacific Consultants, 2002). To live in Pohnpei you walk two paths: tradition and modern (Balick et al., 2009). Pohnpei traditional knowledge and cultural practices embody respect towards the natural environment. Traditional culture is very much alive in Pohnpei, as shown in rituals, feasts and beliefs infused into daily life (Balick et al., 2009). Pohnpei's traditional system co-exists with the marine resources and the two are very much intertwined.

1.4.2 Marine species

Traditional Pohnpei diet exploits reef and lagoonal species, from mollusks, crustaceans, echinoderms, fishes and turtles to other sea food species (US Army Corps of Engineers, 1986). From the exploitation of the marine resources came traditional classification systems, social ranking of particular use of certain species, and the development of subsistence extraction seasons.

Even though the locals did their part to alter the marine environment they learned not to overharvest the marine resources for the worse and always acknowledged sustainable use. While Pohnpei's marine resources are still rich, respect for people and environment is a foundational belief of traditional living (Balick et al., 2009).

1.4.3 Traditional system being challenged

Today, traditional systems are being challenged as evidence by increased coastal development, rising population of Pohnpei Island and over-exploitation of the marine resources by the cash economy, consequently affecting how people live and deal with the marine resources. Although Pohnpeians have inflicted destructive practices, traditional also culture plays an important role in marine resource conservation (Pacific Consultants, 2006; Balick et al., 2009).

1.5 Establishment of Pohnpei's Marine Protected Areas

1.5.1 Where, when, and why?

To help mitigate the growing anthropogenic impacts in the Pohnpei lagoon the Pohnpei state government created a total of 11 Marine Protected Areas (MPA). Marine Protected Areas are defined by the International Union for Conservation of Nature and Natural Resources (IUCN) as described in Gubbay (1995), *"Any area of intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment"* (p. 3). Nine MPAs surround the main island lagoon (Figure 1.11) while two are on the outer low-lying atolls of Pohnpei. Seven MPAs were first established in 1999, while four were established in 2001 (Marine Resources Conservation Act, 1981; Marine Sanctuary and Wildlife Refuge Act, 1999). They are, starting from the north side of Pohnpei to the west: Sapwititk, Mwand/Dekehos, Dehpehk, Namwen Na, Namwen Nangingih, Enipein Forest Mangrove Reserve, Nahtik, Kehpara, and Pwudoi Mangrove Forest Reserve. Each marine reserve was designated either by ecological or cultural values. There are two outer low-lying atolls that are Marine Protected Areas: Oroluk and Minto Reef. The MPAs were established and designated under the Pohnpei State Marine Sanctuary and Wildlife Refuge Act, 1999: SL. NO. 4L-115-99 §1, 7/23/99 and are "no-take" reserves, which bans all extraction and disturbance by humans. The MPAs were created according to cultural, historical, and biodiversity importance. They include:

- **Kehpara**: Grouper spawning ground
- **Enpein Marine Park:** Mangrove dwelling marine organisms
- **Pwudoi:** Mangrove dwelling marine organisms
- **Nahtik**: General
- **Nahmwen Na Sting Ray sanctuary:** General/cultural heritage
- **Nahmwen Naningih Sting Ray sanctuary:** General/cultural heritage
- **Sapwitik**: General/ rabbitfish spawning ground
- **Mwahnd/Dekehos**: General/ Manta ray dive site
- **Dehpehk**: General/Mangrove dwelling marine organism
- **Oroluk**: Turtle nesting ground/General
- **Minto Reef**: General

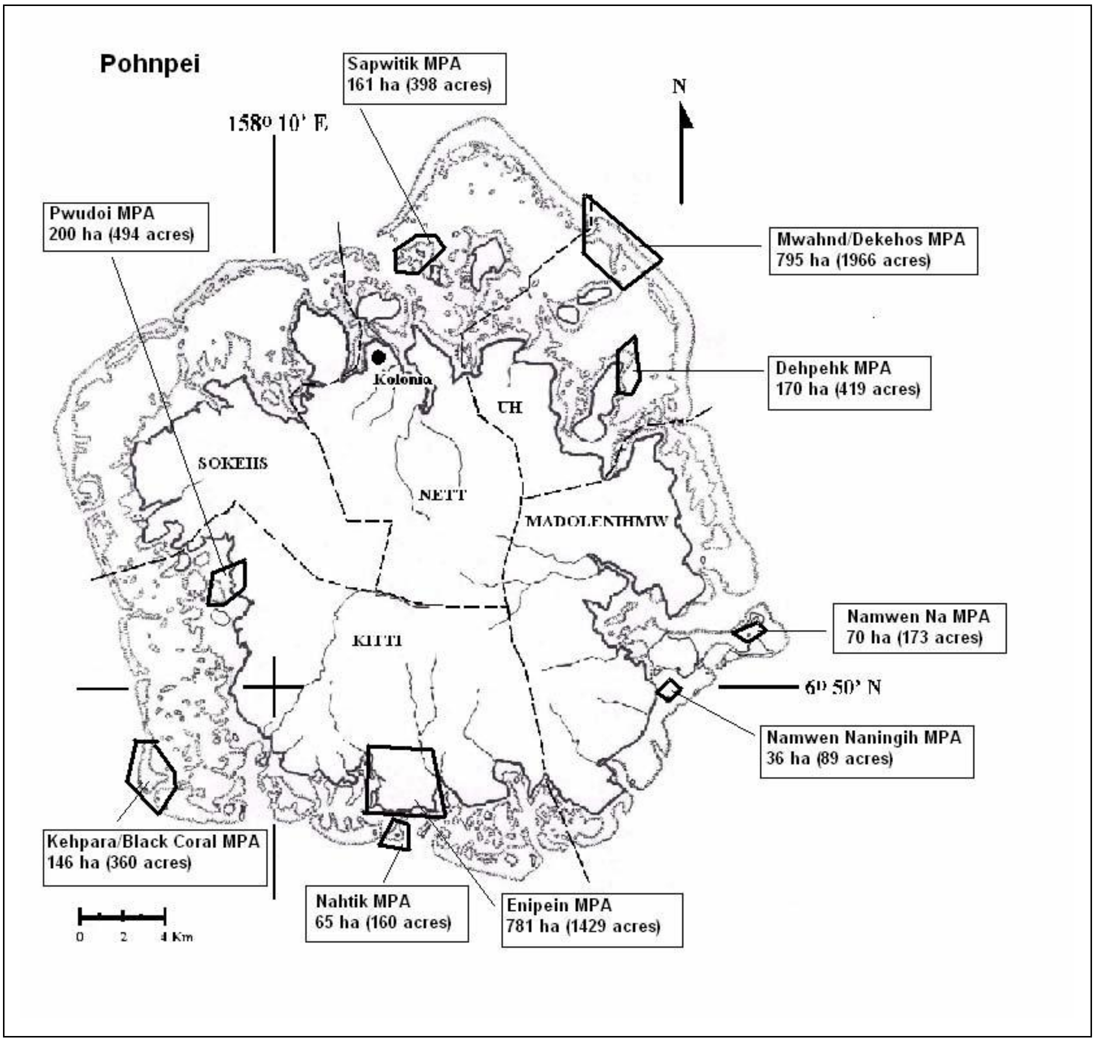


Figure 1.11: Map of Pohnpei Island and lagoon systems showing 9 Marine Protected Areas (MPA) and their sizes in hectares (ha) (Bourgoin & Joseph, 2008)

1.6 Conclusion

A timeline of past and recent events of the Pohnpei Lagoon showed how humans used and threatened the coral diversity and fish populations. Historical records from archaeological research and oral history show that there was intensive human labour on the east coast of Pohnpei from the building of Nan Madol (900 A.D-1700s), traditional fish traps (1600s-1700s), dredging of mangrove estuaries (1800s), World War II (1900s), and to the 21st century with sedimentation, overfishing, and pollution.

Evidence from the 1600s-1700s of human impact consists of the finishing stages of construction of the Nan Madol complex, hand dug mangrove forest estuaries for canoe channels, and fish traps made from basalt stones and coral rubble which were being constructed in mangrove estuaries adjacent to fringing reefs around the Pohnpei Lagoon (US Army Corps of Engineers, 1986). Corals were used as construction materials between the heavy basalt stones stacked on top of each other. Corals were also used to fill inside the walls to form a dry surface several feet above high-tide level. The historical record since the 1600s does provide evidence that there was intensive human labour on mangrove estuaries, and fringing and barrier reefs around Pohnpei Lagoon, affecting the marine environment.

In the mid 1700-1800s, the population of Pohnpei was severely depleted by foreign disease introduced by the European whaling ships. One would assume that with a reduced population in Pohnpei the marine environment might have seen less harvesting and exploitation. Anchoring of the whaling ships inside the lagoon was likely to be the only evidence of human impact on the reefs at that time.

Terrestrial and coastal development began in the late 1800s to the middle of the 1900s for roads, pathways, seaports and airstrips. This was a time when heavy machinery was introduced to clear terrestrial and marine coastal areas. Pohnpei's coastline of mangrove estuaries was flattened, extended, and dredged. Then World War II began in the Pacific, where Pohnpei Island was bombarded by dynamite on land and in the sea. It is evident that both the terrestrial and marine environment of Pohnpei faced serious environmental degradation by humans during WWII. Without research data on the coral loss and recovery period during that time I can only assume that the marine ecosystem was extremely threatened and then slowly recovered. Again, how the corals and fish recovered after the war is a sign of extreme resilience, to have thrived in such extreme conditions.

Coastal destruction continued into the late 1900s to the beginning of the 21st century. With increased population and becoming an independent nation, Pohnpei was to become the capital site of the newly formed government of the Federated States of Micronesia (FSM). Pohnpei's coastline of mangrove estuaries were again flattened, extended, dredged, and filled to accommodate the growing private business, government, and public sectors. In response to serious threats to the marine ecosystem, the Pohnpei State Government created 7 Marine Protected Areas (MPA) consisting of mangrove forest reserves, coral islets, and outer-low-lying atolls in 1999 (Marine Sanctuary and Wildlife Management Act, 1999). The marine flora and fauna were also protected under seasonal bans, with restrictions on sizes and types of marine species (Marine Resources Conservation Act, 1981). However, marine regulations were poorly enforced and monitored making the MPAs paper parks. In 2001, the Conservation Society of Pohnpei (CSP) with community and government support, established 4 MPAs (Joseph et al., 2003) bringing a total of 11 MPAs for Pohnpei. Thus, the enforcement and scientific monitoring of the MPAs was strengthened. However, there is still more work to be done in order to understand the effect of historical human impact events and present climatic conditions (ENSO phenomena). Such human threats in the Pohnpei Lagoon can be reversed with local traditional knowledge, scientific monitoring, and understanding of the ocean and weather conditions affecting the marine ecosystems.

1.7 Research aim and objectives

There is a need for study on the human and natural influences on Pohnpei's existing Marine Protected Areas (MPA) before further MPAs are created. Pohnpei, like many other Pacific Island countries, is on the verge of creating new MPAs. However, although the management aspects are in place with traditional practices, there is a lack of scientific monitoring, technical support, and funding (Raynor et al., 2004; Rhodes et al., 2005).

Although little can be done to mitigate the adverse effects of natural climate factors, much can be done to control the additional stress caused by human factors (Pararas-Carayannis, 2003).

The general aim of this research was to investigate the natural and human influences that are affecting the MPAs and the marine environment in the Pohnpei Lagoon. The ultimate goal of this study is to contribute to the overall use, function, evaluation and management of Pohnpei's marine environment over the long-term.

The specific objectives of this thesis were to:

1. Review the literature on human impacts and compare it with study findings on ocean and weather conditions for Pohnpei’s marine environment;
2. Investigate the impact of natural influences (climatic and oceanographic data) on Pohnpei Lagoon;
3. Collate existing reports and data on corals, fish, and sediment in Pohnpei’s marine environment;
4. Make recommendations to the government and marine managers on the monitoring and evaluation of the marine environment.

Chapter Two: Literature Review

2.1 Introduction

Chapter two gives a brief overview of the weather and ocean patterns in the western pacific region, how the weather and ocean patterns of Pohnpei's is affected by the ENSO variability, thus, affecting the terrestrial and the marine environment of Pohnpei. It will also discuss how the ENSO events in the world have caused mass coral bleaching events and how Pohnpei's location is influenced by the "Western Pacific Warm Pool" (WPWP), where sea surface temperatures are known to be over 29°C. It also examines the types of human factors that attributed to coral bleaching, such as sedimentation, overfishing, and pollution. This chapter will also discuss how corals can also recover by "symbiont shuffling". It will also highlight how ENSO events may affect corals and reef fish relationships. Lastly, I will examine how Pohnpe's reef may have the ability to recover from climatic conditions and human disturbances as experienced by the Tanzanian coral reef studies and findings.

2.2 Ocean, weather, and climate

2.2.1 Regional and climate

The climate of the Pacific Island regions is ocean-dependent. The specifics of tropical climates are influenced by various environmental conditions causing rainy seasons and drought events. The equatorial regions follow inter-annual changes associated with El Niño which affects the natural processes from sea level, winds, precipitation through air and water temperatures (Federated States of Micronesia Sea Level and Climate Change Project, 2006). For example, the winds in the western Pacific tend to be northeasterly with strong sea surface temperatures (SST) north of the equator (Wang, Xie, & Carton, 2004) during New Zealand summer months, and variable throughout the winter months suggesting weaker SST in the southern hemisphere (Baynham, 1994). Normal wind velocity in the western Pacific rarely exceeds 3 ms^{-1}. However, a notable exception is the 'westerly wind bust', where westerly wind velocity exceeds 10 ms^{-1} (Eriksen, 1993). The westerly wind bust event lasts a few days or weeks, usually occurring in the months of November through January and is known to have a relationship with El Niño events.

2.2.2 Seasonal variations of land and sea

The following information in figure 2.1 gives the Pohnpei seasons and the effect as described in Chapter 1, that typical ocean and weather patterns have on the land and sea (National Oceanic and Atmospheric Administration, 1983; US Army Corps of Engineers, 1986; Holthus, 1986; de Korte & Meltofte, 1996; Buden et al., 2001; Raynor, 1991; Pohnpei Surf Club, 2008; Balick et al., 2009).

1. October-November: associated with the highest tides of the year; early season swells for surfing due to clean conditions since trade winds shift from northeast to southwest; surf swells from typhoon season coming from west, from North Pacific lows of Japan or trade winds swell from the east, the east side of Pohnpei gets large wave swells; beginning of yam season.
2. November-June: Strong northeasterly trade winds starting comeback.
3. November-December: "period of food scarcity" due to low numbers of fruit bearing trees; yam season; endemic Pohnpei pigeon breeding season and also pigeon hunting season (December only); most wave swells start to come from north in early December.
4. January: Rising or sprouting of new fruit on trees and breadfruit trees starting to develop at this time; Beginning of migration of reef fish species to spawning sites. Trade winds comeback.
5. February-March: Fish migration and spawning seasons, especially for groupers in Kehpara Marine Reserve beginning in early February; sales ban of any grouper fish; Sea birds migration and breeding season begins.
6. March-April: In late March maturing or ripening of fruit trees indicating major season around Pohnpei; sales ban of grouper fish at the end of April; light to moderate trade winds; certain species of reef fish start their migration to specific reef locations for their spawning period; sea birds begin nesting in islets and outer islands.
7. April-May: Wettest periods from heavy rainfall; trade winds begin to diminish in strength and last chance to catch waves at Palikir Pass before the end of April; shrimp of the ocean *Myacrobrachium* species, *Atyoida pilipes* or *Cridina* species (local name *likathapw en seth* or *luhr*) migrates from lagoons and up the rivers; final migration and spawning of certain reef fish and lobsters before end of May; young sea birds are sited in nests.
8. July: Lighter and more variable winds of the doldrums.
9. April-August: "time of plenty". Breadfruit, mangoes, Malay apples, Polynesian Chestnut, avacado, Seir en Wai, orange, and pandanus bear their fruits with shrub crops; Fattening time for birds.

10. June-August: Breeding and nesting seasons of sea turtles. It is illegal to take or kill any species of sea turtles in these months.

11. August-December: Harvesting pearl oyster is illegal in these months, as it is believed to be their spawning seasons.

12. December-January: Breeding and nesting season of sea turtles. It is illegal to take or kill any species of turtles in these months; most wave swells start to come from north in early December and the Palikir Pass.

The migration and spawning seasons for terrestrial and marine species have not been documented with the changing weather patterns of Pohnpei. The weather patterns and seasons are vital periods for production of future stocks for terrestrial and marine resources. It is important that future research takes full attention of such natural influences.

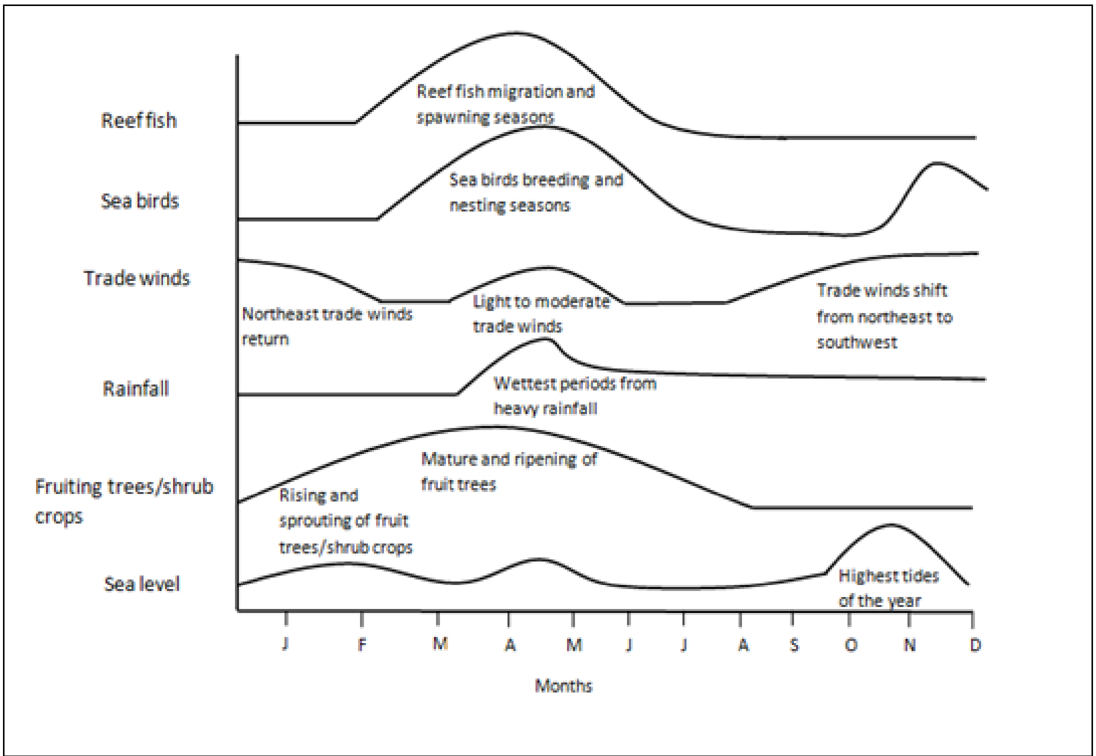


Figure 2.1: Pohnpei's seasons from various literatures

The weather conditions in the Federated States of Micronesia have become inconsistent over the past years with increased ENSO events (Federated States of Micronesia Sea Level and Climate Change Project, 2006) causing typhoons, flooding, and coral bleaching. Coral bleaching (loss of symbiotic algae) happens when mean sea surface temperatures increase by 1-4 °C for prolonged periods, and this is the likely case of El Niño events (Hoegh-Guldberg, 1999; Hughes et al., 2003). Such weather conditions might hold sway over daily life and cultural activities that are practiced over time with the fruit and shrub crop seasons (e.g. breadfruit and yam) (Balick et al., 2009) in accordance with the seasonal migration and spawning of the marine species of the Pohnpei Lagoon. The seasons are interconnected with other elements of the natural world of Pohnpei: the land, sea, winds, tides, fish, birds and plants. However, fruiting trees, fish spawning season, and trade winds are not the same every month and they are becoming different every year. One factor that may affect the fish spawning and migration season is the shifting of the fish direction passages. According to Holthus (1986), the direction of the fish passages may be one way, may be seasonally reversed, or may occur in both directions over short time periods.

2.2.3 ENSO

El Niño and Southern Oscillation are linked and referred to as ENSO. The identifiable sequence of ocean-atmosphere interaction events are respectively known as El Niño and La Niña (Sharp, 2003). La Niña is when normal environmental conditions return after El Niño events, and currents reappear with stronger and colder and stormier conditions. El Niño is when abnormal conditions of high pressure trade winds build up in the west and reverse from west to east causing unusually low sea levels and severe droughts (King, 2007).

El Niño happens every several years and can last a year or longer (King, 2007). Pohnpei encountered El Niño events in 1982-1983 (Raynor, 1991), 1997- 1998 (NOAA), and 2002 (Turak & De Vantier, 2005). Increasing temperatures more extreme weather events, sea level rise, changing rainfall patterns, and continued El Niño phenomena could potentially have severe consequences for islands (Nunn, 2004), especially for their corals and reef fish species.

2.2.4 Western Pacific Warm Pool

The "Western Pacific Warm Pool" (WPWP) is located in the western Pacific Ocean and it is one of three known ocean warm pool regions (Figure 2.2). The African warm pool is located off the eastern coast of Africa and the Caribbean warm pool is located in the Caribbean Sea (Carter, 1994). The African and Caribbean warm pool regions are temporary as they disperse during winter months while the WPWP is permanent. The WPWP is an area about the size of

Australia (Kleypas, Danabasoglu, & Lough, 2008). Warm pool regions are areas of the oceans where sea surface temperatures (SSTs) can exceed 29 °C. The warm pool regions comprise 25-45% of the tropical ocean surface, which is about 20% of the world's surface area (Scientific Plan for TOGA Coupled Ocean Atmosphere Response Experiment, 1990). The warm pool is caused by a shift in the easterly tradewinds deepening the thermocline and this causes an upwelling, therefore, keeping the SST warm in the western Pacific region (Baynham, 1994; Carter, 1994) and cold in the eastern Pacific (Wang et al., 2004; Wang & Picaut, 2004).

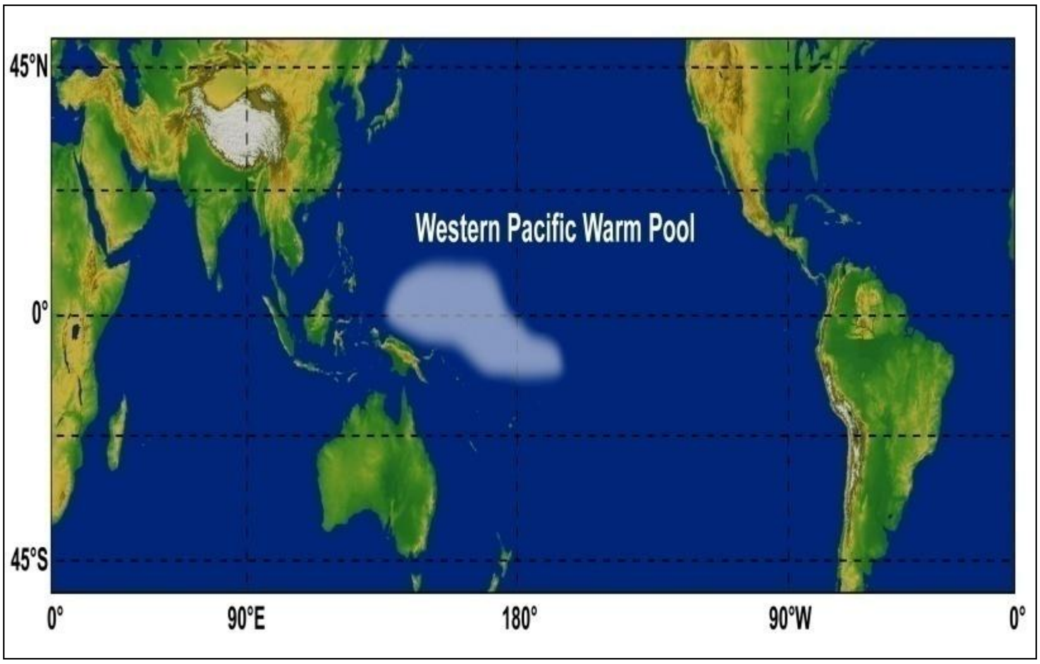


Figure 2.2: Western Pacific Warm Pool (Deyo, 2009)

A recent study by Kleypas et al. (2008) explained a much debated theory about the "ocean thermostat", where SSTs maximum in the open ocean should be around 30-31 C and this thermostat mechanism is important for coral reefs that are in the warmest regions (Western Pacific Ocean and Eastern Indian Ocean) limiting coral bleaching events. There will probably be less coral bleaching due to less warming in the future. Hoegh-Guldberg (1999) believes that the primary cause of regional bleaching or mass bleaching events is increased sea temperature. But according to Marshall and Schuttenberg (2007), using collected global data, regional bleaching is caused by warming of sea surface temperatures which are mainly caused by ENSO phenomena. It could be possible that future regional coral bleaching in the Western Pacific region (FSM States: Kosrae, Pohnpei, and Chuuk) will be protected by this "ocean thermostat". Whereas reefs in the western Pacific region evolved in naturally warm waters that will not warm much more in the future, this is opposite to the reefs that live in slightly cooler waters, like Hawaii. To the east of the Eastern Caroline Islands is Hawaii, which might face more significant warming. While great progress has been made, the WPWP is being debated by numerous scientists, about its size, maximum SSTs, depth of SSTs, and how the processes will be affected by global warming (Kleypas et al., 2008).

2.3 Corals and reef fish

2.3.1 Sclerectinia corals

Scleractinia corals are the main reef builders in Pohnpei and the Micronesian region (Turak & De Vantier, 2005). These types of hard corals are found in tropical waters. There are two groups of scleractinia corals;

1. Colonial corals found in clear, shallow tropical waters and are considered the world's primary reef builders.
2. Solitary corals found in all regions of the oceans and which do not build reefs (Cnidarian, 2009).

Corals grow best where the variation in water temperature throughout the year is slight and considerable amounts of sunshine penetrate through waters to encourage the growth of reef corals (Summerhayes & Thorpe, 1996). Corals' optimal temperature for growth is around 23-25 °C (King, 2007), but this can vary throughout tropical regions.

2.3.1.1 Coral bleaching

In 1998, tropical sea surface temperatures were the highest on record, topping a 50-year trend for some tropical oceans. This caused coral reefs around the world to suffer the most extensive and severe bleaching, and subsequent mortality on record (Reaser, Pomerance, & Thomas, 2000). This was caused by El Niño events (Hoegh-Guldberg, 1999; Hughes et al., 2003). Coral bleaching is when corals either degenerate or eject their symbiotic algae (zooxanthelle). The coral appears white (losing color) and eventually dies if prolonged stress factors are for more than a few weeks (Hoegh-Guldberg, 1999; King, 2007; Marshall & Schuttenberg, 2007). The zooxanthelle is dinoflagellate algae (genus

Symbiodinium) within the coral tissue containing single celled plants that produce food for the coral from sunlight (King, 2007).

The corals most affected by temperature increase are the genus *Acropora* corals, and they are most thermally vulnerable corals during bleaching events, according to Loya et al. (2001). Coral genera like *Montipora* show greater tolerance to coral bleaching and climate change (Hughes et al., 2003). Meanwhile, *Montipora* is a small and encrusting species, and has shown itself to survive better than *Acropora* which are branching corals (Sheppard & Obura, 2005). *"A minor and localized coral bleaching event involving Acropora species was observed at the northeastern barrier reef (Manta Road dive site) of Pohnpei in 2004, but the corals were fully recovered by 2005"* (Turak & De Vantier, 2005) (p. 58). Bleaching events in Pohnpei have been triggered by extreme freshwater runoff events rather than high sea temperatures, according to Turak and De Vantier (2005). In Palau, a local bleaching event occurred in 1998 causing widespread coral mortality in the inner lagoon, with coral cover still recovering today (Golbuu et al., 2007).

Hoegh-Gubldерg et al. (2007) believe that coral reefs are pressured by changes in ocean temperature, pollution, sedimentation, acidification, overfishing, oxidation stress, and the synergistic effect of some these problems may destroy reefs even when one cause by itself would not. Coral bleaching events vary because coral reefs are strategically located in different regions of the world with different ocean and weather conditions. Coral bleaching events have different survival rates in accordance with coral species type (Golbuu et al., 2008; Marshall & Barid, 2000), colony size (Ben & van Woesik, 2004), depth (van Woesik, 2001; Golbuu et al., 2008), flow rates (Nakamura & van Woesik, 2001), geographic location (van Woesik, 2001; Sheppard, 2003), habitat type, seasonal irradiance and temperature extremes (Golbuu et al., 2008), and *Symbiodinium* clade types (Rowan et al., 2007). Also, there are various disturbances (biological or physical) in spatial and temporal scale areas (Connell, 1978; Sousa, 1984); leading to dominance (predation and competition) of various marine species by recruitment and post-larval settlement (Gaines & Roughgarden, 1985).

National Oceanic and Atmospheric Administration (NOAA) are using a satellite to keep a watchful eye on the recent 2009 ENSO build up in the Pacific, predicting coral bleaching event. The NOAA Coral Reef Watch Program's satellite data provides current environmental information for coral bleaching events (National Oceanic and Atmospheric Administration Coral Reef Watch Program, 2009). However, climate forcing is "noisy" with various decadal and long term patterns, but never the less provides useful insights into where, and what to monitor that will help track the likely ecological processes (Sharp, 2003). Ponchaut, Lyard, and Le Provost (2001) stated that, *"the complexity of the distinct station might be related to the bathymetry, the meteorological effects, or the presence of ocean currents in the vicinity"* (p.85). Flooding, landslides, droughts and tropical storms are part of the natural disasters of the ENSO in the FSM. The 2008 Coral Reef Report for Pacific Island States suggests the global threat to coral reefs is associated with climate change, warming temperatures and ocean acidification (Waddell & Clarke, 2008). At the time of writing natural disasters had struck the Pacific region, such as tropical cyclones in the Philippines, Indonesia was hit by earthquakes, and low coral island of Tonga, Samoa, and American Samoa had just experienced a tsunami.

2.3.1.2 Symbiont shuffling

When reef building corals bleach they can also recover by "symbiont shuffling". This is an ingenious way in which an environmental stress may be replaced by one or more varieties of zooxanthelle (*Symbiodinium* symbiont Clades) that are more tolerant of the stress caused by bleaching (Rowan & Powers, 1991; Rowan et al., 1997). Rowan et al. (1997) suggested that symbiont shuffling occurs in corals that host dynamic multispecies communities of *Symbiodinium* symbiont Clades A, B, C and D. Rowan et al. (1997) believe that corals adjust to climate changes by recombining their existing host and symbiotic genetic diversities, thereby reducing the amount of damage that might occur from high temperature anomalies. Oliver and Palumbi (2009) believe that the symbiont clades are not only reflecting temperature, but other environmental stresses like sediment.

There are various zooxanthelle genotypes and clades. Two types, Clade C and Clade D, are discussed here. Clade D favors marginal habitats where other symbionts are poorly suited by conditions such as irradiance, temperature fluctuations, and sedimentation (Rowan, 2004; Oliver & Palumbi, 2009). Clade C is found in cooler habitats (Rowan, 2004). Clade D symbionts are the dominant are symbiont clade in corals of American Samoa (83%) diminishing in Palmyra, Fiji, and the Philippines (<1%) (Oliver & Palumbi, 2009). Along the coast of Panama Baker et al. (2004) surveyed ecologically dominant corals in the genus *Pocillopora* before, during and after ENSO bleaching, finding that *"colonies containing Clade D were already common (43%) in 1995 and were unaffected by bleaching in 1997, while colonies containing Clade C bleached severely. By 2001, colonies containing Clade D had become dominant (63%) on these reef*s*"* (p. 183). Baker et al. (2004) also noted that *"corals containing thermally tolerant Symbiodinium in Clade D are more abundant on reefs after episodes of severe bleaching and mortality, and that surviving coral symbioses on bleached reefs had more closely resembled those found in high-temperature environments"* (p. 187), where Clade D predominates. Other scientists argue that coral clades and subclades have different resistance to different stresses.

Corals routinely cope with environmental heterogeneities and survive the consequences (e.g., recover from coral bleaching) (Lien et al., 2007). Clade D symbiont corals may have become symbiont resistant, helping coral communities recover and might be more resistant to subsequent bleaching events caused by increased sea temperatures. Baker et al. (2004) believe that the genus *Pocillopora*, is the Clade D symbiont coral for the eastern Pacific region. A coral study is needed to find what types of clades are dominant in Pohnpei's Lagoon and how corals are coping with other stress-like events.

2.3.2 Reef fish

Reef fish will mean herbivorous fish in this review. In Pohnpei, the highest fish biodiversity is in the channels and outer reefs (Allen, 2005) due to the availability of food and shelter and diversity of substrata in healthy reef areas (Turek & De Vantier, 2005). Herbivorous fish such as the Acanthuridae (Tangs, surgeonfish, and parrotfish) and Scaridae (unicornfish) are highly targeted by local fishermen inside the Pohnpei Lagoon (Rhodes et al., 2005).

2.3.2.1 Reef fish and coral relationship

The worldwide coral bleaching events in the 1980's have increased attention to see the relationship between reef fishes and corals (Cheal et al., 2008). In Pohnpei, there has been no research on the affect of coral bleaching on reef fish in the Pohnpei Lagoon.

Ranges of herbivorous fish tend to protect corals from algal dominance by grazing on algal and fleshy macro algae (Pratchett et al., 2008). Studies have shown that reef fish increased in areas where corals bleached while in some areas fish numbers decreased (Cheal et al., 2008). Herbivorous fish (Acanthuridae and Scaridae) increased in abundance immediately after bleaching but decreased noticeably as the habitat eroded (Garpe et al., 2006). Studies have also indicated that fish abundance is greater with large areas of coral cover and fish numbers reduce with less coral cover. According to Holbrook, Russell, and Brooks (2008) fish assemblages are not sensitive to change in live coral cover over a wide range of areas. Both species richness and total abundance of fish were unchanged with an increase in cover of live coral, meaning that fish communities may be resistant to decline over a wide range of living coral cover prior to rapid collapse as coral becomes scarce. Hoegh-Guldberg (2007) mentioned, using current data on global climate change, affects fish metabolic rates and behavioral patterns of fish communities with bleached corals.

Fishing communities and likely many other residents, still perceive Pohnpei's marine resources as abundant and inexhaustible while there are clear signs of reef fish overexploitation (Rhodes et al., 2007). So, it is unclear whether the fish community is likely to retain a trend of resistance and resilience as the abundance of coral declines with the increasing climate-driven environmental changes (Holbrook et al, 2008). What is known is that fish diversity will be maintained during coral decline while fish abundance will decrease (Cheal et al., 2008). Therefore, the tropics need research on fish physiology and ecology since little research has been conducted there. Thus, researchers will be able to more accurately predict future situations (Hoegh-Guldberg, 2007).

2.4 Local actions to solve local problems

2.4.1 Northern Tanzania coral reefs

Study was done on climate changes and associated disturbances on coral reefs in northern Tanzania by five researchers (McClanahan et al., 2009). With respect to the current and future health of earth's coral reefs, the authors note that Jones et al. (2004) have argued that *"climate overrides and undermines local resource use and management"* (p. 758), and they say that Aronson and Precht (2006) have thus further argued that "*this position emphasizes the need for management of the atmosphere at the global scale*" (p. 758), if we are to preserve the planet's corals.

McClanahan et al. (2009) surveyed the coral reefs of northern Tanzania in 2004/05 *"with the aim of comparing them over an ~8-year period during a time of increased efforts at fisheries management and the 1998 El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole coral mortality event that caused 45% mortality in northern Tanzania and much of the Indian Ocean"* (p. 758).

The five researchers report that changes associated with both management, its absence, and the 1998 ENSO were found, but they say that the changes were generally small and that *"ecological measures indicated stability or improvements"* over the period of their study. In fact, they state that *"northern Tanzania reefs have exhibited considerable resilience and in some cases improvements in reef conditions in the face of dire global predictions for overfishing, climate change, and their interaction"* (p. 769).

This means that in light of their most interesting findings, the international team of Kenyan, Swedish, Tanzanian, and American scientists conclude that *"Tanzanian and possibly many other reefs that exhibit similar environmental conditions have the ability to recover from large-scale climatic and human disturbances"* (p. 770), and they thus urge local action to deal with local problems as the best formula for protecting earth's coral reefs in the days and years to come.

2.5 Human impacts in the 21st century

2.5.1 Coral dredging

The introduction of heavy machinery for infrastructure development in Pohnpei created widespread dredging of mangrove forest swamps and fringing reefs for coral rubble and sand mining. The clearing of mangrove swamps for dredging have also led to coastal development along the mangrove forest for landfills: from residential areas, commercial lease, and boat channels with dikes. Coral dredging is undertaken in many tropical countries for road construction and buildings. The government has enforced laws on earth moving permits in Pohnpei, but monitoring is not followed thoroughly, sometimes leading to unnecessary dredging of corals outside permitted boundaries.

The growing population and coastal development are influencing water borne diseases. Water quality testing showed faecal coliform levels present around coastally developed areas. This is a health hazard concern at near-shore areas (Cowan & Clayshuttle, 1980). Presently, the Pohnpei State Environmental Protection Agency (EPA) has been conducting water testing and issuing warnings for coastal areas with poor water quality. The poor water quality can be attributed to a variety of poor land use practices: pig pens along rivers, streams, and coastal areas; discharge of waste into estuaries and bays; leakage of waste materials from waste management facilities; planting of *sakau* (*Piper methysticum*) or kava in the upland forest (Victor et al., 2006); and clearing of mangrove forests and estuaries for fringing reef dredging (Maharaj, Naidu, & Hatch, 2004). Many other poor land practices that have not yet been investigated may have other influences as well.

The main roads on tropical countries are filled using dredged corals, compacted, and then paved over. Dredging and coral reef mining have also caused significant impacts on marine biota around Pohnpei (Maharaj, Naidu, & Hatch 2004) as well as sand mining in the lagoon (Turak & De Vantier, 2005). Human impacts, like coral dredging, can also trigger coral bleaching by silting of corals (Victor et al., 2006; Richmond et al., 2007). Dredged materials in fringing reefs were of bio-clastic origin mixed with volcanic mud and gravel (Tsuda et al., 1974).

A request for active and inactive dredging data from the Office of EPA was requested for this study, but never received. There were various communications between myself and the Office of EPA that were never fruitful. I then relied on dredging reports from the Pacific Islands Applied Geoscience Commission (SOPAC) and other secondary literature.

2.5.2 Sedimentation

Pohnpei over the past several decades has experience increased sedimentation, particularly to near shore coastal marine communities. Sedimentation has been linked to inappropriate land use practices, notably the construction of roads, clearing for infrastructure and cash crops, and dredging/coral reef mining in the lagoon for sand and fill (Turak & De Vantier, 2005). Increased sedimentation, particularly to near-shore coastal marine communities has been happening over several decades in Pohnpei (Victor et al., 2006; Richmond et al., 2007). There are about 40 streams and rivers that flow into the Pohnpei Lagoon (Balick et al., 2009) which are constantly silting coastal areas. Sedimentation is part of the natural process; however, the developments of coastal areas, and planting and building near streams and rivers have speedily reversed the natural flow, thus affecting the marine environment.

Sedimentation follows inappropriate land use, notably the construction of roads, clearing for infrastructure and cash crops (Turak & De Vantier, 2005). For example, the Tekehtik causeway road towards the Pohnpei international airport has prevented the natural flow of water, thus creating heavy sediment build up on one side while both sides are slowly eroding away (Smith, 1998). There are only two culverts in Tekehtik for flushing of water, which is proven to be too few for such a wide body of water. Not only has the natural flow of water ceased, but there is also the loss of reef fish migration pathways and spawning sites. The local fisherman catch fish by gill nets, fish traps and spears on various coastal reefs and reef holes, but this is now being threatened by sedimentation through coastal development.

The deforestation for the planting of kava (*Piper methysticum*) (Pohnpeians call it, *sakau)* in the Pohnpei watershed forests have increased sediment flow that is silting the corals in the lagoon (Victor et al., 2006). Aerial surveys of the island showed progression of forest percentage cover loss over the years. In 1975 43% of the forest cover was lost while in 1995 15% and the last survey was done in 2002 with 12% loss (Trustrum, 1996; Raynor et al., 2004). Deforestation of the watershed forest is also used to convert to agriculture areas for food producing agro-forests (Balick et al., 2009). Victor et al.'s (2006) study on sedimentation in Pohnpei at the Enipein Mangrove Forest reserve found that the sedimentation rate was high in comparison with other Micronesian islands, attributable to inappropriate land uses in the catchment. The rapid population growth, escalating dependence on subsistence farming and fisheries, and a growing cash economy are some of the human stressors contributing to coral loss in Pohnpei (Richmond et al., 2007).

The rates of deforestation have slowed by combined efforts of governments, and local and international organizations, through a community-based effort campaign called, "Grow (sakau) Low" (Buden et al., 2001). The campaign is aimed at discouraging the planting of kava in the watershed areas and encouraging planting kava at low altitudes with vegetable seedlings as an alternative source of income. Sediment rates are also being monitored by local and international agencies to find solutions for coral dredging issues.

2.5.3 Overfishing

Pohnpei Lagoon is experiencing over-fishing by local fishermen and overfishing has also led to the collapse of some reef areas around the world (Rhodes et al., 2007). In Pohnpei, coral reefs have not only been disturbed by heavy dredging but by over-fishing as well and other forms of destructive fishing techniques which have been linked to the degradation of coral reefs.

Studies on targeted reef fishes have indicated that over-fishing is contributing to the decline of age and size of targeted reef fishes in Pohnpei. Overfishing and other forms of destructive fishing techniques have also been linked to the degradation of coral reefs from loss of herbivorous fish that feed on algal growth on corals (Cheal et al., 2008), shifting from coral to more algal dominance (Hughes et al., 2007). This change is from an insufficient number of herbivorous fish as a result of overfishing (Hughes et al., 2007). Herbivorous fish, such as the Acanthuridae (Tangs, surgeonfish, and parrotfish) and Scaridae (unicornfish), are highly targeted by local fishermen by nighttime spear fishing inside the lagoon (Rhodes et al., 2005). There are other types of migratory fish, such as Mugiladae (mullet), which migrate each month on new moon phases, and *Siganidae* (rabbit fish, which follow the same routes moving along reef flats and scatter in fringing reefs (US Army Corps of Engineers, 1986). The parrot fish family is the most abundant at all zones throughout the reef system (US Army Corps of Engineers, 1986). Night spear fishing, which is done by holding a spear in one hand and an underwater flashlight in the other, is claimed to be the most overexploited type of fishing technique in Pohnpei. The Pohnpei government has introduced laws to ban such fishing technique in past years, but to no avail. The fish catch was significantly greater during periods of low lunar illumination and it is believed that low lunar illumination affects how zooplankton grows and increases fish feeding (Rhodes et al., 2007). Rhodes et al. (2007) estimate that over 65% of fishers targeted inside reef locations, while 33.7% fished either in outer reef locales or a combination of both (1.1%). Thus, there is a greater fishing effort within the lagoon and consequently lower overall fish abundances observed in the lagoon. Today, predator fish species are now being locally threatened just as the herbivorous fish have been by the increase of sport fishing popularity. The increased popularity of sports fishing of predator fish might also affect predator fish populations. Pohnpei's sport fishing is presently unregulated by the government of Pohnpei.

The most obvious evidence of overfishing on a tropical marine species was in the case of the giant clams, *Tridacna gigas*. Giant clam numbers in the wild are greatly reduced by extensive over-fishing for food and the aquarium trade. Giant clams can grow over 1 m in length, weigh more than 200 kilograms, and are usually found in shallow reefs. Giant clams have a life span of about 40 years (Tridacna gigas, 2009). You can find large shells around the coastal areas of Pohnpei, but not in the water anymore. The loss of giant clams in Pohnpei waters may have been caused by local over-fishing, dredging of fringing reefs, or natural predators. The knowledge of giant clam (*Tridacna gigas*) disappearance may require extensive investigation. The over-harvesting of marine species by fishermen, illegal sales of marine products by fish markets, and illegal exportation of marine related goods by individuals are an on-going problem (Rhodes et al., 2005; Phillip Jr., 2006).

2.5.4 Crown-of-thorns

There have been outbreaks of Crown-of-thorns (COT's) star fish in Pohnpei since the 1970s (Randall, 1980) and these can also lead to decline of corals. The COT outbreaks have been linked with overfishing of keystone predators (e.g. Giant Triton shellfish *Charonia Tritonis* and various fishes - ballistids, lethrinids, lutjanids) and changes in water quality in river run-off, both of which may implicate Pohnpei in supporting their population growth (Rhodes et al., 2005; Turak & De Vantier, 2005; Victor et al., 2006). COT's predation on preferred corals, particularly species of *Acropora*, and avoidance of un-preferred species, notably poritids, is causing shifts in Pohnpei's coral community structure (Turek & De Vantier, 2005).

Disturbances like coral bleaching and outbreaks of COT's will damage the coral tissue, but leave the hard skeleton intact (Cheal et al., 2008). In some reef areas inside the Pohnpei Lagoon the COT outbreaks have become a serious management concern. There are a few locally controlled programs to remove the COT's from the reefs in Pohnpei, but eradication protocols are limited by funding, collaboration between organizations, and education awareness.

2.5.5 Mari-culture of marine species

The Pohnpei Lagoon has experienced various mari-culture species, first with the introduction of trochus (*Trochus nilocticus*) for trochus fisheries in the 1930s-1940s during the Japanese ruling period (Smith, 1988), followed by sea sponges (1940s-present), seaweeds (1980s), black lip pearl oysters (*Pinctada margaritifera*) (1940s-present), giant clams (family Tridacnidae) (1940s-present) for reseeding and live coral (1940s-present) for aquarium trade. The trochus was to become an important commercial species for the production of buttons and jewelry for export. It also provided a source of income for fishermen/farmers

(Smith, 1988). The trochus fisheries generated interest for studies on its growth, culture, and management (Smith, 1979; Hesling & Hillmann, 1981; Heslinga et al., 1984). However, the trochus fisheries declined after the Pacific War (McGowan, 1958). Today, the trochus fisheries are still on-going, but only in accordance to harvest seasons dictated by the Pohnpei State Marine Resources Office. Management measures and seasons of trochus are in place, but studies on potential effects of trochus populations on reefs are not known.

The sea sponge, seaweeds, black lip pearl oysters, giant clams, and live corals also followed the same trends as commercial fisheries with the idea of export (sea sponge, seaweeds, black lip pearl oysters and live corals) and reseeding programs (giant clams). However, seaweed farming was not successful after a pilot project in the 1980s and was banished (Smith, 1992). The rest of the marine commercial species declined in production in the late 1980s and were revived again in the late 1990s with better technical experts and funding. At present, trochus, sea sponge, black lip pearl oysters, giant clams, and live corals are still commercially viable with small mari-culture farms and aquaculture facilities in Pohnpei. The management, regulations, and harvest seasons are still in place, but are poorly regulated and monitored. For example, the governments are for economic development of the marine environment, but lack policy and monitoring measures on the amount of size, space, and density for mari-culture as well as aquaculture facilities on a reef site.

The lack of regulations and monitoring may have local effects, from effects on mari-culture and aquaculture ventures leading to loss of nutrients in the water column and outbreak of diseases (Folke & Kuatsky, 1989). For example, mari-culture studies of mussel farms indicate that mussels can compete with the marine species of the local area for food, thus altering the natural reproduction of the site (Folke & Kuatsky, 1989). In New Zealand, mussel farming is a million dollar industry and requires sustainable farming and monitoring techniques. An investigation of potential effects on the marine environment by mari-culture and aquaculture is needed for the Pohnpei Lagoon.

2.6 Discussion

The lack of investigation and understanding of the relationship between reef fish and corals before and after coral bleaching events, along with human threats in the Pohnpei Lagoon needs to become a priority. The recognised threat by natural climatic variability, particularly ENSO, may pose a significant threat to the scleractinia corals in Pohnpei and the Micronesian region. While coral bleaching of *Acropora* genus is widely studied it might also shed a light on how it may be resilient in Pohnpei. However, examining past historical events, *Acropora* and *Porites* may have become dominant corals possibly by chance due to ideal water temperature, predation from Crown-of-thorns (COTs), or ideal weather conditions. This is unlike *Acropora* corals in the Cosmoledo and Aldabra atolls of the Indian Ocean, where *Acropora* corals are believed to suffer from coral mass mortality events due to reproduction and to dispersal failure leading to slim distribution and species loss. *Acropora* corals in Cosmoledo and Aldabra atolls have significantly dropped by past and on-going increases of sea temperatures attributed to ENSO events (Sheppard & Obura, 2005). The authors believe that the corals in Cosmoledo and Aldabra atolls will decline in the future due to reproduction and dispersal failure by the coral mass mortality events, leading to loss of coral species distribution.

Coral bleaching in the Pohpei Lagoon is attributed to past, present, and on-going activities which include coral dredging for coral rubble, sedimentation from poor land use practices leading to outbreaks of Crown-of-thorn (COT) starfish, over-fishing of herbivorous fish, mari-culture and aquaculture of marine species. However, corals without regular flushing will in turn bleach according to the reef location and exposure to various elements. Pohnpei Islands' unique physiographic and climatic conditions could be the key to coral reef survival of the Pohnpei Lagoon, where corals inside the lagoon are protected by the regular freshwater flushing of rivers and streams, dense mangrove forests, seagrass beds, underwater springs, intricate reef patches, and the barrier reef.

In contrast to the situation in the Pohnpei lagoon, regional coral bleaching is attributed to the western Pacific Warm Pool and ENSO conditions. However, from the literature review coral bleaching events in the western Pacific region can be attributed to cooling of sea surface temperatures (SSTs) not increased warming of the WPWP (Kleypas et al., 2008), while the warming of SST in the cold Eastern Pacific region may be attributed to coral bleaching events. Coral reefs in the western Pacific region evolved in naturally warm waters and may only bleach if warming of waters becomes cooler, whereas, warming of water in the future may significantly threaten the reefs of Hawaii, which is in the east of the Western Pacific Ocean, and is to the east of the warm pool. The trade winds from the northeast are an important source for coral growth since the east trade winds drive the warm surface water near the equator in a westward direction (Denny, 2008). Pohnpei's reef may have the ability to recover from climatic conditions and human disturbances, similar to the Tanzanian coral reefs. However, further research and investigation on the human influences that is coupled with natural influences of the ocean and weather (Western Pacific Warm Pool); ENSO conditions) is needed for the future understanding of coral diversity and fish populations. The next chapters will discuss past, present, and recent investigations to help with future coral diversity and reef fish populations of the Pohnpei Lagoon.

2.7 Conclusion

The Western Pacific region of the Micronesian islands appears to have suffered relatively few episodes of regional coral bleaching events (Kleypas et al., 2008), a phenomenon that has damaged reefs in other areas where temperature increases have been more pronounced (Wilkinson, 2004) with ENSO events. The Western Pacific Warm Pool (WPWP) is believed to have had its warm sea-surface temperatures raised little since the 1950s. It is possible that low levels of coral bleaching events in Micronesia are possibly due to low reliability reporting; however, observation and studies show consistent results in Micronesia and nearby regions (Kleypas et al., 2008). The weather and climate at Pohnpei is strongly affected by ENSO variability. Coral bleaching is not necessarily temperature related, as there are other factors. However, when corals bleach they recover by symbiont shuffling. This is an ingenious way in which corals replace symbionts since corals host a dynamic multispecies community of symbiont type clades (A, B, C and D) during subsequent bleaching events caused by increased sea temperatures and human factors. Ranges of herbivorous fish tend to help corals by grazing on algal dominant areas, and it is unclear whether the fish community is likely to retain a trend of resistance and resilience as the abundance of coral declines with the increasing climate change. Pohnpei's northern and eastern inshore reefs are degraded (Turak & De Vantier, 2005) by human impacts such as sedimentation, coral dredging and over-fishing, whereas, the outer reefs appear to be well off being exposed to oceanographic currents. However, outer reefs have been hampered by the foreign fishing purseiner fish nets caught along barrier reefs or ship groundings by various local boats and commercial ships.

While great progress has been made in understanding the WPWP, it is also being debated by numerous scientists regarding what the upper SSTs might be in the western pacific region, what processes control warm pool limits, and how the processes will be affected by global warming (Kleypas et al., 2008). In summary, the present scientific literature presents convincing arguments that many reefs in the world exhibit similar environmental conditions and have the ability to recover from large-scale climatic and human disturbances. It is unclear whether corals and reef fish can cope with the increasing pace of climate change; however, humans have greatly impacted on the coral diversity and fish populations in the Pohnpei Lagoon. Future research into rapid recovery of coral reefs needs further undertaking before the loss of coral reefs and fish populations worsens. The need for local action to deal with local problems is the best formula for protecting earth's coral reefs in the days and years to come (McClanahan et al., 2009).

Chapter Three: Methodology and Timeline of Events

3.1 Introduction

My research methods consist of combining local reef, fish, and sediment monitoring data with historical sea surface temperatures (SSTs), regional buoy ocean and weather data, and satellite data projects of SSTs of the western Pacific Ocean. The combined data is essential for the understanding of the coral bleaching extent and intensity during over-fishing, sedimentation, and extreme weather events. Such combined data not only help forecast bleaching sites, but also provide a better understanding of the impacts on the marine environment. Collection and analysis of data related to Pohnpei's Marine Protected Areas (MPAs) was done as follows:

1. Finding data from Pohnpei MPAs and monitoring sites;
2. Collecting data about meteorological and oceanographic patterns of the western Pacific Ocean and the Pohnpei lagoon from local and international organizations;
3. Gathering of secondary materials such as reports, articles, and research about the Pohnpei MPAs and developing a timeline of significant ecological events that have impacted the MPAs and marine ecosystems;
4. Investigating trends from natural and human factors that correlate with the decline in coral and reef fish diversity in the MPAs and lagoon recorded by underwater observation were also investigated;
5. Analyzing data statistically using "R" software to see any trends in the western Pacific Ocean that might be affecting the MPAs in the Pohnpei lagoon through natural influences.

3.2 Pohnpei's marine protected areas and monitoring sites

The Conservation Society of Pohnpei (CSP) with local, regional and international agencies has undertaken biophysical monitoring of coral and fish in five of the Marine Protected Areas (MPAs) over eight years since 2001 (Table 3.1). Seagrass beds and sediment monitoring sites have been included in the CSP biophysical monitoring since 2008. However, both seagrass and sediment monitoring data sites are outside the MPAs.

Table 3.1: Marine reserves for which monitoring data are available (Marine Sanctuary and Wildlife Refuge Act, 1999)

MPA	Km^2	Established	Main characteristics
Mwahnd/Dekehos	8	2001	General (coral reef ecosystem biodiversity), tropical vegetation, rocky shore, and manta ray feeding area and dive site.
Dehpehk	2	2001	General (coral reef ecosystem biodiversity), tropical vegetation, rocky shore, mangrove dwelling organisms
Nahtik	1	2001	General (coral reef ecosystem biodiversity), sandy beach islet, bird nesting area in about 3 dwarf mangrove trees.
Kehpara	1	1999	General (coral reef ecosystem biodiversity), grouper spawning aggregation site, tropical vegetation, rocky shore, and cultural heritage.
Sapwitik	2	2001	General (coral reef ecosystem biodiversity), rabbit fish spawning ground, bird nesting area, tropical vegetation, and rocky shore.

The data available for the five MPA monitoring sites include coral and fish data. The profiles of the five monitoring MPAs (Table 3.2-3.6) indicate population numbers, stakeholders, types of infrastructure or facilities that are available and what types of transportation can be used to access each MPA and were compiled from the Marine Sanctuary and Wildlife Refuge Act (1999) and Federated States of Micronesia Census report (2000).

Table 3.2: Kehpara (Black Coral) Island Marine Protected Area

Location	West Coast of Kitti Municipality
Population (FSM Census FY 2000)	4
Stakeholders	***Type***
Kehpara (Black Coral Island)	Privately owned
Kitti Municipal Office	Local Government
Pohnpei State Marine Resources Office	State Government
Dept. of Land and Natural Resources	State Government
Conservation Society of Pohnpei	Local non-profit organisation
Village organizations	None
Infrastructure and facilities	Water catchments and local bungalows
Transportation	Boats and canoes

Table 3.3: Nahtik Island Marine Protected Area

Location	Southeastern Coast of Kitti Municipality
Population (FSM Census FY 2000)	0
Stakeholders	***Type***
Kitti Municipal Office	Local Government
Pohnpei State Marine Resources Office	State Government
Dept. of Land and Natural Resources	State Government
Conservation Society of Pohnpei	Local non-profit organisation
Enipein Powe	Village Organisations
Enipein Pah	Village Organisations
Mwakot	Village Organisations
Soumwei	Village Organisations
Infrastructure and facilities	None
Transportation	Boats and canoes

Table 3.4: Sapwitik Island Marine Protected Area

Location	Northern Coast of Nett Municipality
Population (FSM Census FY 2000)	2
Stakeholders	***Type***
Etscheit family	Privately owned
Adams family	Privately owned
Nett Municipal Office	Local Government
Pohnpei State Marine Resources Office	State Government
Dept. of Land and Natural Resources	State Government
Conservation Society of Pohnpei	Local non-profit organisation
Lenger Island community	Village Organisations
Parem Island community	Village Organisations
Infrastructure and facilities	Water catchments and local bungalows
Transportation	Boats and canoes

Table 3.5: Dehpehk Island Marine Protected Area

Location	Northeast coast of U Municipality
Population (FSM Census FY 2000)	85
Stakeholders	***Type***
U Municipal Office	Local Government
Pohnpei State Marine Resources Office	State Government
Dept. of Land and Natural Resources	State Government
Conservation Society of Pohnpei	Local non-profit organisation
Dehpehk Island community	Village Organisations
Takaieu Island community	Village Organisations
Infrastructure and facilities	Water catchments and concrete buildings
Transportation	Boats and canoes

Table 3.6: Mwand (Dekehos) Island Marine Protected Area

Location	Northeastern coast of U Municipality
Population (FSM Census FY 2000)	109
Stakeholders	***Type***
U Municipal Office	Local Government
Pohnpei State Marine Resources Office	State Government
Dept. of Land and Natural Resources	State Government
Conservation Society of Pohnpei	Local non-profit organisation
Mwand Island community	Village Organisations
Infrastructure and facilities	Water catchments and concrete buildings
Transportation	Boats and canoes

3.3 Biophysical coral and fish data collection methods

The Conservation Society of Pohnpei (CSP) biophysical coral and fish monitoring method is to look at long term trends of coral reef health and diversity (Bourgoin & Joseph, 2008), while Turak and De Vantier (2005) documented the number of coral genera. Allen (2005) looked at the amount of reef fish diversity for Pohnpei and Rhodes et al.'s (2007) fish market surveys followed CSPs long term goals for fish diversity and population.

Turak and De Vantier's (2005) were contracted by CSP to do a one month Rapid Ecological Assessment (REA) of Pohnpei Lagoon and outer islands. The 28 coral survey stations are used by Turak and De Vantier (2005) for Pohnpei Lagoon (Figure 3.1, Appendix 1). The REA was to provide a detailed coral list of findings as part of the biological surveys done within and adjacent to, the MPA networks of CSP. Turak and De Vantier's (2005) coral survey method consisted of scuba diving at shallow stations <10 m depths and deep stations >10 m depths. Coral stations covered an area about 5,000 m^2, approximately 10,000 m^2 in each station. The coral stations included a broad range of reef habitat types in relation to different environmental conditions (slope angle, depth, current and wave exposure and distance from shore).
Allen's (2005) reef fish survey method consisted of underwater observations for about 75 minutes made during a single dive at each station site (Figure 3.2, Appendix 2). The technique involves rapid descent to 30-55 m, then a slow ascent back to the shallows. The shallows' 2-15 m depth zone usually harbors the highest number of species and the majority of time was spent in the shallow zones. There were approximately 52 hours of scuba diving for the fish surveys to a maximum depth of 55 m.

Bourgoin and Joseph's (2008) survey report was based on CSP's biophysical monitoring methods. The fish monitoring method used the stationery diver method of Bohnsack and Bannerot's (1986) visual censuses on selected individual sample reef sites, within and outside the reserves. In each sample, divers identified targeted fish species, counted individuals, and estimated the mean, minimum and maximum sizes seen in the transect lines (Bourgoin & Joseph, 2008). Total length (TL) of the surveyed fish was estimated to the nearest centimeter, counting 17 moderately sized reef fish species (≥10 cm total length, TL) from September to November 2004 and the 19 larger sized reef fish species (≥ 20 cm total length, TL) from December 2004 to February 2005. Transect tapes were laid randomly at fixed GPS points. Surveys for moderately sized species had two sets of five replicate 250 m^2 (50 m X 5 m) belt transects, for a total of ten samples taken inside marine reserve and non-marine reserve areas. Transect lines were laid parallel to reed drop-off areas at 8 – 10 m depths. Divers recorded targeted fish species lists within 2.5 m – 5 m on either side of the transect line. Surveys of large sized fish were at 5 and 15 m depth zones with two belt transects covering 8000 m^2 (400 m X 20 m) (Bourgoin & Joseph, 2008).

3.4 Sediment monitoring site data collection methods

Sediment monitoring was added to the CSP marine biophysical monitoring plan in October 2008 in collaboration with Palau International Coral Reef Center (PICRC). Sediment cores were obtained at Dausokele mangrove bay, along fringing reefs and onto patch reefs near the Tekehtik International Airport. Traps were deployed in the mangroves and along the patch reef edges at about 5 to 10 m intervals from Stations (S) S1 to S7 (Figure 3.3, Appendix 3). Sediments were collected in double, bottom-mounted sediment traps, with a diameter of 5.08 cm which were mounted along transects between S1 and S7. All traps were deployed for a period of one month (for no more than 31 days and no less than 29 days) after which they were replaced with new traps. Sediment will be dried and weighed by CSP then sent to PICRC for data analysis. Data collected from the sediment traps will be used by CSP to look for trends in short and longer term changes in sediment load in the northeastern bay of Pohnpei lagoon. The protocol for the sedimentation project follows the same techniques used by Victor et al.'s (2006) sedimentation study in Kitti on the southeastern side of Pohnpei.

3.5 Observations of local fishermen

I talked to local fishermen who gave accounts of the health of Pohnpei lagoon, types of fish that are endangered, coral bleaching, and how they feel about Pohnpei's marine resources.

3.6 Pohnpei site visit and photo-quadrant technique

I had the opportunity to join CSP and visit some of the photo-quadrant marine monitoring sites during my Pohnpei visit in July, 2009. Ecological datasets are collected inside and outside reefs at 16 sites in the Pohnpei Lagoon (Figure 3.4, Appendix 4). Ecological datasets include benthic estimates, fish population, macro-invertebrates and coral abundances and diversity. Data collection involves a sequence of measurements undertaken in the following order (Conservation Society of Pohnpei, 2009b):

1. scuba divers lay 5 x 50 m transects at 8 m depths at site location;
2. Fish counters record commercially targeted fish within 2.5m to 5m width on both sides along transect lines;
3. An abundance count of macro-invertebrates (sea cucumbers, sea urchins, sea stars, clams, trochus, and other conspicuous echinoderms and gastropods) using the same transect width and distance;
4. Coral data are collected using a photo quadrant technique, where coral photos are taken inside a 0.5m x 0.5m quadrant at each 1 m interval; and
5. Coral abundance data are recorded by randomly tossed 1 m^2 quadrants along the transect lines, providing estimates of coverage and evenness.

3.7 Meteorological and oceanographic data compilation

3.7.1 Meteorological data

The meteorological (air, wind, and rainfall) datasets were acquired by e-mailing people that I knew, and my contacts also provided their contacts to help research data needs. Data were compiled and sorted into different dataset folders for analysis. Data contacts were from three local and five international institutions (Table 3.7). Numerous types of unpublished literature from organisations were also given to me for interpretation of their collected data.

Table 3.7: Local and international contacts for biophysical, meteorological and oceanographic datasets.

Local Data	Covered	Contacts details
Conservation Society of Pohnpei (CSP) biophysical coral, fish, and sediment data.	2001-2009	Eugene Joseph and Selino Maxin
Pohnpei meteorological and oceanographic data.	2002-2008	Johnny Musrasrik, Wallace Jacob, Kenely Andon, Eden Skilling
Aggregate-quarry sites on Pohnpei	1998-1999	Russell J. Maharaj
International Data	**Covered**	**Contacts**
Columbia University	1949-2008	http://iridl.ldeo.columbia.edu/maproom/.ENSO/
National Oceanic and Atmospheric Administration (NOAA), University of Hawaii (a)	2002-2008	http://oceanwatch.pifsc.noaa.gov/
National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory (c)	1990-2010	http://www.pmel.noaa.gov/tao/jsdisplay/
National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center (NCDC) (b)	2002-2008	http://threadex.rcc-acis.org/
Pacific Islands Applied Science Geoscience Commission, SOPAC	2001-2008	Salesh Kumar, Jens Krugar, Arthur Webb, Keleni Raqisia, and Russell J. Maharaj
National Oceanic and Atmospheric Administration (NOAA)	2002-2008	http://tidesandcurrents.noaa.gov/tides09/tab2wc3.html
Pacific Islands Applied Geoscience Commission, SOPAC	2002-2008	http://geonetwork.sopac.org/geonetwork/srv/en/main.home

3.7.2 Oceanographic data

The oceanographic (sea level, and sea surface temperature) data acquisition followed the same form as meteorological data access and storage by e-mailing various contacts (Table 3.7). We also used satellite and buoy datasets produced by online information sites for the Micronesia region. Satellite and buoy datasets consisted of 25 year trend data over time of sea level and sea surface temperatures (Table 3.7). The land based data sets of the past 7 to 10 years comprised only air and water temperature with sea level (Table 3.7).

3.8 Pohnpei Lagoon literature with meteorological and oceanographic reports

The literature available is summarized from the various local and international organizations where I acquired some of my data (Table 3.8). Various international organizations have studied Pohnpei lagoon, but most studies were done in the northern lagoon in the 1970s. In the 1980s most of Pohnpei lagoon was catalogued and surveyed to produce the Pohnpei Atlas and marine inventory. By the 1990s to 2000 numerous international research institutes and organizations provided technical support and analysis toward the conservation and management of Pohnpei's lagoon. From 2000 to present local non-profit organisations have teamed up with the government of Pohnpei to manage and monitor the marine resources.

Table 3.8: [1]*Literature on Pohnpei Lagoon, meteorological and oceanographic studies with period data covered.

POHNPEI LAGOON LITERATURE		
Data	Data covered	Author(s) and year
Ponape port facilities: oceanographic design criteria and environmental impact of construction	1971	A* Lyon Associates, 1971
Limited current and biological study in the Tuanmokot channel, Ponape	1974	B* Tsuda et al., 1974
Marine biology survey of northern Ponape lagoon	1980	C* Birkeland, 1980
Pohnpei coastal resource atlas	1985	D* U.S Army Corps of Engineers, 1985
Pohnpei coastal resource inventory	1986	E* U.S Army Corps of Engineers, 1986
Management of Reef Resources: Pohnpei Island, Federated States of Micronesia	1986	F* Holthus, P.F., 1986
Impact of dredging for aggregates from fringing reefs: Pohnpei state recommendations and alternatives	1998	G* Smith et al.,1998
Assessment of onshore aggregate resources, Pohnpei, Federated States of Micronesia (FSM)	1999	H* Maharaj, Naidu, & Hatch, 2004
Seven marine reserves established	1999	I* Marine Sanctuary and Wildlife Refuge Act of 1999: S.L. NO. 4L-115-99 §1, 7/23/99
Status of Coral Reefs in the Federated States of Micronesia	2000	J* Lindsay & Edward, 2000
Four marine reserves established	2001	K* Amended Wildlife Management Act of 1999
Reef building corals and coral communities of Pohnpei, Federated States of Micronesia: Rapid ecological assessment of biodiversity and status	2005	L* Turak & De Vantier, 2005
Reef fishes of Pohnpei, Federated States of Micronesia: Rapid ecological assessment of biodiversity and status	2005	M* Allen, G.R., 2005
Characterization and management of the commercial sector of the Pohnpei coral reef fishery, Micronesia	2005	N* Rhodes et al., 2007

[1] * Letter references refer to reference listed in Table 3.8

POHNPEI LAGOON LITERATURE continued		
Data	Data Covered	Author(s) and year
Sedimentation in mangroves and coral reefs in a wet tropical island Pohnpei, Micronesia	2006	O* Victor et al., 2006
Japan International Cooperation Agency, Nippon Koei Co., Ltd., and Japan Airport Consultants, Inc.	2006	P* The study on improvement of Pohnpei International Airport in the FSM: Final Report, 2006
METEROROLOGICAL AND OCEANOGRAPHIC LITERATURE OF POHNPEI		
Local climatological data: Annual summary with comparative data Pohnpei (Ponape), Eastern Caroline Islands, Pacific (PTPN)	1982, 1983, 1997, & 1998	Q* National Oceanic and Atmospheric Administration (NOAA) 1982, 1983, 1997 & 1998
Climate proofing: A risk based approach to adaptation, Pacific Studies	2005	R* Asian Development Bank, 2005
Pacific Country Report on Sea Level and Climate: Their present state- Federated States of Micronesia	2006	S* Federated States of Micronesia South Pacific Sea Level and Climate Monitoring project, 2006
Preliminary results from multibeam and seismic surveys: Pohnpei, Federated States of Micronesia	2006	T* Krüger & Kumar, 2008
Pohnpei atmospheric and oceanographic data	1949-2008	U* Columbia University, 2008
Pohnpei underwater observations at biophysical data sites	2009	V* Phillip Jr. 2009
Conservation Society of Pohnpei sediment monitoring	2008-2009	W* Conservation Society of Pohnpei sediment monitoring, 2009
TAO buoy, TOPEX and Jason satellite data in the western Pacific Ocean	1990-2010	X* National Oceanic and Atmospheric Administration (NOAA)1990-2010

3.8.1 Timeline of ecological and human events in the Pohnpei Lagoon

The literature available from Table 3.8 is summarized below into a timeline and diagram of events as they happened in the Pohnpei Lagoon (Figure 3.5). The timeline below highlights events from natural and human factors that may have altered the coral health and fish populations inside the Pohnpei Lagoon. While there may be other factors that I may not have included due to lack of data, these can be included later to expand the timeline for future research.

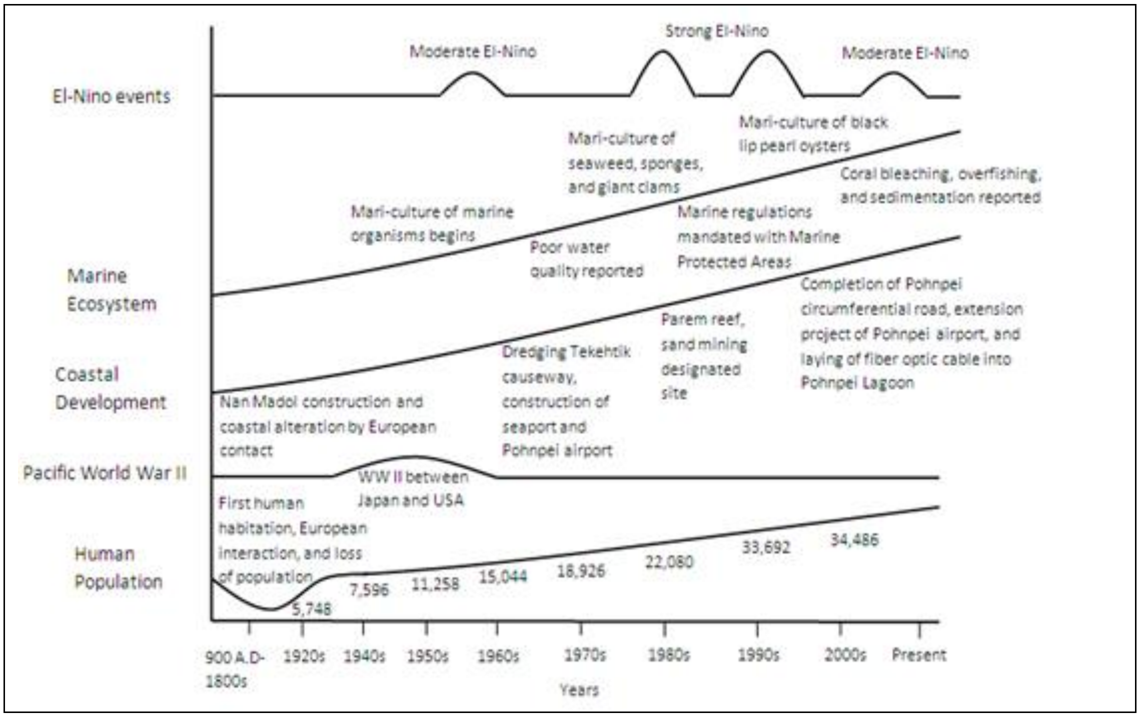


Figure 3.5: Natural and human activities since 900 A.D-Present inside Pohnpei Lagoon. This diagram was compiled from sources listed in Table 3.8.

3.9 Statistical analysis

3.9.1 "R" Statistics

I will be using the statistical package "R" for data analysis and interpretation. "R" is a statistical computation system and graphics based on the S language using run-time environment, a debugger, access to certain system functions, and runs systems that are stored in script files (Rizzo, 2008). "R" is suitable for students and researchers learning/using statistics (Verzani, 2005; Rizzo, 2008).

Chapter Four: Sediments, Meteorological and Oceanographic Time Series Data

4.1 Introduction

This chapter reviews the sediment, meteorological and oceanographic data acquired for the Pohnpei Lagoon. Recently, in 2008, the Conservation Society of Pohnpei began sediment monitoring at seven sediment stations on the northern coast of Pohnpei Lagoon (Conservation Society of Pohnpei, 2009a). The meteorological and oceanographic data covers various years from 1983, 1997, 1998, and 2002-2008. The sediment, meteorological and oceanographic data were analysed to investigate the weather and ocean conditions during normal and abnormal (El Niño periods) climatic conditions in the Pohnpei Lagoon and to see if the past El Niño years of 1983, 1997, and 1998 had the same effect on the Pohnpei Lagoon as El Niño conditions in 2002. The past El Niño years of 1983, 1997, and 1998 will be baseline data to compare with present El Niño conditions of 2002 and current years. The Pacific Islands Applied Geoscience Commission, SOPAC, undertook a bathymetric survey of the Pohnpei Lagoon in 2006. The SOPAC research provided bathymetry maps of near-shore and offshore areas of the Pohnpei Lagoon, which can also be used with my thesis investigation. The sediment, meteorological, and oceanographic findings will give a better understanding to see whether or not natural influences affect the marine environment, when nature is slow to recover after ENSO events, with the same ramifications as human threats.

4.2 Sediment sites and data acquisition

Sediment data were acquired from CSP who recently began a sediment monitoring program in October 2008 using the Victor et al. (2006) sediment survey method. This approach was tested on the southeastern coast of Pohnpei as a baseline for the northern lagoon site. Sediment traps are being collected at approximately monthly intervals of no less than twenty nine days and no more than thirty days. This means that some months may have two samples but no data for the month of February 2009 (Conservation Society of Pohnpei, 2009a). The first sediment monitoring study of

Pohnpei Lagoon was done by Victor et al. (2006) in the Enipein Mangrove Forest Reserve (Station 28) estuary and inside lagoon patch reef areas near Nahtik MPA (Station 24), which is on the southeastern side of Pohnpei.

The purpose of the Victor et al. (2006) sediment study was to address the problem of coral reef degradation presumed to be resulting from land-based activities. CSP's seven sediment sites and monthly datasets are summarised in Table 4.1.

Table 4.1: Monthly sediment weights (g) of the seven sediment data sites including months and sediment weight (g) from October 2008-October 2009 (Conservation Society of Pohnpei, 2009a)

Year	Month	Sediment weight (g)
2008	October	0.95
2008	November	1.04
2008	December	0.81
2009	January	0.73
2009	February	N/A
2009	March	1.21
2009	April	0.76
2009	May	1.03
2009	June	0.99
2009	July	1.06
2009	August	1.44
2009	September	1.45
2009	October	0.60

The seven sediment sampling stations of the northern lagoon are located in Kolonia municipality, which is the city center of Pohnpei. Kolonia municipality hosts the majority of Pohnpei's infrastructure and coastal development projects. Since the 1940s, the majority of coastal development projects have been in the northern lagoon of Pohnpei. The northern lagoon, especially the Kolonia and adjacent Sokehs harbor, is believed to be in poor state. The poor marine conditions of both harbors (Kolonia and Sokehs) can be attributed to the increased coastal development, dredging, pollution, ship grounding, and waste water outflow. The major coastal alteration was the construction of the Tekehtik causeway in the 1970s, connecting Pohnpei to Tekehtik Island and blocking natural water movement (Lyon Associates Incorporation Engineers & Architects Consultants, 1971). The findings from the sediment data of the northern lagoon can help assess future coastal development plans in less developed coastal areas, thus ensuring less environmental damage to the health of the marine resources in those areas.

Victor et al.'s 2006 salinity findings of near-shore mangrove estuaries and fringing reefs show various salinity levels at sites (Figure 4.1, Appendix 5). In sites S1 (at 0.5 m above water surface and below water surface bottom at 2.5 m depth) during non-flood conditions salinity was approximately 32 mg cm^{-2} d^{-1}, but during flood events with low and high tide, salinity fluctuated between 5 cm^{-2} d^{-1} and cm^{-2} d^{-1} (Figure 4.2,). The sites S3, S6, and S7 (at 0.5 m above water surface and below water surface bottom at 2.5, 4, and 5 m depths) salinity levels varied. At site S7 near fringing reefs, the salinity fluctuated between 30.4 mg cm^{-2} d^{-1} and 32 cm^{-2} d^{-1}, unlike the near shore sites S3 (Figure 4.2).

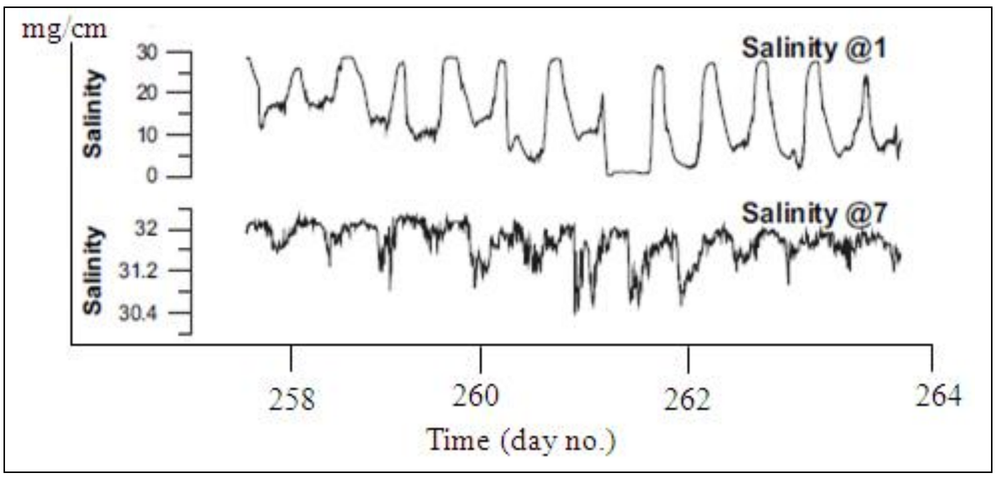


Figure 4.2: Salinity level at S1 near shore mangrove estuaries and salinity at S7 in fringing reef areas (Victor et al., 2006)

4.2.1 Sediment data analysis and summary

The CSP's seven sediment sampling stations in the northern lagoon were analysed by the R statistics as shown below. In the box plot in figure 4.3 are blue rectangles representing the enclosed 50% of the data between the upper and lower quartiles, whereas the thick horizontal lines are the median notches where the median allows comparison between sites. If the notches do not overlap the median values are statistically different. The thin horizontal whisker lines are 1.5 quartiles from the median. If the data are symmetric, the median will be half way between the whiskers. Most of these data are not symmetric.

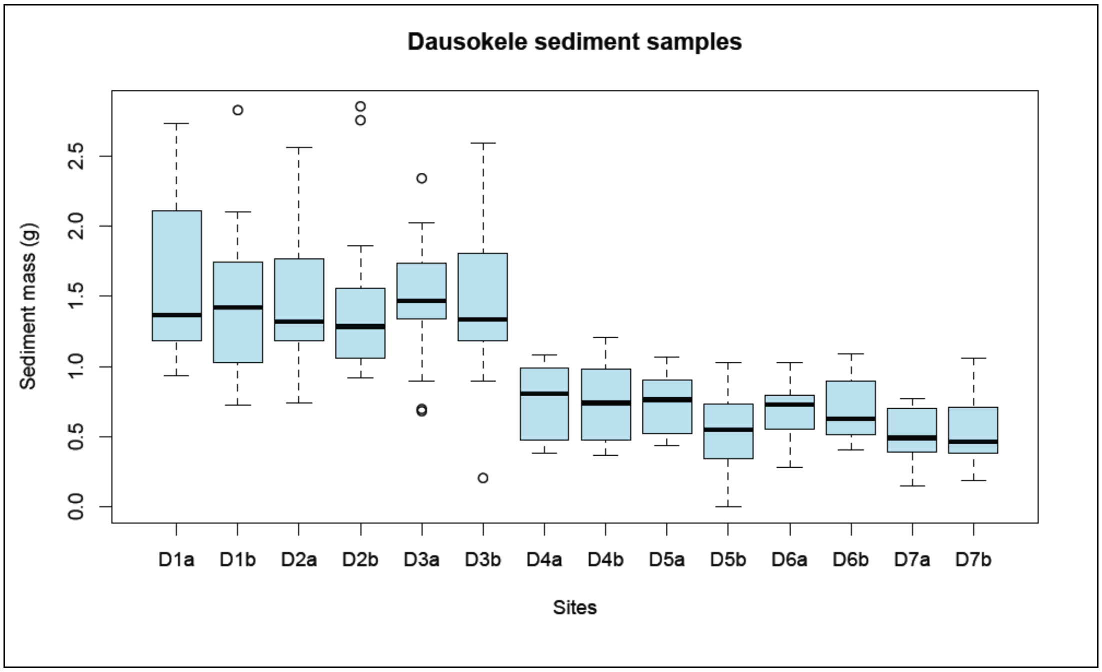


Figure 4.3: Sediment mass (g) by sites from October 2008-Ocotber 2009

The box plot in figure 4.4-4.5 shows that there are two groups of suspended sediments. The first sites, D1a-D3b receive higher suspended sediment while the second group sites D4a-D7b receive lower suspended sediments (Figure 4.5).

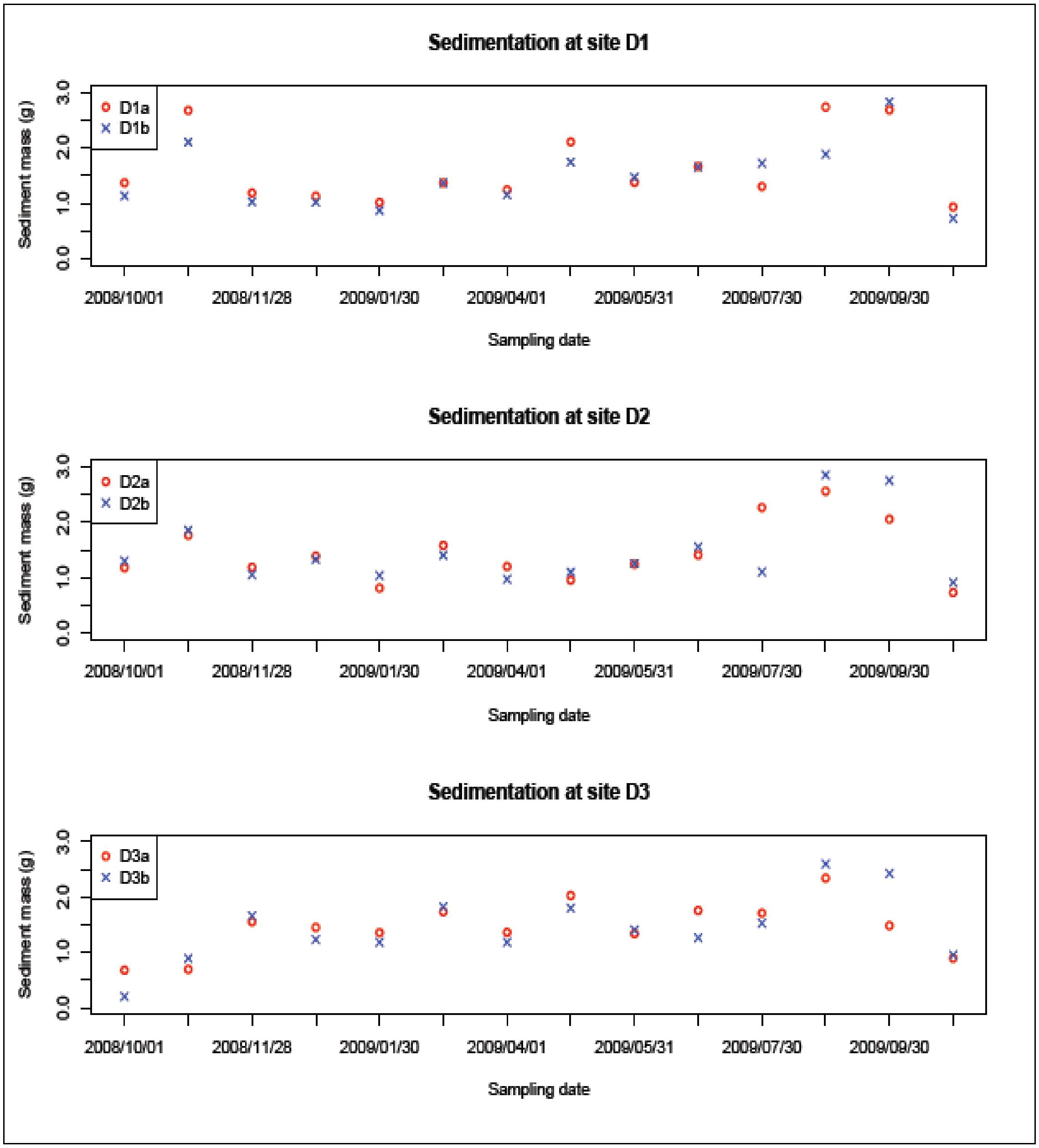


Figure 4.4: Sediment sites D1a-D3b mass (g) by months October 2008-October 2009

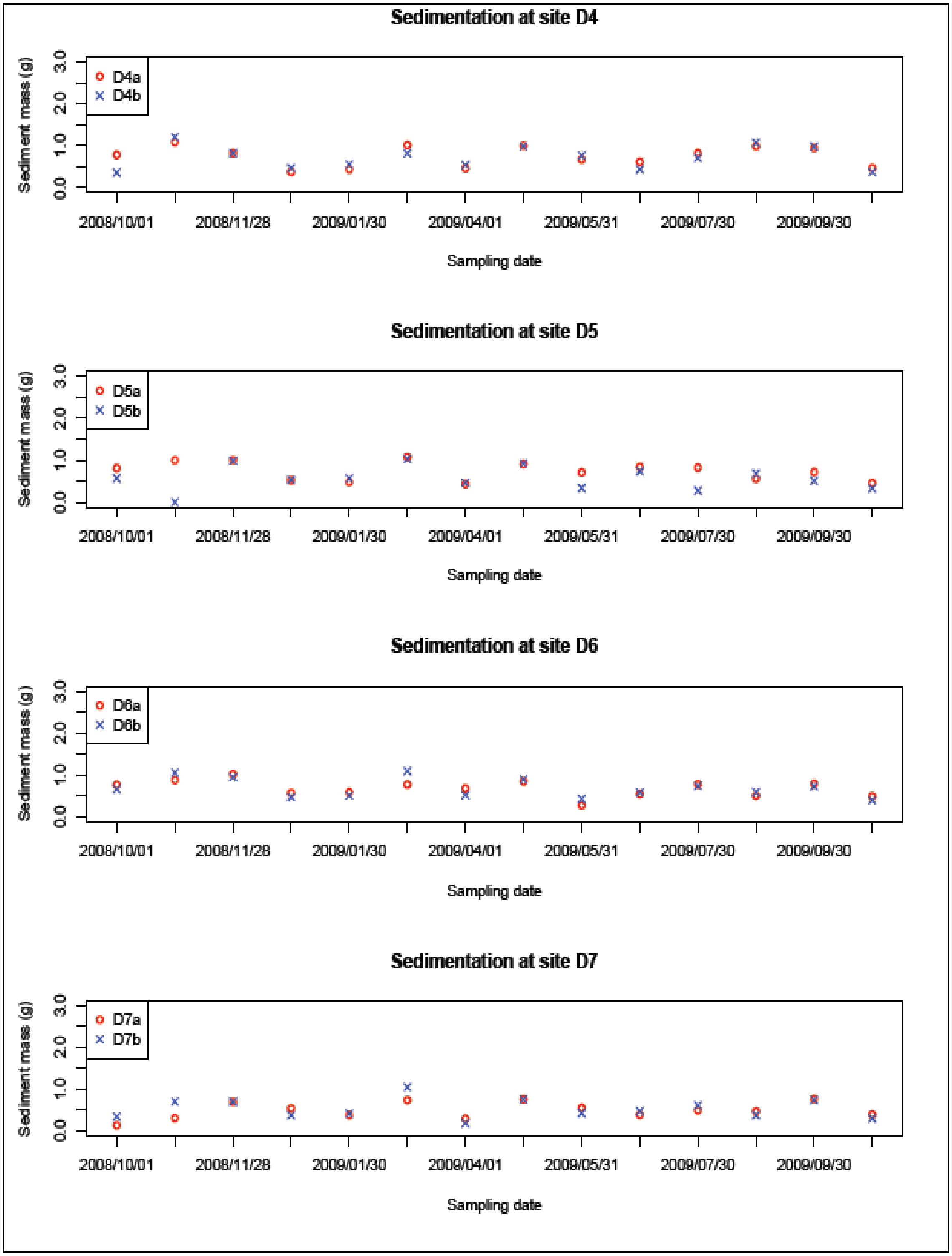


Figure 4.5: Sediment sites D4a-D7b mass (g) by months October 2008-October 2009

The second groups of sites, D4a-D7b (Figure 4.5), receive less sediment, probably due to a combination of dilution and losses due to sedimentation closer to source. The data indicate that some high rainfall periods bring increased sediment to the outer sites (D5a-D7b), but others do not. If the discharge of sediment is associated with episodic flood events, then the distribution of sedimentation will depend on the sediment load, the volume of the flood and whether the flood coincides with predominantly ebb or flood flow conditions. The sediment traps in the outer sites (D4a-D7b) do get exposed to moderate current and waves, which may re-suspend sediment, or prevent deposition.

4.3 Meteorological data acquisition and results

The meteorological data were acquired from local (1997, 1998, and 1983) and international agencies (2002-2008) and some from published and unpublished literature. The international agencies consist of the National Oceanic and Atmospheric Administration (NOAA) working with the University of Hawaii at Manoa (UHM) and other NOAA departments, Columbia University in New York, the Pacific Islands Applied Geoscience Commission, (SOPAC), and the Federated States of Micronesia South Pacific Sea Level and Climate Monitoring Project, (2006), who have been working in collaboration with the Pohnpei Weather Service Station. Other rainfall data was collected by CSP who has collaborated with the Water and Environmental Research Institute of the Western Pacific (WERI) from the University of Guam (UOG) (Lander & Khosrowpanah, 2004). The meteorological datasets consist of rainfall, wind, wind speed, and air temperature, which were then analysed by using the “R” statistical software.

4.3.1 Rainfall data analysis

Pohnpei is located in one of the wettest regions of the western North Pacific (Lander and Khosrowpanah, 2004). Rainfall peaks in the months of April and May with highest mean monthly rainfall of 495.5 mm in May (National Oceanic and Atmospheric Administration 1983, 1997, 1998; Lander & Khosrowpanah, 2004), while dry months are in January-February, with lowest mean rainfall at 266.4 mm in February (Lander & Khosrowpanah, 2004). Historical records suggest that the annual mean rainfall on Pohnpei differs substantially across the island and is strongly affected by the topography, with heaviest measured annual rainfall of over 8,000 mm occurring in the central highlands (Lander & Khosrowpanah, 2004).

Pohnpei goes through an unusual pattern of rainfall months and years, with some days getting very high rainfall then other days without rainfall at all (Lander & Khosrowpanah, 2004). During El Niño years Pohnpei's mean monthly rainfall decreases below normal from about 508 mm per month (Lander & Khosrowpanah, 2004) to < 1 mm (National Oceanic and Atmospheric Administration, 1983, 1997, 1998). The lowest mean rainfall < 1 mm occurred during the 1998 El Niño in the month of January (Lander & Khosrowpanah, 2004). The low rainfall months occurred from December to May of the following year, coinciding with the peak of the El Niño event (Table 4.2). However, April 1997 is an exception as rainfall averages increased during the El Niño period. Low El Niño rainfalls have caused severe droughts that have lasted several months. Low rainfall years, especially during 1998, have also been identified and linked to coral bleaching events worldwide (Figure 4.6).

Table 4.2: Comparison of El Niño event monthly rainfall (mm) for 1983, 1997 and 1998 with normal monthly rainfall for 1982 and 1996 (National Oceanic and Atmospheric Administration, 1983, 1997/98)

Year	Month	Rainfall (mm)	Year	Month	Rainfall (mm)
1983	January	48	1982	January	357.1
	February	43.7	-	February	415.3
	March	38.6	-	March	328.6
	April	51.6	-	April	421.4
	May	56.1	-	May	575.8
1997	April	721.4	1996	April	617.2
	December	85.6	-	December	326.1
1998	January	16.3	1996	January	591.8
	February	50.3	-	February	173.7
	March	74.9	-	March	220.9
	April	126	-	April	617.2

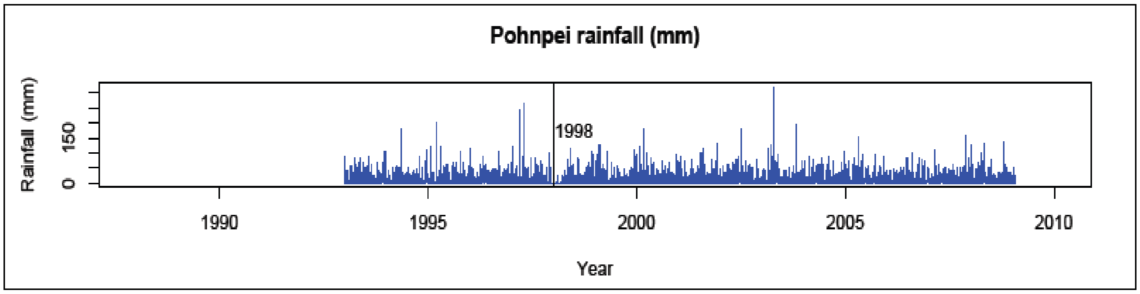


Figure 4.6: Pohnpei rainfall (mm) from 1993-2008. Note the extremely low rainfall during the 1998 world wide bleaching event (Columbia University, 2009)

4.3.2 Wind data analysis

The trade winds of Pohnpei are predominantly from the northeast. The wind rose plots represent Pohnpei Island in the center of circle (Figure 4.7). The coloured lines show the wind direction according to the data. If the line bars do not overlap between years then it is statistically different. In 2002 El Niño year, the trade winds coloured green, yellow, and pink came from the westerly direction, whereas in 2003-2008 trade winds in same colours were from the northeast as shown in the wind rose plots. As for the wind speed (m/s) shown in the box plot where green is < 2.5 m/s, the mean wind speed was stronger in 2002, approximately > 10 m/s while other years wind speeds were between > 2.5 m/s to 7.5 m/s.

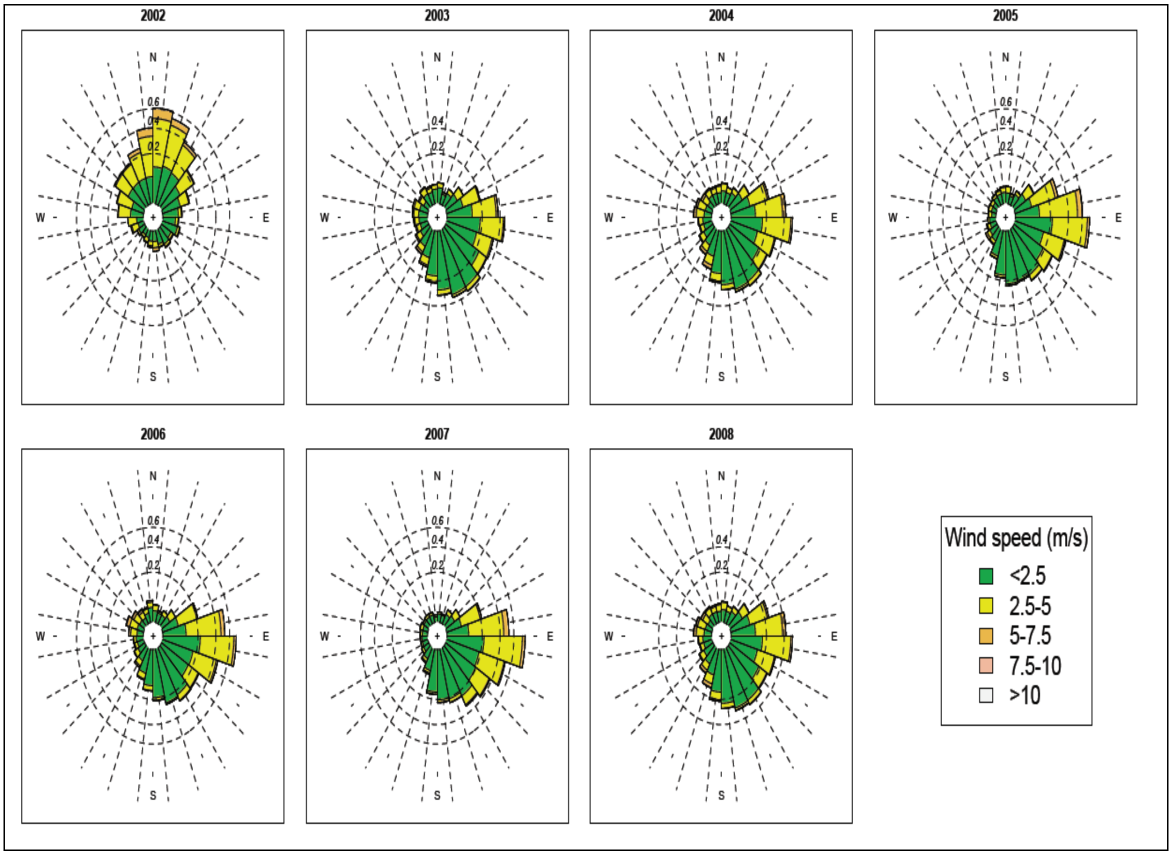


Figure 4.7: Wind rose plots of trade wind directions during 2002 El-Nino year and 2003-2008 normal years with wind speed (Pacific Islands Applied Geoscience Commission, SOPAC, 2009)

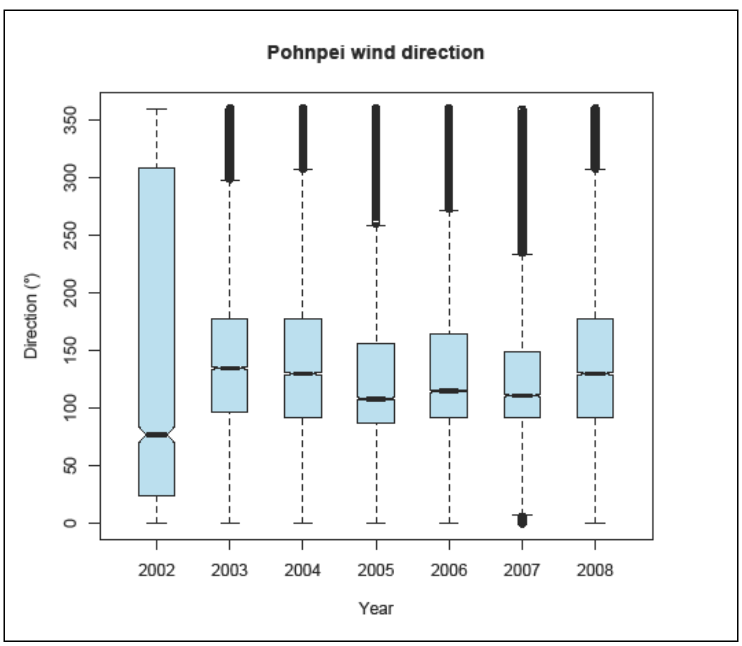


Figure 4.8: Pohnpei wind direction 2002-2008 (Pacific Islands Applied Geoscience Commission, SOPAC 2009)

4.3.3 Air temperature analysis

The Pohnpei air temperature, in Celsius (°C), is summarized by a box plot (Figure 4.9). These data indicated no real trend over time as indicated for the past six years from 2002-2008.

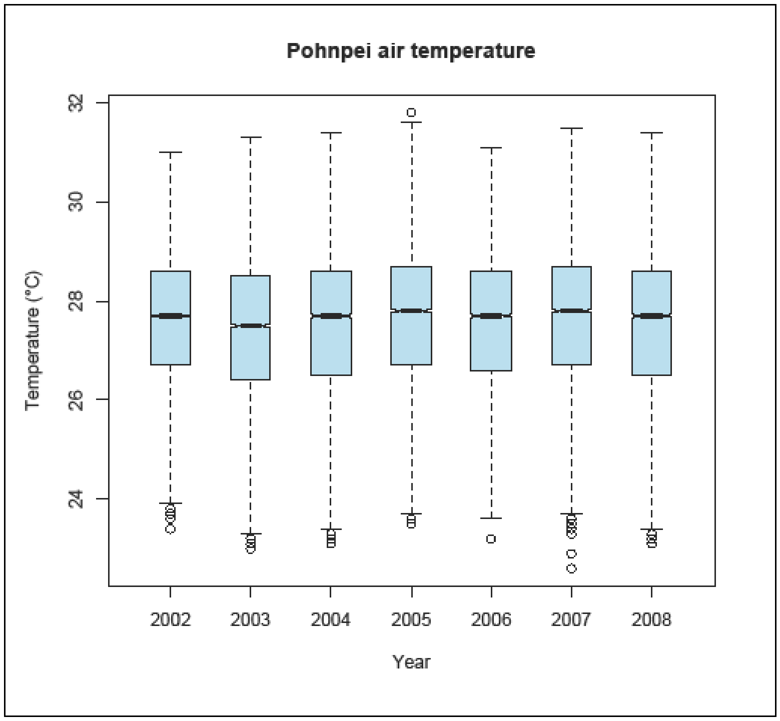


Figure 4.9: Pohnpei air temperature for the past six years (2002-2008) (Pacific Islands Applied Geoscience Commission, SOPAC 2009)

4.4 Oceanographic data and results

4.4.1 Oceanographic data acquisition

Pohnpei oceanographic datasets from the 1990s to 2008 consist of water temperature, sea level, barometric pressure, ocean currents and salinity, and they were acquired from National Oceanic and Atmospheric Administration (NOAA) working with the University of Hawaii at Manoa (UHM) and other NOAA departments, Columbia University in New York, and the Pacific Applied Geoscience Commission, SOPAC. The water temperature, sea level, and barometric pressure were analysed by using the "R" statistical software. Oceanographic ocean current patterns, salinity, and water temperature were from local studies by Victor et al. (2006) and Japan Airport

Consultants (2006). The near-shore and off shore salinity data was acquired from the Pacific Islands Applied Geoscience Commission, SOPAC (Smith & Kumar, 2007).

4.4.2 Sea temperatures data

Ocean sea temperature near Pohnpei varies over a relatively small range throughout the year (Figure 4.10) and reaches minimum temperatures in January (Federated States of Micronesia South Pacific Sea Level and Climate Monitoring Project, 2006). The 1998 strong El Niño year had cooler sea surface temperatures below 27.5°C while the moderate El Niño of 2002 sea surface temperatures were above 27.5°C (Figure 28). Sea surface temperatures measured in the lagoon are more variable than those in the open ocean. Since 2000, the highest sea surface temperature of 31.8°C occurred in the month of September 2004 while the lowest was 27.3°C, in January 2003 (Federated States of Micronesia South Pacific Sea Level and Climate Monitoring Project, 2006).

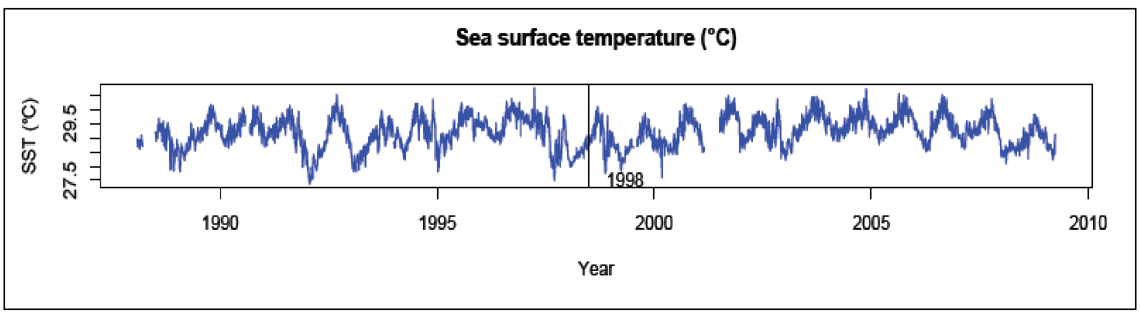


Figure 4.10: Sea surface temperatures of a five year scale (Columbia University, 2009)

In 2002 sea temperature (°C) yearly box plot appears at ~ 29°C, being cooler but with slightly warmer water temperatures in 2003-2004, though the differences were not statistically significant (Figure 4.11).

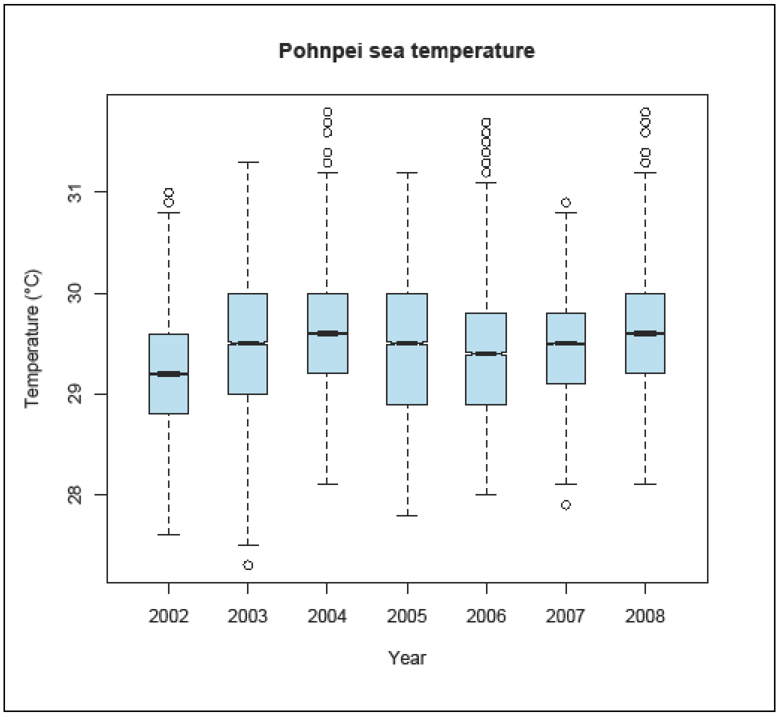


Figure 4.11: Pohnpei sea temperature is slightly cooler in 2002 and fairly constant during 2003-2008 (Pacific Islands Applied Geosciences Commission, SOPAC, 2009)

4.4.3 Sea level data

Pohnpei sea level (cm) varies between years. The sea level shows a steep drop in the strong El Niño of 1997/98 below -30 cm and not such a steep drop in the moderate El Niño of 2002 with above -10 cm (Figure 4.12).

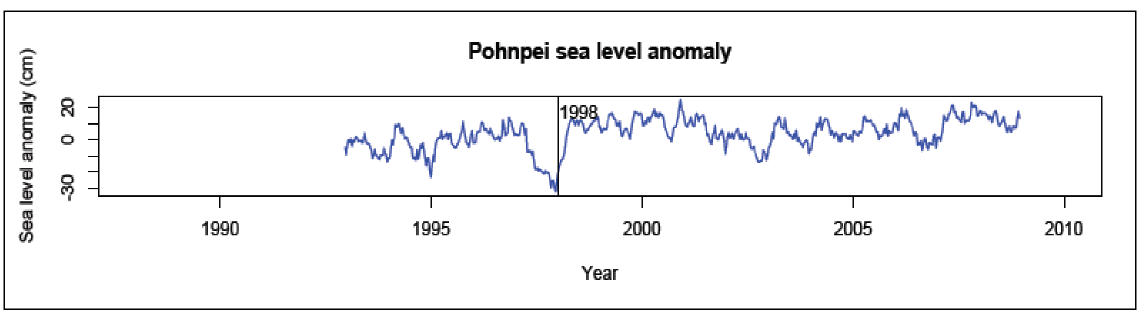


Figure 4.12: Pohnpei sea level (cm) from 1993-2009, highlighting the drop proceeding the 1998 world-wide bleaching event (Columbia University, 2009)

The box plot shows sea level (m) where in 2002 the sea level was significantly lower than the other years, whereas in 2007 sea level was higher (Figure 4.13).

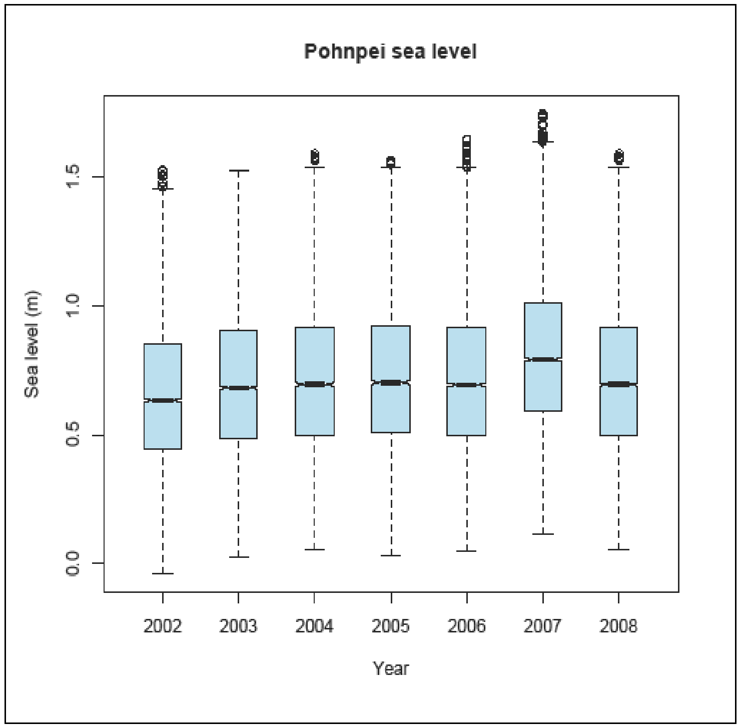


Figure 4.13: Pohnpei sea level 2002-2008 in (m) (Pacific Islands Applied Geosciences Commission, SOPAC, 2009)

4.4.4 Barometric pressure data

The barometric pressure in Pohnpei also varies throughout the year. Since 2000 the highest recorded pressure was 1014.8 hectopascals (hPa) in March 2005, with minimum at 996.7 hPa on December 2002 (Federated States of Micronesia South Pacific Sea Level and Climate Monitoring Project, 2006). The Pohnpei barometric pressure measured in 2002 had Pohnpei in a low pressure system, below 1010 hPa (Figure 4.14).

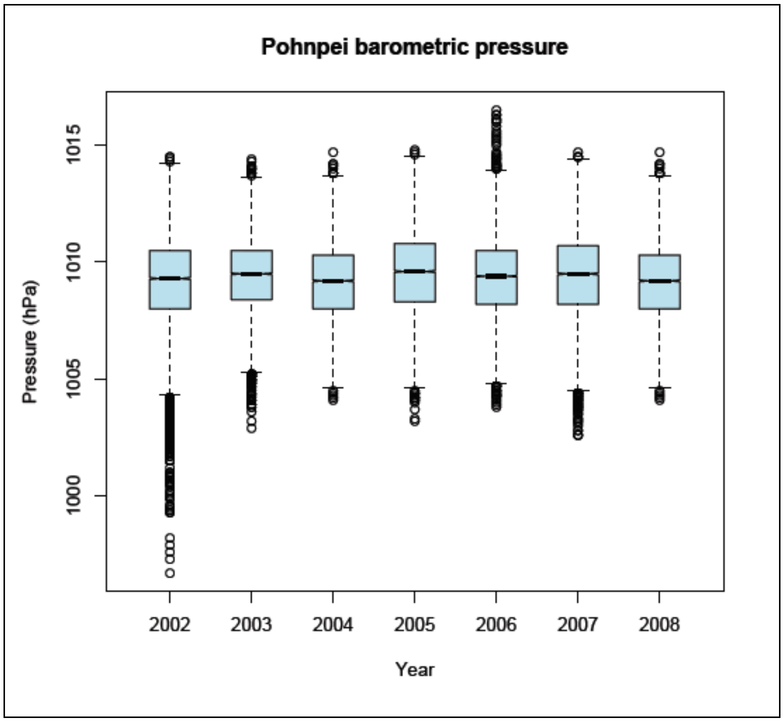


Figure 4.14: Pohnpei barometric pressure (2002-2008) showing low pressure in 2002 (Pacific Islands Applied Geosciences Commission, SOPAC, 2009).

4.4.5 Ocean currents

The western Pacific regional currents are dominated by the wind-driven subtropical gyres of the northern and southern hemisphere (Baynham, 1994). The main currents flow westward along the Equator into the region (Figure 4.15).

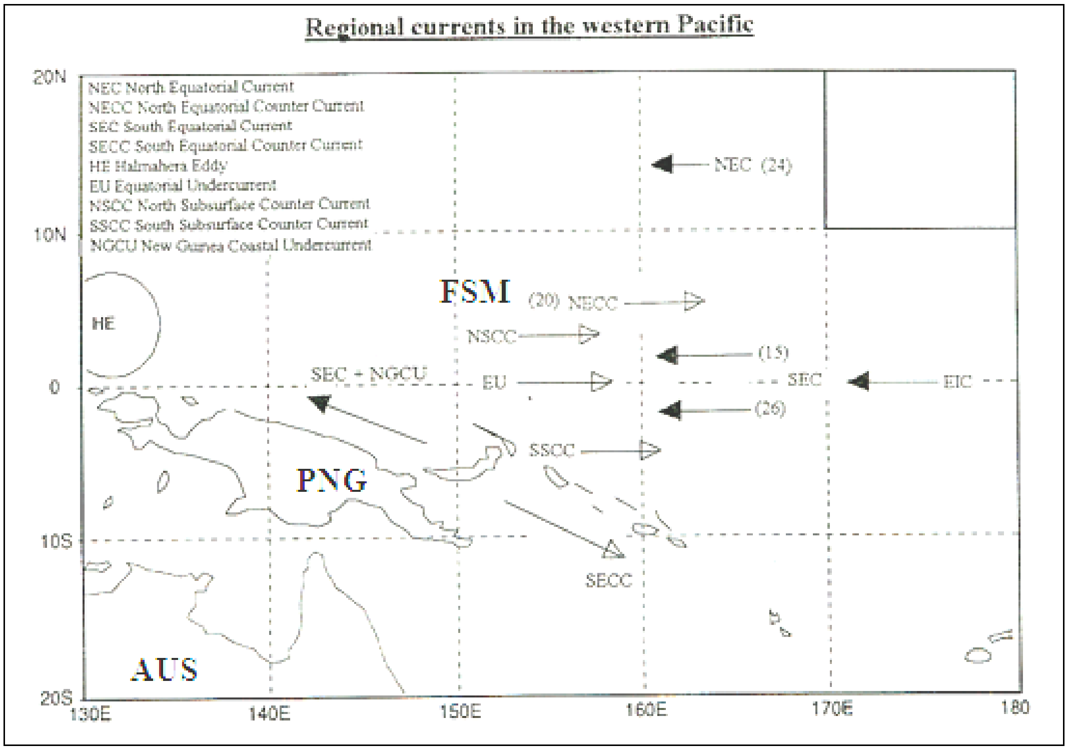


Figure 4.15: Regional currents of the western Pacific Ocean (Baynham, 1994)

Ocean currents in the central Pacific have been observed with a series of moored buoys as part of the Tropical Atmosphere Ocean (TAO) research programme. The network of buoys was completed in 1994 after being proposed following the strong El Niño of 1982-1983 and the TOGA COARE investigation into the behavior of the Pacific Warm Pool (Scientific Plan for TOGA Coupled Ocean Atmosphere Response Experiment, 1990).

However, there have been few observations of currents inside the Pohnpei Lagoon. The only studies that recorded currents inside the lagoon studied areas near river mouths for sediment studies (Victor et al., 2006), or seaport and airport development projects (Lyon Associates, 1971; Japan Airport Consultants, 2006). Therefore, I will have to rely on my personal experience and knowledge of the area to describe current conditions inside the Pohnpei Lagoon.

Victor et al. (2006) measured currents inside the southeastern lagoon of Pohnpei in conjunction with sedimentation studies in 2004 at eight study sites. Current profilers were placed in S3 and S8 at 2.5 m depths to assess sediment flow (Figure 4.1, Appendix 5). The Japan Airport Consultants (2006) placed a current meter at 12 m depth in the northeastern lagoon (end of airport runway patch reef) for tidal current vectors and direction in 2005. The tidal current direction shows two dominant direction patterns, and ebb flow between NW and NE and flood flow between SE and SW.

4.5 Bathymetry maps

In 2006, the Pacific Islands Applied Geoscience Commission, SOPAC undertook a bathymetric survey of the Pohnpei Lagoon to determine the depths of Pohnpei's harbors and surrounding lagoon. The bathymetry surveys were determined by measuring the conductivity, temperature, and depth (CTD) through the Pohnpei water column (Table 4.3). The collection of CTD data covered approximately 50 m depths near shore to ~5 km offshore distance, reaching 1500 m water depths offshore at five different locations: Kolonia harbour (CTD cast 2) and lagoon, Sokehs harbour and lagoon (CTD cast 2), Pohnpei passage (CTD cast 2), Madolenihmw harbour (CTD cast 3), Nan Madol lagoon (CTD cast 3), Ron Kitti harbour (CTD cast 6), and offshore around the island (CTD cast 1 and CTD cast 5) (Figure 5.12) (Krüger & Kumar, 2008). Bathymetry maps of Pohnpei Lagoon (Figure 4.16, Appendix 6) of Kolonia, NanMadol, and the Madolenihmw harbour (Figure 4.17-4.21, Appendix 7) were created. The bathymetry maps may have provided and in-depth look at the studied sites, however, my work was limited to getting current and wave data of studied areas. Therefore, the bathymetry maps are included for future work on Pohnpei's marine environment.

Table 4.3: Details of CTD profiles (Krüger & Kumar, 2008)

Open water Profile	Date	Time	Easting	Northing	Total Water Depth (m)
CTD cast 1	02/07/2006	10:14	395247.92	766991.36	1400
CTD cast 2	05/07/2006	09:05	409372.9	772939.8	35
CTD cast 3	06/07/2006	16:00	428151	758990.58	75
CTD cast 5	11/07/2006	10:13	408050.65	747300.16	712
CTD cast 6	11/07/2006	13:08	407438.27	750229.24	82

4.6 Discussion

4.6.1 Effects of causeway construction

The CSP sediment data findings show that there is a correlation between natural influences and human factors. The correlations happening at near-shore sediment stations D1a-D3b (Figure 4.4) may be influenced by on-going coastal development projects. Since the 1970s the Dausokele Bay, including the Tekehtik causeway, has seen on-going coastal development projects. The construction of the Tekehtik causeway in the 1970s is attributed with causing a major loss of natural flow of water (Tsuda et al., 1974). There are three rivers discharging into the Dausokele Bay with various run-off catchments that flow into the Tekehtik causeway. Tekehktik causeway has only two short bridges or culverts directing water flow to both sides of the causeway road, suggesting that sediment is either deposited in greater amounts on either side of the causeway or is not regularly flushed out to settle elsewhere. The two routes are narrow culverts, with the east culvert leading to East Bay and a southwest culvert leading to Makota Channel (Tsuda et al., 1974). Before the connecting of Tekehtik Island and Kolonia there were three observations between February 26, 1968 and March 1, 1968 by Austin, Smith and Associates, 1968 (as cited on page 13 in Tsuda et al. 1974).

> *On rising tides, water flows southward between Kolonia and Sokehs Island through the Makota Channel until the flow meets the flooding tide from the south western side of Sokehs Island. On the ebbing tide the flow reverses itself and flows northward west of Tekehtik Island any floating material is slowly driven to the mangrove areas along the eastern shoreline of Sokehs Island by the north easterly winds.*

With the construction of the Tekehtik causeway there are now only three confined routes that the body of water can take to reach the west side Tekehtik causeway and Sokehs Island. The primary route is through Sokehs passage west of the Pohnpei International Airport and the other two routes are to the east and southwest of the two existing culverts. The international airport is under construction for an airport runway extension that began in 2009 and is being completed in 2011 (Japan International Cooperation Agency, 2006). The Tekehtik causeway may have damaged the ecological system in the past and at present. A study in 2006 of the various sites near the Tekehtik causeway and Pohnpei International Airport has concluded that the marine area is already receiving massive amounts of sediment (Japan International Cooperation Agency, 2006). An investigation of the Tekehtik causeway is needed to mitigate the erosion, sedimentation, and water flow of the area.

4.6.2 Effects of rainfall

Sediment increases during heavy rainfall periods (April and May) where the inner lagoon reefs adjacent to coastal areas and river mouths become heavily silted. During high rainfall the mangroves, estuaries and coral reef lagoon turn brown, caused by heavy runoff from land and river discharge. The mangroves, estuaries and coral reef are highly stratified in suspended sediment concentrations. The sediments smother corals and lead to increased coral mortality in the lagoon, which in turn affects other marine species that are dependent on the coral reefs (Victor et al., 2006). In drier months (January-February) or days without heavy rainfall river waters remain clear of sediment (Victor et al., 2006). As indicated by Victor et al. (2006), (Chapter 2) poor land use practices and deforestation from planting of kava (*Piper methysticum*) is causing high sediment load into reefs on the south-eastern coast. Aerial photos and vegetation mapping has shown that the Pohnpei watershed forest had been declining over the 20 years between 1975 and 1995 (Trustrum, 1996). The construction of roads and other human activities that require removal of soil next to streams in the upland forest (Buden et al., 2001) can also lead to increased sediment. It is important to know how patterns of coral recruitment and fish population patterns could be affected by the sediment deposits inside reef areas of the Pohnpei Lagoon. Sedimentation is considered to contribute to the increased population of the Crown-of-thorns (COTs) starfish and causing shifts in the structure of coral communities at various reef sites (Turak & De Vantier, 2005).

4.6.3 Effects of oceanographic and weather conditions

The Pohnpei Lagoon is also affected by meteorological and oceanographic conditions such as rainfall patterns, winds, sea level, and air and water temperature. At Pohnpei, rainfall varies by 30-60 days of daily rainfall (Lander & Khosrowpanah, 2004) which is likely to be due to the Madden-Julian Oscillation (MJO) pattern, which is common to Pohnpei, with it being close to the equator. The Madden-Julian Oscillation is an inter-annual fluctuation of atmospheric pressure over the equatorial western Pacific Ocean and Indian Ocean (Madden-Julian Oscillation, 2009). The Pohnpei rainfall variation is closely linked to the El-Niño/Southern Oscillation (ENSO) and as Pohnpei is in the ENSO core region where it gets very dry conditions following an El Niño year (Lander & Khosrowpanah, 2004). El Niño events can be moderate or strong. During increased rainfall months (May and April) and after major storms with rainfall exceeding 5 cm day^{-1} there is higher sediment runoff into the coral reef lagoon (Victor et al., 2006), while in drier months (January-February) or days without heavy rainfall the lagoon is calm and clear. In January-May of 1983, Pohnpei experienced a five-month long drought period believed to have been the second driest year (in a fourteen year period) before the driest recorded year of 1998 (Lander & Khosrowpanah, 2004). As described by Lander and Khosrowpanah (2004), there is a trend with lowest rainfall months and highest mean normal rainfall months attributed to El Niño periods. Monthly rainfall values below 127 mm have occurred twice in a five-month cycle, from December, January, February, March, April and May. The mean rainfall months have all occurred with the El Niño periods of 1983, 1997, 1998. The highest mean rainfall above 762 mm have occurred in the months of April, May, July, August, September and November (Lander & Khosrowpanah, 2004). The 1997 increased mean rainfall reading in the month of April was the highest for all of April months since 1968 (Lander & Khosrowpanah, 2004). Also in the months of December-April 1997 and 1998, the rainfall readings were below average (Table 4.2) and there were also drought months as experienced in 1983 (National Oceanic and Atmospheric Administration, 1983). The 1997 to 1998 year was believed to be a worldwide coral bleaching year attributed to El Niño periods (Figure 4.6). Experiences from past abnormal weather conditions are valuable for understanding how such climatic conditions affect Pohnpei Island. There were no records of coral bleaching events documented in Pohnpei in 1997 and 1998, only the natural disaster of 1997, where rainfall for the month of April 1997 peaked above normal readings, and when a typhoon and massive landslide were observed. The landslide caused damage to vegetation as well as infrastructure, and 19 deaths in Sokehs community

(Raynor, 1991; Asian Development Bank, 2005). There was a similar major typhoon in Pohnpei in 1905, wiping out nearly all livestock and food crops and causing displacement of islanders on the outer low-lying atolls (Raynor, 1991). Most islands have a pronounced wet season (June to October) and dry season (November to May). For Pohnpei, the "dry" season runs from January to March. With a severe El Niño episode, drought can begin as early as late autumn and extend into the following summer (Hay et al., 2003). During an El Niño event the FSM is most vulnerable to typhoon activity during November and December, when typhoons have the greatest likelihood of forming directly east, then tracking west, and gathering strength before traveling across the FSM (Hay et al., 2003).

The El Niño year in 2002 was believed to have been moderate (Lander & Khosrowpanah, 2004) with rainfall readings not as low as in 1983 and 1997/98. The moderate 2002 El Niño year had wind directions in the opposite direction than in normal years and for an El- Niño year (Figure 4.7). The wind direction for Pohnpei is mainly from the easterly direction and is fairly consistent for most of the year (Lander & Khosrowpanah, 2004) and during El Niño years the wind changes direction to a stronger westerly as described in figure 4.7. In the 2002 moderate El-Niño, the wind came to Pohnpei from the westerly direction with strong wind gusts. As indicated by local fishermen, were wind gusts were attributed to typhoon winds, which are mostly in November and December months of El Niño-like events. Pohnpei is south of major northern Pacific typhoon tracks, thus safeguarding the island (National Oceanic and Atmospheric Administration, 1983). High air pressure in Pohnpei is associated with thunderstorm activity during high rainfall. In 2002 data, Pohnpei had low air pressure and might probably have had more thunderstorms that year (de Lange, W. personal communications June 23, 2009). Lander and Khosrowpanah (2004), indicated that El Niño years also bring strong westerly winds and a greater threat of typhoons. This was also verified by the Federated States of Micronesia South Pacific Sea Level and Climate Monitoring Project (2006), where variations in monthly mean air were affected by the 1997/1998 El-Niño. The trade winds in 2003-2008 are like other normal years, being easterly (Figure 4.7); the easterly winds become stronger and more dominant from 2003 on-wards. From the local literature, Pohnpei needed numerous ship harbours in the 19th century, due to the trade wind variations. When trade winds were from the northeast the whaling ships anchored on the west and southeast coast of Pohnpei. As the trade winds reversed the whaling ships anchored in the east at the Madolenihmw harbor (Hezel & Hezel, 1973).

The trade winds have some variations of wind speed and maximum gust over time (Figure 4.8), while the air temperature remained constant. Wind and air temperature data behave differently overall with very little change over the past 9 years. Even with the data from 2001-2009 being limited, it is possible to identify periods where the wind is quite different from an El Niño. However, the water and air temperature behave differently, as does the sea level, when compared to normal weather conditions. The 1998 strong El Niño year is indicative of abnormal weather conditions for Pohnpei.

4.6.4 Salinity variations

Variations in rainfall and wind can also influence salinity levels in some sections of Pohnpei Lagoon, affecting the marine species health. Changes in salinity also affect the everyday normal conditions of the Pohnpei population. For example, during an El Niño event the western coast of Pohnpei will have episodes of low to high rainfall, and stronger wind gusts, while the eastern side of Pohnpei will experience less wind action and rainfall. According to Victor et al. (2006), salinity levels fluctuated near-shore at low tides during heavy rainfall and flooding, where salinity varies between 5 Practical Salinity Units (PSU) and 30 PSU, while at patch reef areas salinity is approximately at 30 PSU or slightly above. The salinity levels vary according to heavy weather patterns, such as increased rainfall, and remain constant during normal weather conditions. However, during El Niño events Pohnpei's salinity levels might increase in near shore ecosystems, especially the mangrove and freshwater swamps. According to Drexler and Ewel (2001), at 0.5-1 m depths salinity levels were twice as high during and after the 1997/1998 ENSO event. Such increase of salinity may pose problems for the development and recruitment of the near-shore and adjacent ecosystems (Drexler & Ewel, 2001). The study area for Drexler and Ewel (2001) was in the Yela watershed of Kosrae. The island of Kosrae is located to the east of Pohnpei and shares similar weather and oceanographic conditions.

4.6.5 Water temperature

Pohnpei water temperatures vary throughout the year, with a seasonal range of around 2°C-3°C (Federated States of Micronesia South Pacific Sea Level and Climate Monitoring Project, 2006). The moderate El Niño of 2002 saw cooler water temperatures for Pohnpei Lagoon, after which water temperature rose in 2003 and peaked at 2004 (Figure 4.10). The highest recorded monthly water temperature since 2000 was 31.8°C, which occurred in September 2004 (Federated States of Micronesia South Pacific Sea Level and Climate Monitoring Project, 2006). The average temperatures in the lagoon match those in the open oceans, but there is a greater variability than for deeper ocean depths > 80 m. This is due to solar heating and atmospheric cooling of the shallow waters within the lagoon. There are no anthropogenic heat sources, which act similar to such as cooling systems for thermal power stations which occur at other Pacific Islands such as Fiji.

In Chapter 2, the western Pacific region was show to get warm sea surface temperature (SST) and cold SST in the eastern Pacific, caused by the Western Pacific Warm Pool (WPWP). The shifting of the SST in the WPWP is attributed to coral bleaching events in the western and eastern Pacific region. Pohnpei is right on the fringes of the western Pacific and out on the edge of the WPWP. The outer low-lying atoll of Kapingamarangi is on the edges of WPWP and was used during the TOGA COARE study in the 1990s; anything that lies to east of that does behave differently. The 1998 strong El Niño year had cooler SST below 27.5°C, while during the moderate El Niño of 2002 SST in Pohnpei were above 27.5°C (Figure 4.11). SST measured in the lagoon are more variable than those in the open ocean. In the western part of the equatorial ocean, surface water is warm; after all the warm pool is established there (Baynham, 1994; Deny, 2008). In the eastern part of the ocean surface water is relatively cool (e.g. Hawaii), warm water having blown from the west to make the water cool (Deny, 2008).

Hoegh-Guldberg (1999) believes that the primary cause of regional bleaching or mass bleaching events is by increased sea temperature. However, Marshall and Schuttenberg (2007), using collected global data, say that regional bleaching is caused by warming of sea surface temperatures and incident light, which are mainly caused by ENSO phenomena. However, the literature reviewed and data analysed in this study indicate otherwise. Coral bleaching events in the western Pacific region can be attributed to cooling of SSTs, not increased warming of the WPWP (Kleypas et al., 2008), while the warming of SST in the cold eastern pacific region may be contributing to coral bleaching events.

4.6.6 Sea level

Pohnpei sea level responds to changes in barometric pressure, where a 1 hectopascal (hPa) fall in pressure for a day or more during normal ocean conditions leads to a change 1 cm rise in sea level (Federated States of Micronesia Climate Change and Seal Level Project, 2006). High pressure in Pohnpei is associated with light winds, hot temperature and bright sun (Lander & Khosrowpanah, 2004). However, during the moderate El Niño year of 2002, the Pohnpei barometric pressure fell below normal pressure readings (Figure 4.14), where during an El Niño event the sea level fall is associated with the eastward displacement of warm water. As water flows eastward, the sea level drops and cooler surface water can move into the western Pacific region. The cooler water also results in a drop in sea level.

However, today climate change and global warming is a hot topic and with the media possibly blowing it out of proportion it is leading to people from island nations thinking sea levels are rising, while in fact this is part of the normal ocean and weather conditions. For example, Pohnpei had unusual increases of sea level in 2007 and 2008. The unusual sea level rise, and accompanying public concern, was mostly due to King (Pergean) tides that affected the outer low-lying atolls of Pohnpei, especially Kapingamarangi, Nukuoro, and Sapwuafik (Hezel, 2009). The sea level rise occurred in the months of November 2007 to March the following year, while in 2008 sea levels rose again in the month of December (Hezel, 2009). The unusual rise in sea level in 2008 happened when the moon’s orbit was approaching closest to the earth (Perigee). The distance between the Earth and the Moon varies on an 8.85 year cycle (Pugh, 2004). As low air pressure is associated with storm surges and 2002 had low air pressure, these contributed to sea level rises. King tides are technically produced at spring tides when the moon is closest to earth and recedes as the moon gets closer and further away during year. There tend to be only two King tides a year and it is not common to have them every year. It could be possible to have storm surge events which occur in relation to the King tide. However, when you have a storm surge during neap tides you do not see it; in contrast, when you have storm surges during spring tides you get sea level rise. It is quite possible Pohnpei will have more storm surges than other years; for example, the barometric pressure data in 2006-2007 showed Pohnpei had them. While there were absolutely none at all in 2003, there were very few in 2005 and 2004. If there was a long enough time series of data collection, such as the 80 years in New Zealand's case, this could predict the next King tides in Pohnpei. During or near the end of Nan Madol construction, sea levels were believed to be lower than normal years. According to Elisson and Stoddart (1991), there were low tides during the Holocene period and the sea level was low in Pohnpei; evidence found in sediment cores supports this (Bloom, 1970; Matsumoto et al., 1986). This would implicate the need for collection of corals on nearby fringing and barrier reefs used as construction materials on the more than 90 human-made islets of Nan Madol.

Today, climate change and sea level rise is often misguidedly identified as the problem for many low-lying atolls (Nunn, 2004). As many low-lying atolls are vulnerable to catastrophic events, depending on their location and people's use, this influences their island's environment. What the islanders have not yet adapted well to is the human effects that are passed on to the marine resources. For example, Tuvalu is a low lying island that is slowly sinking and believed to be the first island country going to be underwater in the future due to sea level rise (Horner, 2004). There has been on-going erosion of the island and salt water intrusion. However, the salt water does not fill the island because sea level rise, but penetrates up under the island's soil. Tuvalu's top soil was scraped by the US military during the Pacific War for military purposes (Horner, 2004) and with years of human alteration of Tuvalu this is contributing to the catastrophic fate Tuvalu is facing. The same threats as Tuvalu are experiencing extend to the low-lying atolls of Pohnpei and other islands of the FSM. The human threats can be controlled for Tuvalu and Pohnpei's low-lying atolls, as is the case of Palmyra Atoll where nature is slowly recovering the atoll to a more natural stage. Palmyra Atoll underwent minor natural changes in size and shape from 1874 and 1940. Major human changes were done by the U.S military between 1940-1945, which dredged channels into the lagoon, created continuous roadways to join several islands, enlarged several islands and created several new ones (Collen, Hughes, & Wallace, 2009). However, since 1945 the island has been uninhabited, construction ceased, and natural erosion has broken several connected islands into small islands. Palmyra Atoll thus represents a unique opportunity to understand how an atoll's islands and lagoon system are subject to change over time (Collen, Hughes, & Wallace, 2009). Today, Palmyra Atoll is a natural marine laboratory for scientists due to its unique isolation from human impacts. However, this is not the case for Tuvalu and the low-lying atolls of Pohnpei where on-going human activities cannot be controlled by nature. The human effects have higher consequences in the longer time period while the natural influences have shorter time scale. The outer low-lying atolls of Pohnpei are at risk to El Niño conditions and threatened by on-going human activities.

The climate of the Pacific Island region is entirely ocean-dependent. When the warm waters of the western equatorial Pacific flow east during El Niño, the rainfall, in a sense, goes with them, leaving the islands in the west in drought. Variations in monthly mean sea level include a moderate seasonal cycle and were affected by the 1997/1998 El Niño. Pohnpei typically experiences its highest monthly mean sea levels around March and its lowest around November and December (Federated States of Micronesia South Pacific Sea Level and Climate Monitoring Project, 2006). As explained earlier, the King Tides occurred in Pohnpei and the outer low-lying atolls in the same months, in November 2007 to March the following year, and in 2008 in the month of December (Hezel, 2009). The Pohnpei mean sea level over the duration of the recording period is 0.71 m (Federated States of Micronesia South Pacific Sea Level and Climate Monitoring Project, 2006).

4.6.7 Currents

The currents inside the lagoon vary in strength with location, reef structures, and alteration of the coastlines. Victor et al's. (2006) sediment study in the southeastern lagoon found complex water circulation patterns and swift currents (0.4 ms^{-1}) being restricted to reef passages and estuaries with small currents (< 0.08 ms^{-1}) prevailing elsewhere. The complex water circulation and currents of the study area are sheltered from oceanic swells and large wind-driven waves. In the northeastern lagoon study area, the Japan Airport Consultants (2006) found that tidal current direction show two patterns, one between northwest (NW) and northeast (NE) and another direction between southeast (SE) and southwest (SW). As for El Niño conditions, Baynham (1994) believes fluctuations in strength of various currents (Figure 4.15) flowing into the western Pacific are related to El Niño periods.

4.7 Conclusion

The Pohnpei sediment, meteorological and oceanographic findings confirm that on-going normal climatic conditions do not affect the Pohnpei Lagoon as greatly as abnormal conditions influenced by El Niño periods. During normal climatic trends, natural influences can still cause environmental stresses for the Pohnpei Lagoon, but these vary depending on locations. For example, rainfall, sea surface temperatures, sea level, and wind may remain constant throughout the year following normal cycles, although, sea levels will rise in the case of King Tide's phenomena, as experienced in 2007-2008. However, during El Niño periods there will be less rainfall, salinity increases in near shore shallow estuaries, sea level will drop, SSTs cools, shifting of trade winds to a stronger westerly gusts and the Pohnpei Lagoon will become highly stressed. I can only assume that the wave and ocean currents might be stronger and swifter on the west coast as well; however, this has not been verified since there was limited wave and ocean current data to analyse. Overall, results from this study suggest that ENSO events will cause dramatic changes inside the Pohnpei Lagoon, which will recover to a natural stage. However, nature is slow to recover and the marine environment may take a lifetime. The ramifications of ENSO events and normal weather conditions should not be considered lightly for both conditions have extreme consequences when combined with human influences.

Chapter Five: Coral and Fish Data

5.1 Introduction

This chapter reviews the information acquired on coral and fish data for the Pohnpei Lagoon. The compiled coral and fish data are used to assess the status of Marine Protected Areas (MPA). A coral and fish spreadsheet was created and analysed with "R" statistical software to allow comparison of the recruitment and productivity of the MPAs to the whole Pohnpei Lagoon. It includes 28 coral stations (Turak & De Vantier, 2005; Bourgoin & Joseph, 2008), 38 fish stations (Allen, 2005), and other coral, fish, and sediment data were compiled from various studies and literature (Victor et al., 2006; Rhodes et al., 2007; Bourgoin & Joseph, 2008; Conservation Society of Pohnpei, 2009a). The Conservation Society of Pohnpei's (CSP) has a new photo-quadrant coral monitoring technique collecting underwater coral photos (Conservation Society of Pohnpei, 2009b). I helped collect photo-quadrant data at 3 of the 16 monitoring stations during my Pohnpei visit. The underwater photos of all the 16 coral stations will be used as baseline datasets for future investigation.

5.2 Coral health

5.2.1 Study sites

Observations of the state of coral reefs were taken at 28 stations within and outside Pohnpei Lagoon (Figure 3.1, Appendix 1) by Turak and De Vantier, (2005) and Bourgoin and Joseph, (2008). The stations included five marine reserves (Stations 1, 2, 10, 24, 27) where the CSP has established long term biophysical monitoring (coral and fish). The five MPAs are mostly adjacent to community centers and co-managed by them, except for Kehpara (Bourgoin &Joseph, 2008) The MPAs are:

1. Kehpara (Station 27), also known as Black Coral, is a family owned barrier reef island resort situated within the Kehpara reserve on the west coast;
2. Dehpehk (Station10) is situated in the northeastern lagoon;
3. Sapwitik (Station 1) is situated in the northeastern lagoon;
4. Mwahnd/Dekehos (Station 2) is situated at the edge of northern lagoon; and
5. Nahtik (Station 24) is situated on the eastern side, with a portion of the reserve extending into the "open ocean".

Dehpehk and Sapwitik are confined to the inner barrier reef, and are described as "lagoonal" sites. Kehpara, Mwahnd/Dekehos and Nahtik include the outer barrier reef. Because of the differences in inner and outer reef zones, they are treated as two distinct ecological zones (Allen, 2005; Turak & De Vantier, 2005).

5.3 Local fishermen's observations

Discussion with local fishermen indicated that some believe that the inner and outer reefs are suffering from over-fishing of herbivorous fish. The local fishermen target mostly herbivorous fish, which graze on algae found on the reefs. The algae growing on corals prevent sunlight from reaching the corals, and corals need sunlight to produce food (Rhodes et al., 2007). The fishermen described how the reefs around the island have changed. For example, twenty or so years ago corals near coastline areas were much healthier and in better condition than today. According to Maxin (personal communications July 4, 2009), an avid fisherman who is now a marine assistant for the CSP, targeted reef fish are being fished in deeper reefs inside the lagoon than in past years, and that corals were bleached in the 1990s inside the lagoon in small patches and have since recovered. Maxin (pers. comm. 2009) also attributed the decrease overtime of reef fish to over-fishing by local fishermen.

5.4 Coral data acquisition

The coral data were acquired from Bourgoin and Joseph's (2008) marine survey report as well as Turak and De Vantier's (2005) Rapid Ecological Assessment (REA) findings in Pohnpei Lagoon. Bourgoin and Joseph (2008) analysed CSP's long term biophysical monitoring data on corals inside and outside the five marine reserves (Stations 1, 2, 10, 24, and 27) on habitat characteristics of coral communities, whereas, Turak and De Vantier (2005) compiled a list of coral species found in the Pohnpei Lagoon and outer islands. They also developed a detailed list of seven coral community types (taxonomic compositions), distinguished from their findings on environmental conditions (water clarity) and ecological characteristics (current flow and wave energy).

The coral data are described in Table 5.1, Appendix 7 and also placed into coral data spreadsheet categories. The spreadsheet in Table 5.1, Appendix 7 is another way to analyse coral health of the Pohnpei Lagoon. The spreadsheet will help give estimates of the overall coral health of Pohnpei's marine resources and the future outlook of the Pohnpei Lagoon, while at the same time it can be compared with the analyses of the photo-quad data from the CSP.

5.5 Reef Fish

5.5.1 Fish study sites

The fish study data consist of 38 fish dive site stations inside and outside the Pohnpei Lagoon (Figure 3.2, Appendix 2). They include the 28 coral sites, with an additional 10 sites Stations 37, 38, 43, 44, 45, 46, 47, 48, 51, and 52.

5.5.2 Fish data acquisition

The fish data were compiled by three surveys; the first was by Allen (2005) during the Rapid Ecological Assessment (REA) of the Pohnpei Lagoon and outer islands (Pakin and And Atoll). Allen's (2005) fish survey was to provide a comprehensive inventory of reef fishes inhabiting Pohnpei Lagoon. Secondly, the fish market survey by Rhodes et al. (2005) examined the overall contribution of individual coral reef fish families to marketed catch from the Pohnpei Lagoon. Thirdly, Bourgoin and Joseph (2008) did a survey analysis of fish abundance and size to assess the five marine reserves' effectiveness.

Rhodes et al. (2007) identified eighteen targeted fish families from about 164 reef fish species recorded during market surveys from January-May 2006. Bourgoin and Joseph (2008) examined the CSP fish data collected from two surveys: 17 fish species recorded in October-November 2004; and 19 fish species recorded during December 2004-February 2005. They identified 14 of 17 reef fish families found in the survey (Bourgoin & Joseph, 2008), and established that 17 reef fish families are considered threatened by fishing. These were divided into reef fish families of herbivores and carnivores, with Mullidae and Labridae (planktivores) being grouped together with herbivores. The herbivore families are: Acanthuridae, Scanidae, Siganidae, Kyphosidae, Mullidae, Labridae, Pomacancthidae, and Mugilidae. The Carinvore families are: Carangidea, Lutjanidae, Lethrinidae, Haemulidae, Kyhphosidae, Balistidae, Caesonidae, Myripristidae, Serranidae, and Priacanthidae. Not monitored by CSP are the herbivores Pomacancthidae and Mugilidae, or Carnivores: Myripristidae and Priacanthidae, since they are not targeted fish species. The fish data are described in (Table 5.2, Appendix 8) and also placed into fish spreadsheet categories.

5.6 Results of spreadsheet using "R" statistics

5.6.1 Introduction

All of the available data were combined into a single spreadsheet and were analysed using contingency tables using the "R" statistic to determine which grouping existed and later put into percentages. The contingency tables 5.3-5.5 are in Appendix 9 and "R" percentages in Appendix 10 table 5.6-5.8. The data were to undertake an Analysis of Variance (ANOVA) test; however, there were not enough data cases to do so.

A number of questions compared various categories of the spreadsheet and their results are in the contingency tables with percentages. The questions are:

1. Is there a relationship between the health of MPA sites' and current strength, waves, or depth?
2. Is there a relationship between fishing sites' coral health, current, and wave energy?
3. Is there a relationship between the MPA's dredging proximity, coral health and sedimentation?

5.6.2 Spreadsheet results

The contingency tables and percentage results were analysed and are as follows:

1. The relationship between non-Marine Protected Area (MPA) and MPA sites and depth, current, and wave energy.

    - 80% of the total sites studied were in MPAs and the other 20% studied sites were in non-MPAs;

- None of the sites studied were rated as having strong currents or strong wave activity;
- There was a strong tendency for sites that were rated as having weak current to also be rated as having weak wave activity;
- There were no obvious differences in wave energy or currents between MPAs and non-MPAs; and
- Across all the sites investigated, about 44% were rated as having weak current and wave activity, about 56% were rated as having weak current and moderate wave activity.

2. The relationship between fishing and non-fishing sites by coral health, currents, and wave energy. No-fishing sites are sites where people choose not to go fishing (usually due to fishing success) or are designated MPA sites.
    - About 20% of the study sites were areas where people do not fish, either because they are in an MPA or because fishing is not successful at these sites. The other 80% of study sites are areas subject to active fishing;
    - None of the fishing and non-fishing study sites were rated as having a strong wave or current activity; and
    - The fishing and non-fishing sites that were rated as having poor coral health were all rated as having weak currents and weak wave activity.
3. The relationship between sedimentation input from dredging distance proximity at non- MPAs and non-MPAs.
    - In the MPAs 13% had poor coral health, 53% had medium coral health, and 34% had good coral health;
    - In non-MPAs 13% had poor coral health, 13% had medium coral health, and 73% with good coral health; and
    - When considering only the MPAs, 13% had high sediment input, 55% had low sediment input, and 26% had medium sediment input.

5.7 Discussion

5.7.1 Introduction

All of the available data were combined into a single spreadsheet (Table 5.1-5.2), Appendix 7-8). The data were to undergo an Analysis of Variance (ANOVA) test; however, there were not enough data cases to do so. The data were then analysed using contingency tables (Table 5.3-5.5, Appendix 9) to determine which groupings existed and also their percentages (Table 5.6-5.8, Appendix 10) using the R statistics software.

Three questions were created to compare various categories of the spreadsheet and results from the contingency tables with percentages. The three questions for analysis were about MPA and non-MPA with regards depths, current and wave action, coral health, live and dead corals, non-fishing and fishing sites, dredging proximity and sedimentation levels.

5.7.2 Current and wave energy at MPA and non-MPAs

The MPA studied sites had no obvious difference in wave energy or currents, which is consistent with poor conditions and the worst affected sites near coastal areas of Pohnpei Lagoon. Such conditions are attributable less to ocean and weather actions than to increased human activities that have altered the coastline. For example, station 16 (Figure 3.1, Appendix 1) is in a bay on the east coast that has been intensively dredged and suffered increased sedimentation. Station 16 follows the same trends as of Kolonia Bay (Tekehtik causeway), with intensive dredging, sedimentation, and pollution. Station 16 and Kolonia Bay (Tekehitik causeway) need to be monitored effectively for future health and marine species concerns. Some corals tolerate areas with low water clarity and need to be further studied for reef resilience. Williams and Hatcher (1983) attribute the lower species richness and numbers of the inshore reefs to the physical and biological environment: higher turbidity and sediment load, reduced levels of incident light, reduced wave energy, high abundance of macro algae, reduced supply of larvae, lack of zonation, and reduced habitat size and diversity. However, some stations near mangrove fringed estuaries and patch reefs do not necessarily have the same effects.

At both the depths (shallow and deep) 80% of the studied MPAs sites had about 44% weak and about 56% moderate current and wave activity. This would suggest that MPA sites have moderate conditions for coral health and fish populations, due to the moderate current and wave conditions keeping regular water flushing at a regular rate. But there was a strong tendency for the sites that were rated to have weak current and wave activity and none of the sites studied were rated as having strong currents or strong wave activity. While the deep depth conditions in the MPAs might be similar to shallow depth MPA sites, the coral and fish diversity does show that some MPA sites are in better condition (Bourgoin & Joseph, 2008) than non-MPA sites. However, this could be caused by a lack of depth data on current and wave energy at certain reef sites or by the contradiction between spreadsheet categories. While there has been limited research on the current and wave conditions relating to depth of the Pohnpei Lagoon, my study does suggest the need for future research on oceanographic conditions of the lagoon.

5.7.3 Fishing and non-fishing sites

Non-fishing and fishing study sites were both rated as having no strong wave or strong current activity. However, both the fishing and non-fishing sites which were rated as having poor coral health were all rated as having weak currents and weak wave activity. This is consistent with poor condition sites having no moderate or strong current and wave energy. The lack of healthy corals and fish populations also suggests why there is no fishing, or only unsuccessful fishing in such areas. While these sites are therefore considered poor it does not necessarily mean that the whole marine ecosystem is unhealthy. There are still ecosystem functions that need to be further studied at such sites. However, these results need further investigation and analysis due to the lack of data from my study and also the contradiction between spreadsheet categories. Over-fishing of herbivorous fish inside the Pohnpei Lagoon by night time spear fishing and sports fishing of predator fish inside and outside the barrier reef needs a precautionary approach, considering the current coral health and oceanographic conditions.

A few local fishermen that I spoke with believe that reefs are suffering from over-fishing in the Pohnpei Lagoon. They have seen how the reefs around the island are different than in the past with less reef fish (local fishermen personal communications July 20, 2009). For example, twenty or so years ago schools of hump head parrotfish and large wrasses could be seen, whereas now they are endangered and rarely sighted (local fishermen personal communications July 20, 2009). Maxin (personal communications July 4, 2009), noticed that fishermen are having to fish for targeted reef fish in deeper reefs inside the lagoon than in past years, and he also attributed the decrease of reef fish overtime to over-fishing by local fishermen. Allen’s (2005) reef fish study found that total fish abundance had the highest recordings in outer reef locations. While outer reefs are rich in fish numbers they are also increasingly threatened by artisanal fishermen and sport fishermen. Pohnpei’s reefs have been constantly fished over the years, either by subsistence or artisanal fishing. Fishing through subsistence involves mainly individual fishermen and their families or community groups, who generally consume their catch. Artisanal fishing is by small, part-time fishing groups who sell some of their catch and consume some of it themselves (Holthus, 1986). More recently sport fishing, which targets predator fish, has become popular, especially with expatriates and locals for the high valued prizes. The sports fishing popularity may affect predator fish populations by the on-going unregulated nature of the fishing and because of no government monitoring. Collaboration between the sports fishing clubs and the government can be beneficial for both, using the sports fishing data to see whether this is affecting the local reef fisheries or not.

Future reef fisheries management plans and regulations need to include sports fishing to create jobs and generate tourist income and at the same time support fisheries management to mitigate fishing stress on the already over-fished Pohnpei Lagoon. On the other hand, as indicated by Holthus (1986), sports fishing could possibly result in competition with traditional fisheries for preferred species. After making a fish market survey, Rhodes et al. (2007) stated that without an overarching policy that combines habitat protection and fishery management practices, Pohnpei's marine environment will continue to decline dramatically. If ENSO phenomena continue to increase due to global warming, subsistence, artisanal and the gaming fishery could be negatively impacted (Garcia, Vieira, & Winemiller, 2001) as well as the Marine Protected Areas (MPA). Pohnpei is heavily dependent economically on herbivorous fish species and also other marine organisms that are targeted for sale. The mangrove estuarine areas (clams, molluscs, crabs) out to the barrier reefs (reef fish, giant clams, sea cucumbers, lobsters) are all being fished. The fishermen's livelihoods will take a major blow, as will the coastal fisheries and health of the marine resources during times of ENSO events (Hay et al., 2003), because of less productive marine stocks during ENSO events, increased cost of fuel to travel to distant fishing grounds caused by shifting of trade-winds, and loss of coral reefs leading to loss of herbivorous fish.

5.7.4 Sediment input

As for the sedimentation input from dredging distance proximity at non-MPA and MPAs, in the MPA sites with poor coral health, 21% had medium sediment input, and about 79% had high sediment input, and all were an intermediate distance from dredging. The MPA sites having 79% sediment input with poor coral health could be located in areas having Crown-of-thorn (COT) starfish outbreaks. As indicated by Turak and De Vantier's (2005) coral survey, COT was sighted mostly in the MPAs. A COT survey is needed to find such relations. Another assumption could be that over-fishing of herbivorous fish populations adjacent to reefs close to MPAs may be another factor, where reduced herbivorous fish populations lead to algal growth on corals. In MPAs with good coral health, 78% of sites had low sediment input, although they were in close dredging proximity. The good coral health may be attributed to location of reefs with moderate current and waves in the area leading to low sediment input. However, this remains conjecture, since most of the MPAs have limited current and wave data. One interesting factor might be that the coral genera in these MPA sites were not affected by dredging because dredging was not done on a consistent basis. Therefore the coral genera of the site remained in good health. An investigation of the types of coral genera, coral larval dispersal, and duration time of dredging in such MPA sites is needed for better understanding.

When considering only the MPAs, about 13% of MPAs studied have high sediment input. That could be related to MPAs being further distance from land. This is ideal for an MPA location, considering its conservation status. However, MPA at distant sites are unlikely to have high sediment level from terrestrial activities. Sediment input at such sites may be from sand mining, where sediments are stirred up by wave action. 55% of MPAs studied have low sediment input. This is likely from having a dredge site operating near an MPA or freshwater inputs from river mouths. The sediment data might contain contradictions between spreadsheet categories. However, it could also be that there is not enough data to run between spreadsheet categories.

5.7.5 Marine management

Pohnpei has been acknowledged in the Micronesian region for having successful community based and government MPA networks. There are convincing arguments that some reef fish populations (inside the lagoon) in MPAs appear to be building-up even though the MPA network implementation is fairly recent for Pohnpei (Bourgoin & Joseph, 2008). However, the establishment of MPAs cannot be the only protection for corals and fish in the Pohnpei Lagoon. Recent research in New Zealand suggests that the current level of knowledge is insufficient for ecologists to predict detailed outcomes of creating new MPAs in other habitats and regions (Langlois & Ballantine, 2005).

The changes in MPAs are likely to be affected by many factors. The MPA size and shape, spatial arrangement of area (relation to currents), behaviour changes responding to new population structures, changes in food webs, and others (Denny, Willis, & Babcock, 2004; Neigel, 2003; Parson & Egli, 2005). MPAs should be designed using a process that clearly defines the role of the general public, scientific community, enforcement officers, fisher communities and other stakeholders. The aim of the process should not be one of compromising scientific advice with the will of fishers, but instead achieving mutually agreed upon goals related to sustaining coral diversity and fisheries into the foreseeable future (Sobel & Dahlgren, 2004).

There are some useful rules of thumb for designing MPAs or MPA networks. While different goals could result in different designs, it is worth paying special attention to understanding the ocean and weather conditions of the MPA sites. This is to minimize the risk of creating MPAs in collapsing fished populations, poor coral health conditions, and the fisheries and ecosystem that it support. Supporting local communities' needs to help strengthen the success of Pohnpei's MPA is also advised. The MPAs provide a seed bank for coral and fish since they are being depleted elsewhere. The movement of larvae by flow will be different at each MPA site. Some currents can create a spatially structured environment even in the absence of variation in habitat quality; different locations may have different value with respect to both conservation and resource management. Therefore, sitting MPAs in different locations may have different outcomes (Gaines, Gaylord, & Largier, 2003). The lack of understanding of ocean and weather patterns at Pohnpei's MPA sites needs to be fully overcome before establishing new MPAs. There are no records of SST in or near Pohnpei's MPAs. Underwater sensors near existing MPAs can be valuable for future research to monitor changes of SSTs, salinity, currents and wave energy. There is also a growing list of MPA factors that are poorly understood, such as the socio-economic effects on fishing communities' livelihoods and to their already dwindling fish sites caused by the pressure to add more MPAs. However, MPAs are also known to replenish nearby reefs from the spillover effects, providing more fish stocks for the fishing communities (Sobel & Dahlgren, 2004).

Policing illegal fishing of MPAs is an on-going issue for the government's and partner's, due to the lack of budget, and policy constraints. However it must be emphasized that perhaps the most important determinant of MPA performance is the degree of protection (Roberts et al., 2001) and the current relationships that are involved. By fully investigating the current state of how human and natural impacts are affecting the MPAs will therefore provide better understanding, if new MPAs sites are to be created.

The studied reef areas show that corals may be well off oceanographically if located near reef passes or the barrier reefs. This confirms what Turak and De Vantier (2005) stated about Pohnpei's outside reefs' increased coral diversity and Allen's (2005) observation on increased fish population at reef passages and barrier reefs. Poor coral health sites could be related to dredging from past and recent years and having MPAs at coastally developing areas. The mangrove estuaries, seagrass beds, and patch reefs are highly stratified in suspended sediment concentrations, thus, threatening nursery sites and migration paths of various marine and freshwater species like the freshwater gobies and ocean shrimp (Buden et al., 2001). The CSP sediment data show both temporal and spatial sedimentation patterns which are similar to Victor et al.'s (2006) findings. For example, sedimentation rates decreased with increased distance from land. However, the CSP sediment monitoring study area is different by having been greatly altered by coastline development, which is still on-going. Furthermore, the Victor et al. (2006) study area was influenced by clearance of upland forests, producing sediments that were carried into the sea by river. Both studies confirm that sedimentation is greater at near-shore coastal areas and less nearer the barrier reef.

5.8 Conclusion

Overall, the coral and fish data of the MPA and non-MPA sites show a highly stressed marine environment inside the Pohnpei Lagoon, with on-going human threats. The reef passes, barrier reef and outer deeper depths may have consistent flow of current and wave energy influenced largely by oceanographic conditions, feeding an environment of healthier corals and increased number of fish species due to the availability of food. Such an environment may have less or no sediment load from land, but on occasions have sediment input from sand mining activities at sandy reef sites. Human activities, like sand mining, over-fishing of herbivorous and predator fish, and on-going mari-cultures sites, have already contributed to changing current and wave patterns in nearby coastal areas. Such factors may contribute to poor coral health growth and loss of fishing sites.

While my data is limited it does show that there is tremendous pressure on the marine environment from human activities, leading to higher turbidity and sediment load, reduced levels of incident light, reduced current and wave action, and poor water quality. These may lead to high abundance of macro-algae, reduced supply of larvae, water borne disease, loss of herbivorous and predator fish, and coral bleaching. Such factors may lead to increased dominance of coral species over other taxa, changing coral species composition, structure, and coral communities, increase competition and predation by less dominant species, and potentially cause possible collapse of subsistence, artisanal, and sports fishing inside the Pohnpei Lagoon.

The MPA and non-MPA sites will therefore be threatened by such factors. Therefore, minimizing the risk to the current MPAs, the government should take into consideration how best to lessen human threats before a collapse of the local fish populations and coral diversity. With respect to our policy makers, regarding my support for creating more MPAs inside and outside the Pohnpei Lagoon, we must fully investigate the on-going human threats to our marine environment first before establishing any new MPAs.

5.9 Pohnpei visit and underwater observation

5.9.1 Introduction

The Conservation Society of Pohnpei (CSP) is conducting a long-term coral reef monitoring program to observe trends in Pohnpei's coral reef communities. CSP's coral monitoring program added the photo-quadrant technique in 2009 and all photo quadrant datasets will be used as baseline data. This photo-quadrant technique yields 250 data photos per transect, and a total of 1,250 photos per site (Conservation Society of Pohnpei, 2009b). The photo-quadrants are analysed using Point count software from (http://www.nova.edu/ocean/cpce/) free of charge (Coral Point Count Program, 2009). The Point count software analyses the coral photo frames by recording the genus of corals, algae, and other invertebrates under 5 randomly generated points. This design has been shown to adequately detect a desirable level of ecological change over time with high statistical power (Houk & van Woesik

2009). The photo-quadrant data are directly comparable with the CSP's existing biophysical datasets. The coral data draw relations with standardized, replicated measures of overall biological diversity, environmental, and biological data.

5.9.2 Conservation Society of Pohnpei (CSP) photo-quadrant site visits

I joined CSP for coral monitoring surveys at three out of their 16 total photo-quadrant monitoring stations. One of the three coral stations we monitored was done inside the lagoon (Parem Reef) and the other two outside the lagoon (Areu Pass and Kitti site). The 16 photo-quadrant stations are on the East and West coast of Pohnpei categorized by station name, number, and photo location. The photo-quadrant station names are described by the following: E=East, W=West, OB=Outer Barrier, IB=Inner Barrier, PR=Patch Reef and FR=Fringing Reef. The sixteen photo-quadrant stations names are: EOB2, EIB2, EPR2, EFR2, EFR1, EIB1, EOB1, WFR2, WFR1, WIB2, WIB1, WOB1, WOB2, WPR1, and two missing data sites; WOB2 and WFR1. There will only be 14 photo-quadrant sites of the corals out of the 16 photo-quadrant stations, due to on-going monitoring that is yet to be finished being slowed by weather conditions. The 14 photo-quadrant sites are compiled onto a compact disc for future referencing. Please look in the back cover of the thesis. The data I collected with the CSP are described below: site location, photo identification and ecological characteristics (Figure 5.1-5.2).

Site: EPR2, inside lagoon

Photo location: Parem Reef

Ecological characteristics: Low wave and current energy, medium sedimentation, low visibility, mostly coral rubble at 10 m.

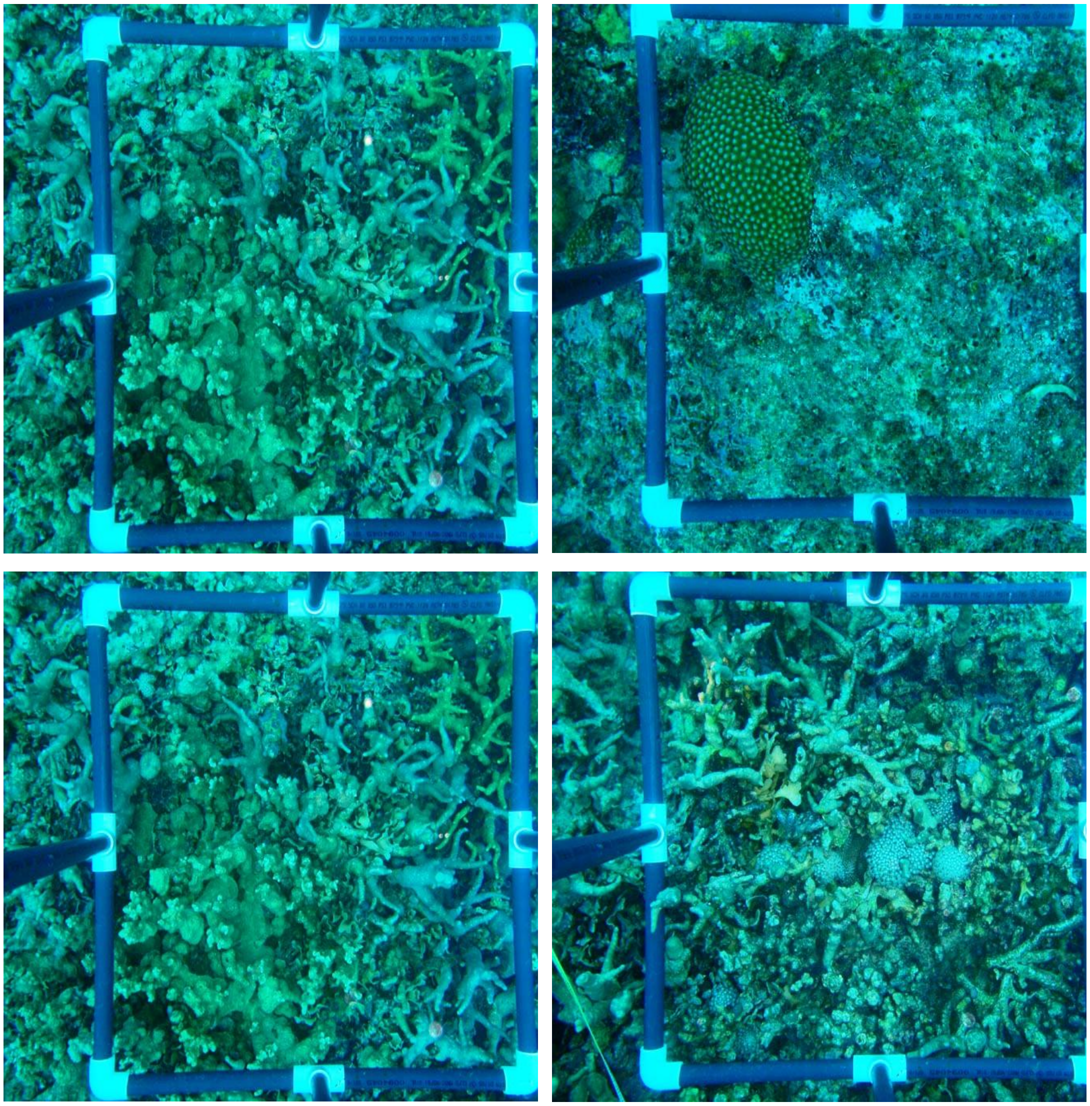


Figure 5.1: Inside lagoon underwater photo at Parem Reef at 10 m on July 2009 (CSP photo, 2009)

Site: EOB1, outside lagoon

Photo location: Areu Pass

Ecological characteristics: High wave and current energy, high visibility, flat coral tables and soft corals, flat reef extends into deeper water.

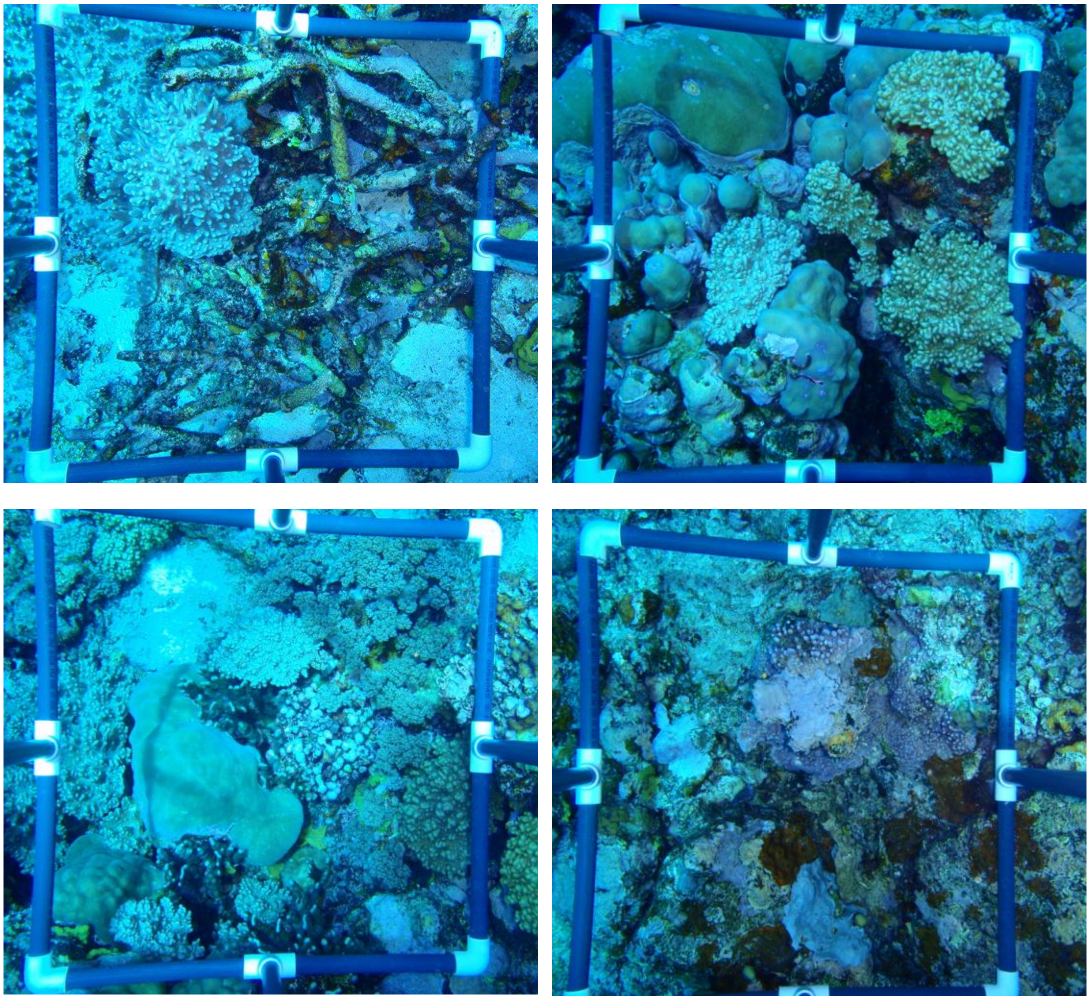


Figure 5.2: Outside barrier reef underwater photo monitoring at Areu Pass (CSP photo, 2009)

Site: WOB2, outside lagoon

Photo location: Kitti

Ecological characteristics: High wave and current energy, high visibility, coral boulders with steep sloping terraces as depth increases, and drops into deep reef wall.

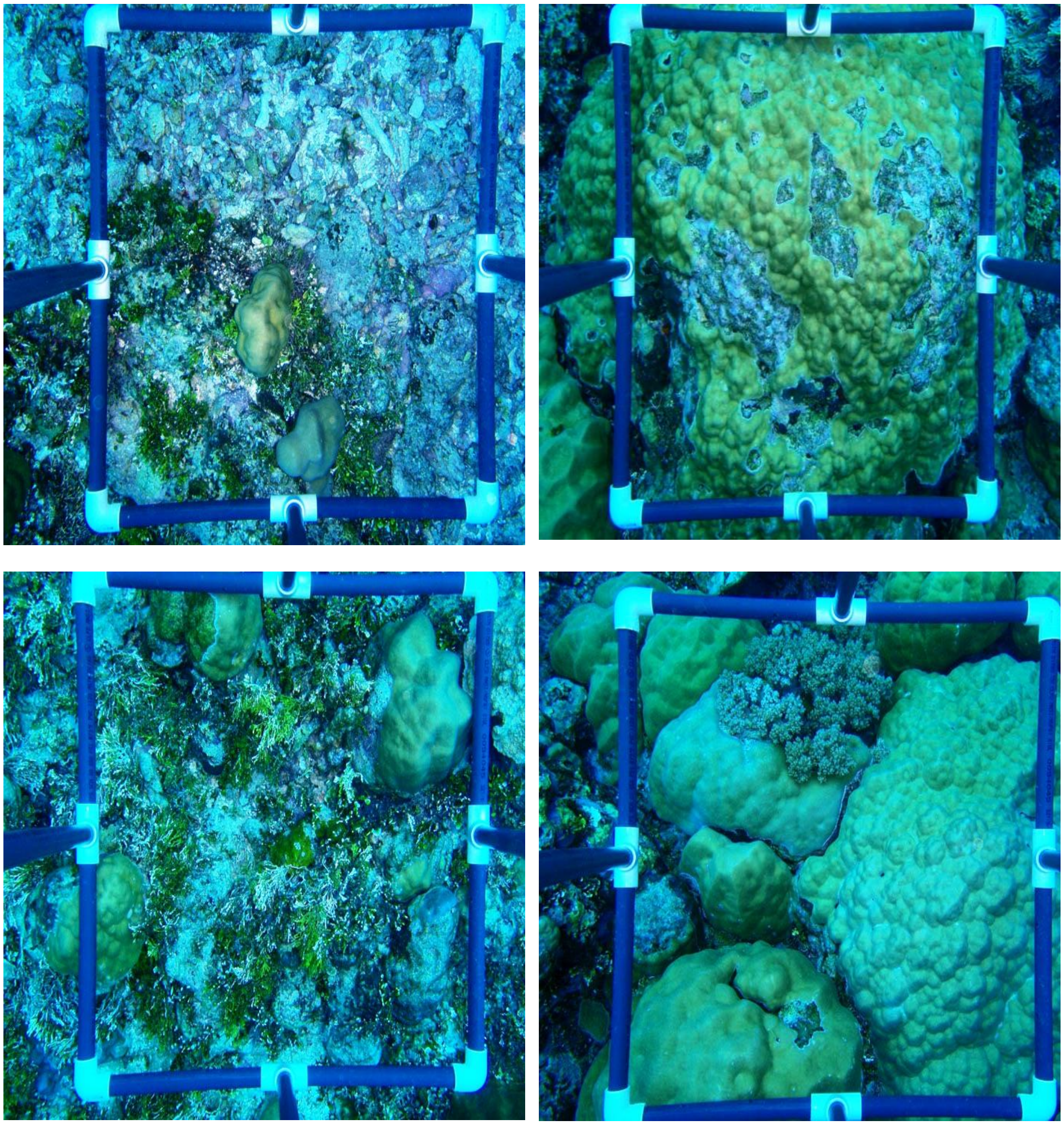


Figure 5.3: Outside barrier reef underwater photo monitoring at Kitti reef (CSP photo, 2009)

5.9.3 Photo-quadrant analysis and discussion

The three photo-quadrant monitoring stations showed significant differences inside and outside reefs. At EPR2 (Figure 5.1), inside the lagoon Parem Reef the upper reef flat appeared healthy with no signs of coral bleaching. This could be from regular surface currents and availability of sunlight. However, at 10 m coral species changed with depth, color, and appear to be in poorer condition than upper reef areas. At 10 m there was less underwater current action, less sunlight, and low visibility. I assume corals at 10 m and > 10 m inside the Pohnpei Lagoon may be of various coral species that may tolerate such depths and conditions. However, the poor coral conditions at 10 m may appear to have been from past and present threats attributed to sedimentation, over-fishing, and pollution. The coral data will be analysed using the Coral Point Count Program (CPCe) at http://www.nova.edu/ocean/cpce/ (Coral Point Count Program, 2009). The monitoring day for Parem Reef was after heavy overnight rainfall, so my observations could have been hampered by on-going suspended sediments and water visibility. Whereas, heavy rainfall and on-going sediment flow after such weather conditions could be a factor of poor coral health conditions, there are other factors to take into consideration caused by other disturbances (physical or biological) or rate of disturbances (Connell, 1978; Sousa, 1984).

The two outer barrier reef sites EOB1 and WOB2 (Figure 5.2 and 5.3) had clear visibility, increased sunlight and strong current action. Underwater photos outside the lagoon had clearer visibility than inside the lagoon. It also appears that outer reef corals are in better conditions than most of the inner reef corals, as indicated by various scientists who have done studies inside and outside the Pohnpei Lagoon. The rate of disturbances on the spatial and temporal scale could be a factor (Connell, 1978; Sousa, 1984), caused by habitat recruitment and post-settlement processes (Gaines & Roughgarden, 1985; Todd, 1998; Mora & Sale, 2002).

5.9.4 Conclusion

The three photo-quadrant monitoring stations showed significant differences inside and outside reefs, however a better analysis of all the 16 photo-quadrant monitoring stations will better inform help pinpoint what factors might be causing such differences. Meanwhile, my current present analysis is presenting what factors that are affecting the three photo-quadrant monitoring stations. Therefore, the 14 photo-quadrant sites are compiled onto a compact disc for cataloguing and for future referencing and research work.

The on-going lack of scientific data, local science experts, funding, and technology may hinder the Micronesian regions vast reef systems, but it makes up for this in traditional knowledge by its strong-minded Micronesian leaders for conservation measures. The "Micronesian Challenge" is a commitment by the Micronesian leaders of Federated States of Micronesia (FSM), the Republic of Palau, the Republic of the Marshall Islands, Guam, and the Commonwealth of the Marianas Islands to effectively conserve at least 30% of the near shore marine areas and 20% of the terrestrial areas of the Micronesian regions by 2020 (Micronesian Challenge, 2009). The next chapter will discuss the major findings from human and natural disturbances that are affecting the coral diversity and fish populations of the Pohnpei Lagoon.

Chapter Six: Discussion

6.1 Introduction

In the past, coral diversity and fish population in the Pohnpei Lagoon have been resilient and recovered from adverse events, but both may now be seriously threatened by natural and human influences. Various human and natural influences have been identified as reducing coral diversity and fish population within Pohnpei Lagoon. Human threats include sedimentation, over-fishing, and pollution. The natural influences include changes in sea level, rainfall, trade winds, salinity, and water temperature. The human effects are thought to have greater consequences on the marine environment and species over longer time periods than do natural influences on the marine environment and species, which tend to involve shorter period fluctuations. The key to economic and cultural development for Pohnpei is to not only provide for an improved quality of human life, but importantly, to maintain and improve the natural ecosystem (Department of Economic Affairs, 2007).

6.2 Major findings of this study

Meteorological and oceanographic conditions, such as the ENSO phenomena, play a significant role in relation to coral diversity and fish within the Pohnpei Lagoon. The Pohnpei climate and oceanographic data (sea level, winds, rainfall, and air and water temperature) appear to follow a trend over the duration of the record (2002-2009), but this trend is much smaller than the year-to-year fluctuations.

The most striking oceanic and climatic fluctuations along the equator in the Pacific are not seasonal, but inter-annual changes associated with ENSO. The ENSO affects a wide range of parameters, including sea level, winds, rainfall, and air and water temperatures. The El Niño phase of ENSO plays an important role in coral reef health. During El Niño in Pohnpei, sea level drops substantially, so the water depth within the lagoon gets shallower, and surface waters gets cooler. These changes could affect primarily species on the reef flat and lagoon edges, where water depths are already restricting coral growth.

Another weather/climate oscillation involving migration zones of higher and lower pressure is the Madden-Julian Oscillation, with a period of 30-90 days. It brings higher than average atmospheric pressure over Pohnpei and is associated with light winds, increased temperatures, increased sunlight due to clearer skies (Lander & Khosrowpanah, 2004) and sea level rise. It is also associated with reduced air pressure and is attributed with increased storminess, including more storm surges and stronger winds, cooler water temperatures, and lowered sea levels.

As Pohnpei is a coral atoll, sea level is closely related to ocean circulation (Lander & Khosrowpanah, 2004), unlike New Zealand where oceanic effects are modified by a continental shelf. This is why ENSO has a strong effect on sea level. During El Niño water flows eastward from the Warm Water Pool, changing the relative strength of the North and South Equatorial Currents and Counter-Current. As water flows eastward, the sea level drops and cooler surface water can move into the region. The cooler water also results in a drop in sea level. La Niña conditions result in a strengthened westward flow of surface water along the equator. These trends increase the size of the Warm Pool and raise sea levels. However, compared to normal conditions, La Niña has much less impact (about an order of magnitude less) than El Niño.

Turbulence is high at reef passages into Pohnpei Lagoon and along the outside barrier reefs, providing significant protection to corals from changes in air and water temperature due to mixing with deeper water (Rasheed & McKenzie, 2005). Inside the lagoon, some reefs are protected from increases of SST, caused by El Niño conditions by freshwater discharge from various rivers, streams and underwater springs, and sheltering by mangrove forests, seagrass beds, and reef holes.

Photo-quadrant monitoring shows inside reefs may be in poor condition, due to reductions in freshwater discharge linked to changes in rainfall patterns, sedimentation, over-fishing, and pollution. Outside reefs are in better condition due to turbulence resulting in greater mixing and dilution of harmful factors. However, in the future, both reef areas may be affected by various disturbances (biological or physical) on different and temporal scales (Connell, 1978; Sousa, 1984), leading to changes in biodiversity and species dominance (Gaines & Roughgarden, 1985; Todd, 1998; Mora & Sale, 2002).

During the past decade, coastal development around Pohnpei Island has increased, but development is now being monitored, reported, and controlled by the governments. There is evidence of extinction of species and increasingly threatened marine species that are of great concern, including:

- Extinction of giant clams *Tridacna gigas* (Tsuda et al., 1974);
- Locally threatened Napoleon Wrasse and Bumphead Parrot fish (Rhodes et al., 2007);
- Coral bleaching by both sedimentation and predation from Crown-of-thorns (COTs) starfish (Tsuda et al., 1974; Turak & De Vantier, 2005);
- Overfishing of herbivorous fish by night-time spear fishing (Rhodes et al., 2007);
- Locally threatened freshwater gobies and ocean shrimp due to sedimentation caused by poor land use practices and alteration of the coastline (Buden et al., 2001);
- High tropic level predator fish populations threatened by sports fishing and competition with traditional fisheries for preferred species (Holthus, 1986);
- Mangrove forests and sea grass beds are locally threatened by sedimentation and on-going dredging for coral rubble (McKenzie & Rasheed, 2005); and
- Development of mari-culture and aquaculture utilizing marine species, for export, reseeding and the aquarium trade, that reduce water quality and spread diseases.

All such threats could lead to:

- Increased growth of algae on corals;
- Loss of herbivorous algae-feeding fish;
- Increased dominance of coral species, like the poritids, over other taxa (Turak & De Vantier, 2005), changing coral species composition and structure of the coral communities;

- Increased competition and predation by less dominant species; and
- Poor water quality with increased diseases in the Pohnpei Lagoon.

All such threats can affect the health of the whole marine ecosystem, and hence the livelihoods of local fisherpersons, as well as increasing health risks for the general public.

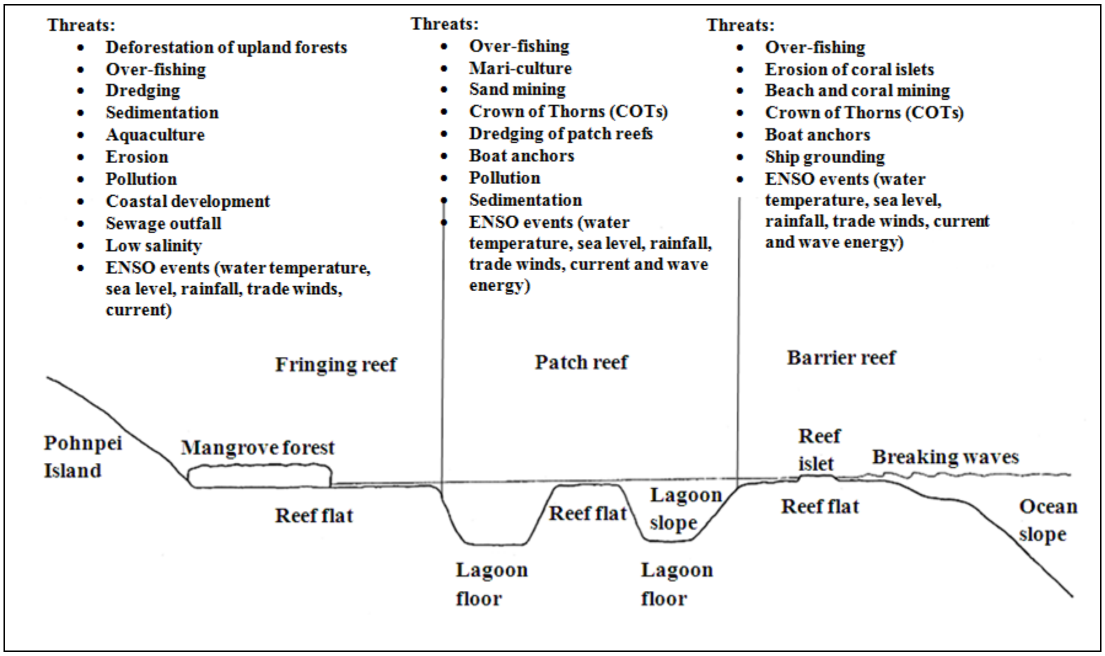


Figure 6.1: On-going and present threats from natural and human activities to the fringing, patch and barrier reef of Pohnpei Lagoon.

Figure 6.1 summarizes the various natural and anthropogenic effects that threaten the different environments within Pohnpei Lagoon, from the fringing mangrove forest to the barrier reef's ocean slopes. For example, the fringing mangrove forest to fringing reefs are nursery sites for juvenile fish, seagrass beds serve for turtles as feeding grounds, and there are other important uses by various marine species. However, near-shore coastline areas are constantly being developed and harvested leading to increased sedimentation and pollution. The patch reef to lagoon slopes provide a safe haven for corals and other marine species from strong currents and wave action, therefore, ideal for fishing of reef fish stocks, sand mining, and mari-culture.

But increased fishing inside lagoon can also lead to overfishing of reef fish stocks, boat anchors breaking corals, sedimentation from sand mining and dredging of reefs, to various loss of nutrients and poor water quality caused by mari-culture sites. The barrier reef to ocean slope may be healthier, with increased number of species encouraged by the constant availability of food created by oceanographic currents leading to upwelling of nutrients. However, all the different environments, mangrove/fringing, patch, and barrier reef, are susceptible to the El Niño phase of the ENSO phenomena. Where sea level drops substantially, water temperature and depth within the lagoon gets shallower, and surface waters get cooler. These changes then affect the primary species on the reef flat and lagoon edges. According to Smith (1988), the *"...longevity of species exposes many years* [sic] *classes* [of fish] *to exploitation and long-lived species are generally characterized by low reproductive rates"* (p.104).

In summary, my study findings show that the environmental damages caused by natural influences recover as part of natural processes, whereas the human activities, including sedimentation, over-fishing, and pollution, have potential to alter Pohnpei's marine environment, speeding up the environmental damages, and slowing the recovery period of the natural processes. The main impact on the Pohnpei marine environment related to climate is the effect of El Niño events, where sea-level is lowered, water temperature becomes cooler and drought conditions and strong winds occur, which contribute to coral bleaching events. The effects of human activities can exacerbate the impacts of El Niño events and potentially slow the natural recovery from such events, especially El Niño events. Thus, both the natural and anthropogenic threats need to be investigated thoroughly for the marine environment before serious long-lasting ramifications occur. The next chapter proposes some recommendations and actions for the future health and sustainable practices of the Pohnpei Lagoon.

Chapter Seven: Actions, Recommendations and Conclusion

7.1 Overview

Pohnpei's Marine Protected Areas (MPA) requires full investigation of marine scientific research along with traditional knowledge and uses. The potential recommendations provided here are steps for governments, MPA managers, and local communities to take to mitigate the human and natural threats to Pohnpei's marine ecosystems.

On the basis of work done in the present study, the following actions are suggested and recommendations are made for the local and regional institutions for present and future research on MPAs and the marine ecosystems.

7.2 Actions to be taken

Serious action must be taken now for the Pohnpei Lagoon, low-lying atolls, and the Federated States of Micronesia (FSM) region. Past and present data is showing significant changes not only to the marine ecosystem, but also the terrestrial areas as a whole. Using the Precautionary Principle can help further the long term health of the marine ecosystem lifelines.

7.2.1 Precautionary Principle

The use of a precautionary approach is advised for the Pohnpei Lagoon and the low-lying atolls, due to lack of scientific understanding of the ocean and weather conditions. The Precautionary Principle was integrated and implemented after talks on sustainability in the 1992 Rio Conference (Raffensperger & Tickner, 1999). The definition of the Precautionary Principle states that when an activity raises threats to harm human health and environments, precautionary measures should be taken if scientific understanding and measures are not fully established. The principle components of it are (Kriebel & Tickner, 2001):

1. Taking preventive action in face of uncertainty;

2. Shifting the burden of proof to the proponents of an activity;
3. Exploring a wide range of alternatives to possibly harmful actions; and
4. Increase public awareness in decision making.

Adoption of the Precautionary Principle can also benefit the data collection process which will lead to improvements in the area of marine management, technical resources, funding, and scientifically determined analysis. Due to a lack of scientific data the use of the Precautionary Principle should be applied to governments, business, and the general public who are involved in activities with potentially grave environmental impacts, and such institutions should take into consideration the ocean and weather conditions of the areas during environmental impact assessments before proceeding with any particular method or site-specific development. Where negative impacts are possible or likely, such projects should be stopped, monitored, modified, and reviewed under strict guidelines.

The Precautionary Principle requires decision makers to take action. However, there are few guidelines and those that are there are not particularly operable guidelines for policy makers (Raffensperger & Tickner, 1999). Yet it is accepted as a guiding principle for policy making by many governments and international institutions, such as the European Union (E.U), United States public and environmental groups, and the United Nations (U.N) (Cameron, & Abouchar, 1991). Therefore, the governments of Pohnpei and the Micronesian region can accept the Precautionary Principle as a guide to policy making to anticipate and act on environmental problems before there is full scientific understanding of the given circumstances.

7.2.2 Key recommendations

There are four key recommendations from the results of this research:

- Integrate coral and fish monitoring during and after El Niño events to understand El Niño effects on the Pohnpei environment;
- Undertake investigation into the population of herbivorous fish inside and outside MPAs to combat algal growth on corals;

- Do not cut down vegetation along coastline areas, as it prevents erosion;
- Investigate *Symbiodinium* coral clades in Pohnpei Lagoon and the outer low-lying atolls.

7.2.3 Local recommendations

Here are a few local recommendations to help mitigate the on-going human threats in the Pohnpei Lagoon:

- Environmental impact assessment (EIA's) protocols should be reviewed and revised to be in line with today's climatic conditions and population growth;
- Launch boats in narrow areas instead of having to dredge mangrove channels so vegetation protects populations from natural disasters, such as tsunamis and typhoons;
- Collaboration and sharing of sports fishing data between the Pohnpei State Government and sports fishing clubs;
- The use of the precautionary approach is advised due to the lack of scientific data and also a lack of an immediate management response that merges traditional knowledge and use with scientific data analysis;
- Closure of fishing in mangrove estuaries, patch reefs, channels, and outer reefs that are not in the MPAs on a rotational basis in certain months during, and following an El Niño year when the environment as been stressed should be undertaken.

7.2.4 Regional recommendations

While some information is available regarding Pohnpei, very little is recorded for other parts of the FSM. Below are some recommendations for the FSM and regional states:

- To have the "Micronesian Challenge" sponsor climate risk related programs for the Western Pacific regions;

- Create a fund for all “Micronesian Challenge” signatory islands to set up a student scholarship for terrestrial and marine research attributed to climatic conditions.

7.3 Recommendations for future research work

The work in this thesis was limited by the information available. Suggested future research could include:

- Have the government and non-profit organizations install temperature, salinity, current, and wave gauges to track changes inside Marine Protected Areas (MPA) and coastlines of Pohnpei;
- Investigation of upwelling areas outside barrier reef to include on-going scientific monitoring for the Conservation Society of Pohnpei and partner agencies;
- Future marine research should also target the two outer low-lying atoll MPAs; Oroluk Atoll and Minto Reef;
- Implement the use of modeling studies into current coral, fish, and sediment data monitoring to address the regional climate related ecosystem concerns;
- Make investigation of Tekehtik causeway to understand the erosion and sedimentation rate and water flow;
- Undertake investigation of migration and spawning areas for freshwater gobies and ocean shrimp;
- Conservation Society of Pohnpei marine monitoring surveys to should include reef hole areas in their fish and coral monitoring sites;
- Have a coral core investigation to find coral bleaching timeline of Pohnpei Lagoon;
- Investigation of the effects on the 1905 typhoon on outer low-lying atolls for future management decisions during natural disasters should be undertaken;
- Investigation studies of current mari-culture and aquaculture projects for nutrient levels should be undertaken to better monitoring water quality;
- Monitor the sediment at western and eastern reefs and compare with on-going sediment data monitoring;

- Use of the current bathymetry maps for future research in the Pohnpei Lagoon;
- Use remote sensing methods (e.g. using multispectral satellite data and hyperspectral airborne data) in Pohnpei's coastal environment for detailed benthic habitat monitoring and management purposes.

7.4 Conclusion

The thesis findings will contribute to the understanding and stability of the Marine Protected Areas (MPA) of Pohnpei, the marine environment, and the vast ocean of the Micronesian region. The Pohnpei MPA networks provide a means for protecting, conserving, and managing Pohnpei's marine resources. They are also a valuable place to conduct meaningful scientific research that will help understanding of the value of Pohnpei's reef systems. The marine environment is affected by both human and natural factors.

My study shows that it is more critical to control human factors during times of abnormal weather conditions so as to have a lesser affect on the marine environment. Pohnpei Lagoon can adapt to slow changes as part of its natural cycle from which it recovers over a certain timescale, but may not recover over the longer time scale from sudden changes caused by human factors.

The weather and climate at Pohnpei are strongly affected by ENSO variability. Coral bleaching is not necessarily temperature related as there are other factors. However, when corals bleach they recover by "symbiont shuffling". This is an ingenious way in which corals host one or more varieties of their zooxanthelle (*Symbiodinium* symbiont Clades) that are more tolerant of the stress caused by increased SST and human factors. Ranges of herbivorous fish tend to help corals by grazing on algaed dominate areas, and it is unclear whether the fish community is likely to retain a trend of resilience as fish numbers decline due to over-fishing. Many reefs in the world exhibit similar environmental conditions and have the ability to recover from large-scale climatic and human disturbances. Humans have greatly impacted on the coral diversity and fish populations in the Pohnpei Lagoon by over-fishing and contributing to the accelerated sediment inputs.

During El Niño periods, there will be less rainfall, salinity will increase in near-shore shallow estuaries, sea level will drop, SSTs will cool, there will be shifting of trade winds to stronger westerly gusts, and the Pohnpei Lagoon will become highly stressed. The present thesis investigation may lack valuable data on ocean and weather patterns; however, it presents convincing arguments that coral reefs and reef fish populations are not only affected by human factors (sedimentation, over-fishing and pollution), but also natural factors (rainfall, wind, sea level, salinity, air and water temperature) during an ENSO phenomenon. Therefore, corals in Pohnpei could be protected by Pohnpei's climate, location in the Western Pacific Warm Pool, various rivers and streams, dense mangrove forests, seagrass beds, reef holes, underwater spring waters, complex reef systems, and having multispecies of *symbiodinium* clade corals. However, coral reefs are strategically located in different unique regions of the world with different ocean and weather conditions.

Idso (2009), points out that,

> *…the earth's corals will likely be able to successfully cope with the possibility of further increases in water temperatures, be they anthropogenic-induced or natural. Corals have survived such warmth and worse many times in the past, including the Medieval Warm Period, Roman Warm Period, and Holocene Optimum, as well as throughout numerous similar periods during a number of prior interglacial periods; and there is no reason to believe they cannot do it again, if the need arises.* (p.25)

It has been reported that increased sea surface temperature (SST) is not the only cause of coral bleaching (Podesta & Glynn, 1997). Coral bleaching may also be caused by ocean and weather conditions on a shorter timescale, e.g. ENSO events, from which coral recovers, whereas numerous human factors on a larger time scale are limiting coral recovery periods. However, pinpointing what types of meteorological and oceanographic conditions lead to coral bleaching is still a challenge, especially since the various data records vary depending on local and regional conditions in the Micronesian region and Pohnpei.

While my data is limited it does show that there is a tremendous pressure on the marine environment from human activities, leading to higher turbidity and sediment load, reduced levels of incident light, reduced current and wave action, and poor water quality. These may lead to a high abundance of macro-algae, reduced supply of larvae, water borne disease, loss of herbivorous and predator fish, and coral bleaching. Such factors may lead to increased dominance of coral species over other taxa, changing coral species composition, structure, and coral communities, increased competition and predation by less dominant species, and potentially cause possible collapse of subsistence, artisanal, and sports fishing inside the Pohnpei Lagoon. However, the recent monitoring work done by CSP using the photo-quadrant technique, and my study findings, may encourage better results helping policy makers to make more-informed decisions about the future of Pohnpei's marine environment.

Illegal fishing of MPAs, association with policy constraints and a lack of budget and, is an on-going issue for the governments and partners. However, in the past five years there has been an increased amount of work done to help improve scientific monitoring, reporting, and enforcement in the MPAs. A great example is the collaboration work done by regional leaders who created the "Micronesian Challenge", to conserve at least 30% of the near- shore marine areas and 20% of the terrestrial areas of the Micronesian regions by 2020 (Micronesian Challenge, 2009). To help minimize the risk to the current MPAs the government should take into consideration how best to lessen human threats before there is a collapse of the coral diversity and local fish populations. Due to a lack of scientific data the policy makers should apply the use of the Precautionary Principle.

Scientific investigation, using meteorological and oceanographic data, requires a collaborative effort from everyone. The recent monitoring work done by CSP using the photo-quadrant technique, and my study findings, have implication for policy makers to make more-informed decisions about the future of Pohnpei's marine environment. This will help improve the future coral diversity and fish populations in the Pohnpei Lagoon and contribute to the overall work in the Micronesian region. The sustainable management of coral reefs and fisheries is vital for Pohnpei and the Micronesian region's economic development and cultural heritage in the long term.

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Appendix 1

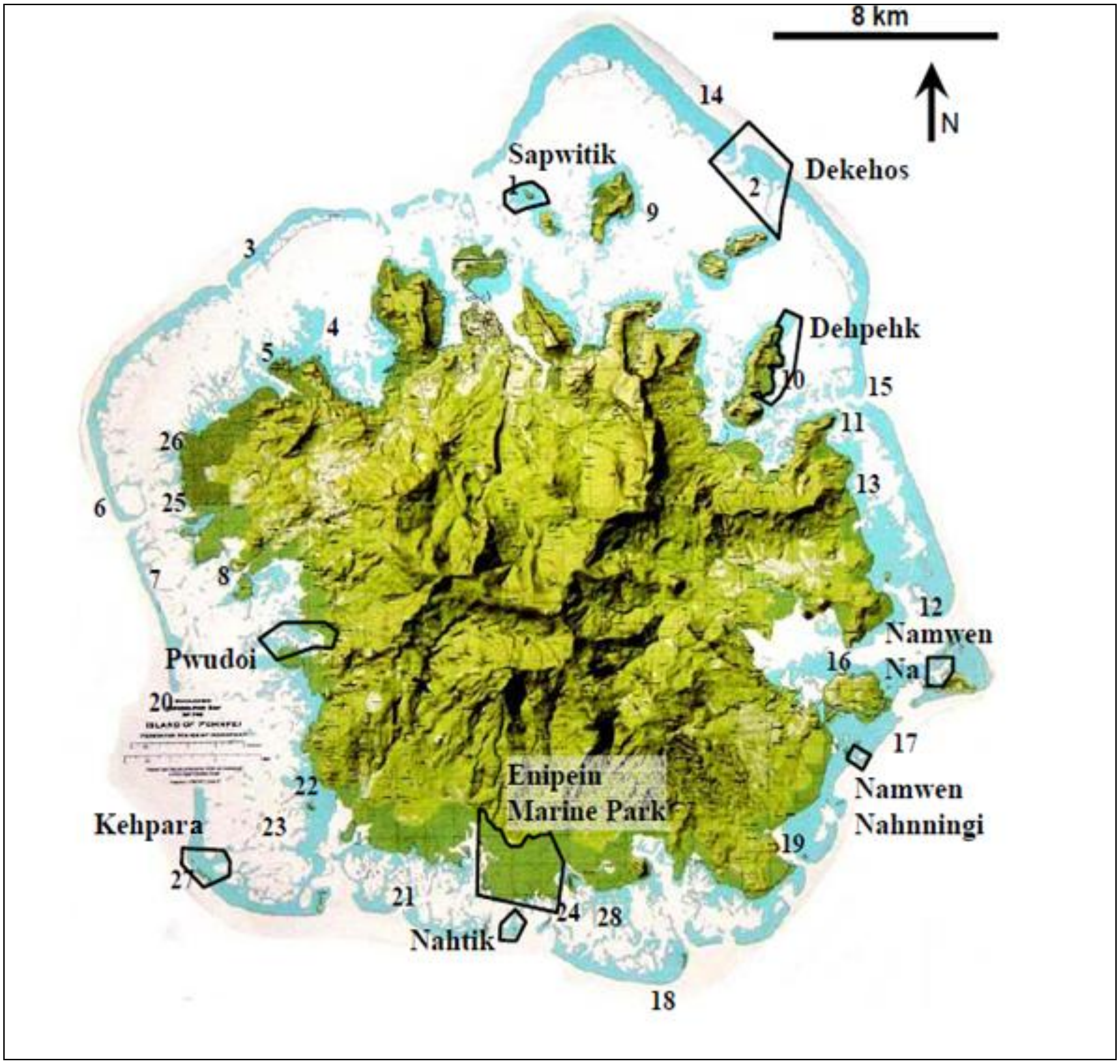

Figure 3.1: The 28 coral monitoring stations (Turek and De Vantier 2005).

Appendix 2

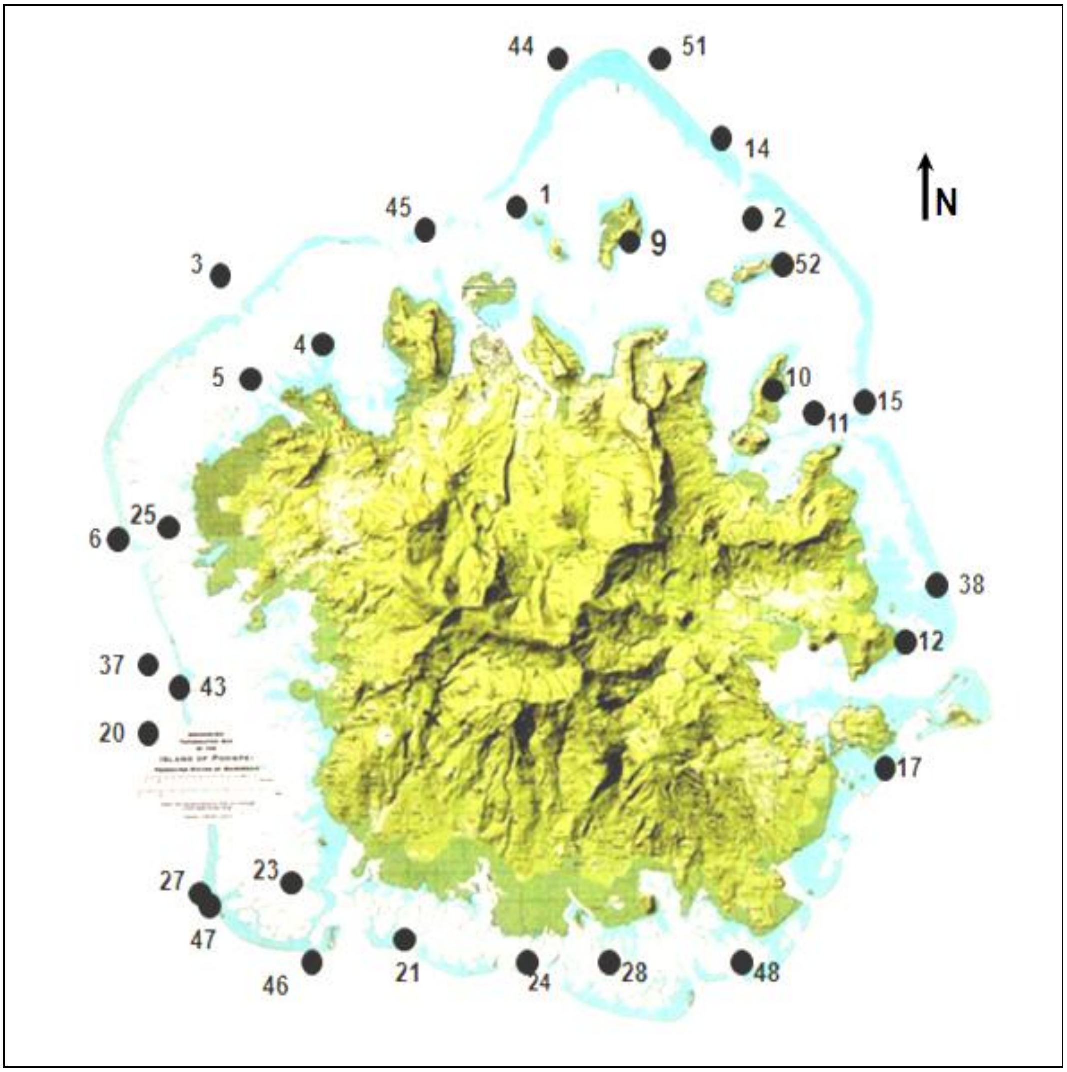

Figure 3.2: Fish dive site station in Pohnpei Lagoon by Allen (2005)

Appendix 3

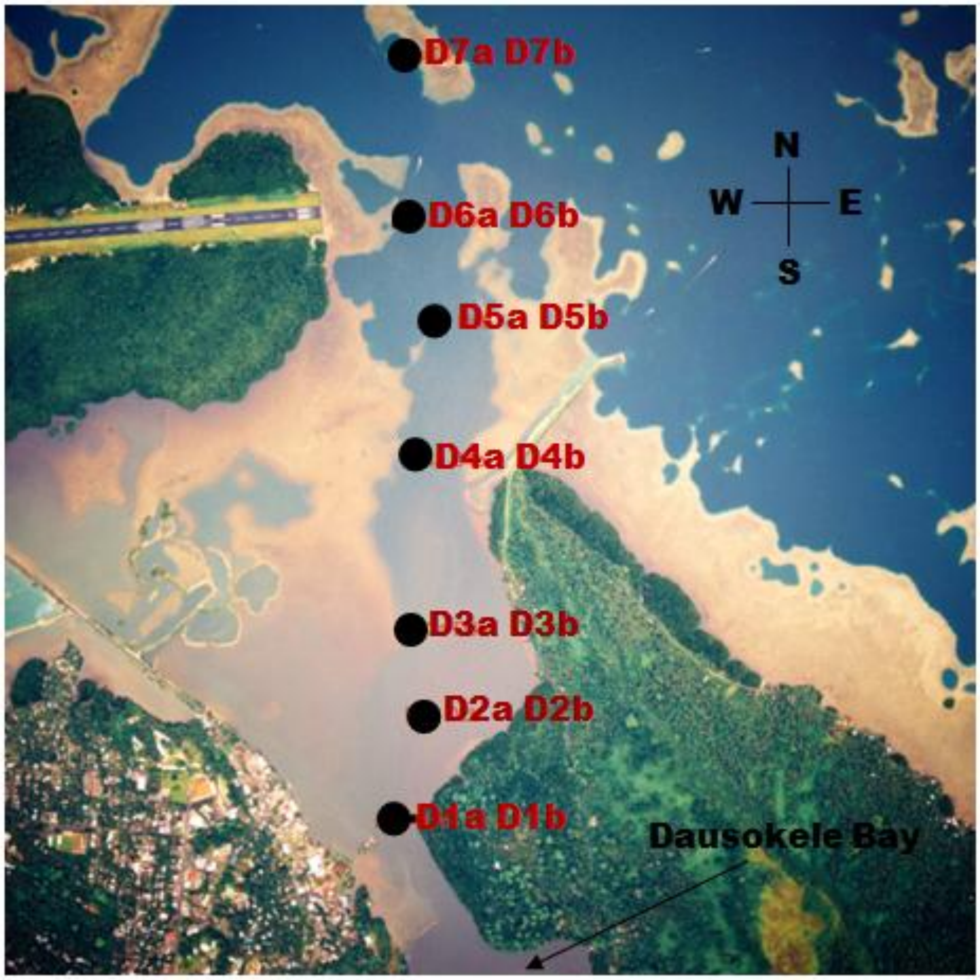

Figure 3.3: Seven sediment collection stations for the Conservation Society of Pohnpei (CSP) (Conservation Society of Pohnpei, 2009a)

Appendix 4

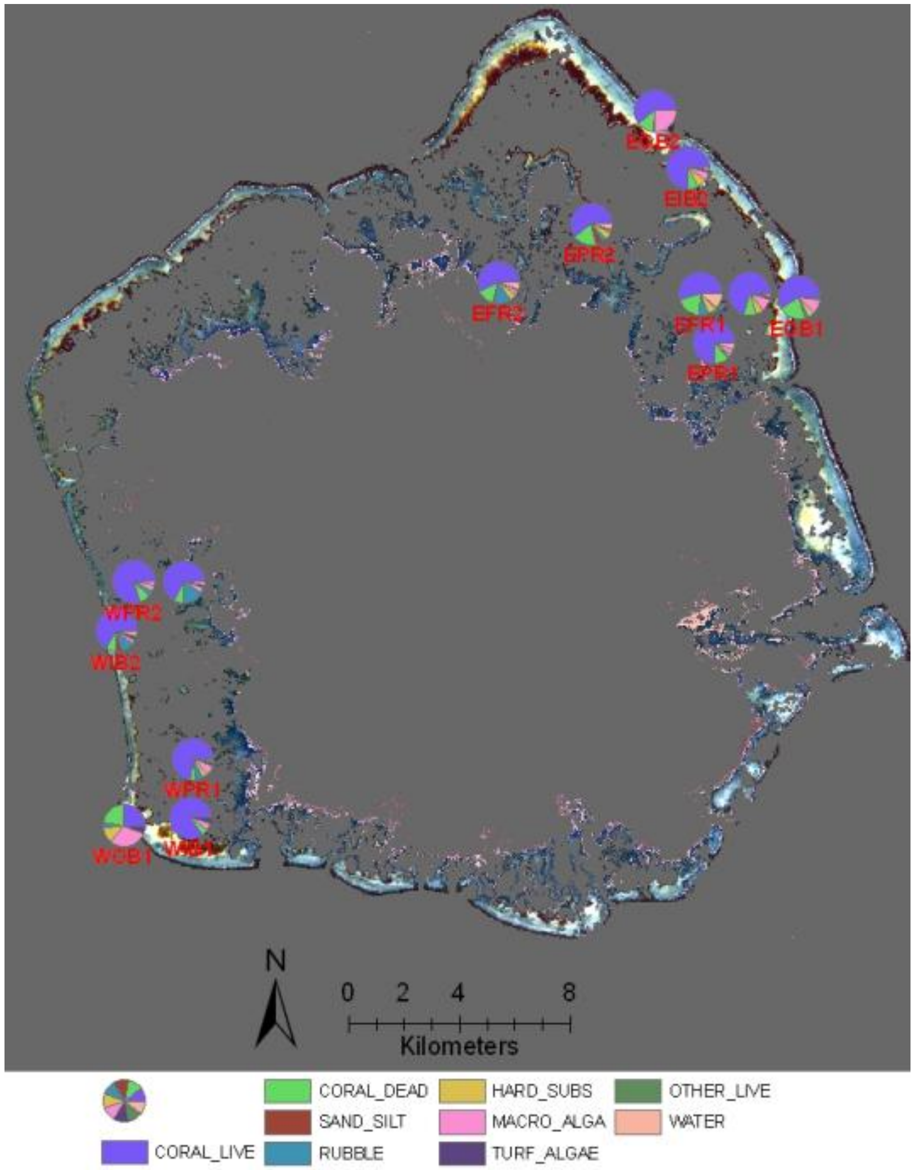

Figure 3.4: 16 photo-quadrant sites of the eastern and western reefs. Note that there are only 14 sites in the figure with 2 sites missing (WOB2 and WFR1) due to lost data location points (Conservation Society of Pohnpei, 2009b).

Appendix 5

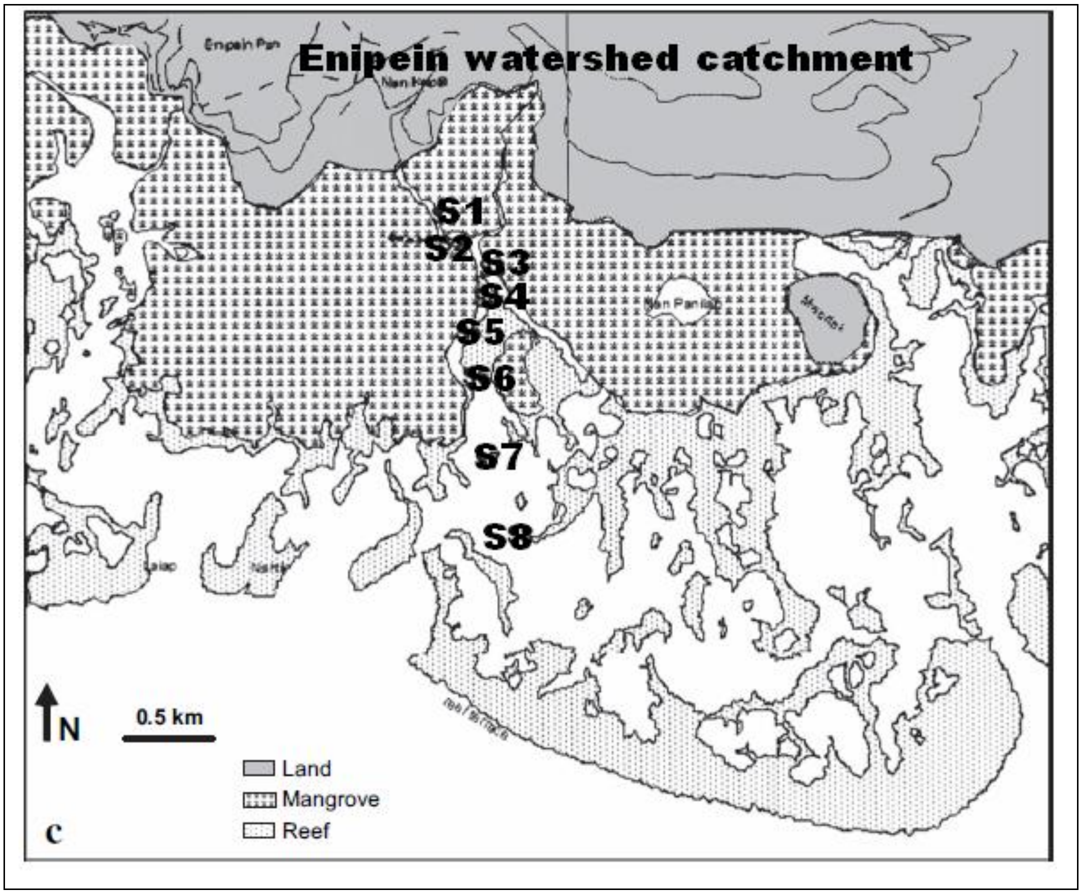

Figure 4.1: Salinity level study stations (Victor et al., 2006)

Appendix 6

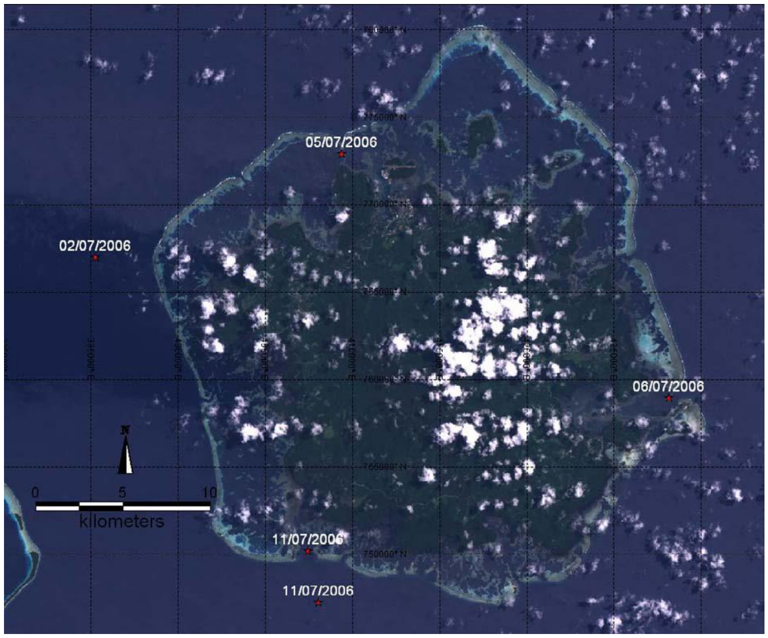

Figure 4.16: Map showing the CTD locations for Pohnpei (Krüger & Kumar, 2008)

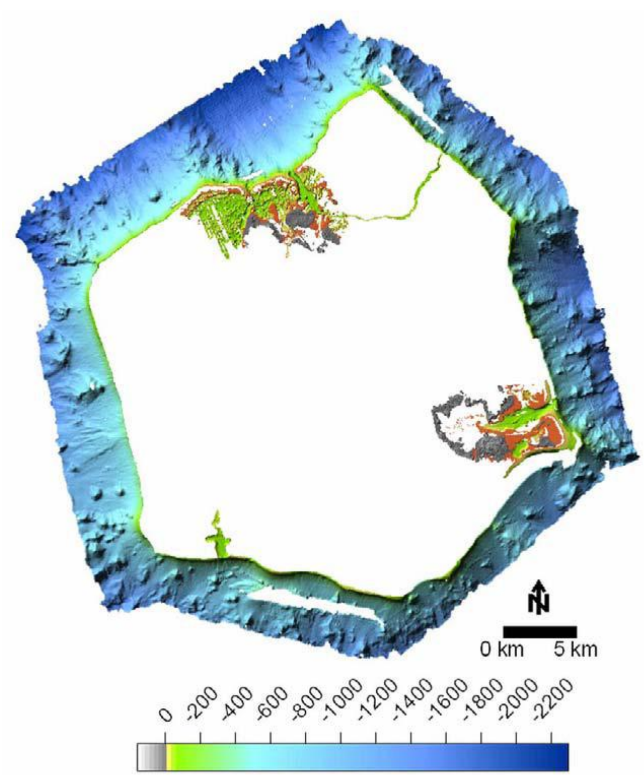

Figure 4.17: Image of Pohnpei in three-dimensional perspective with elevations and depths (m) (Krüger and Kumar, 2008)

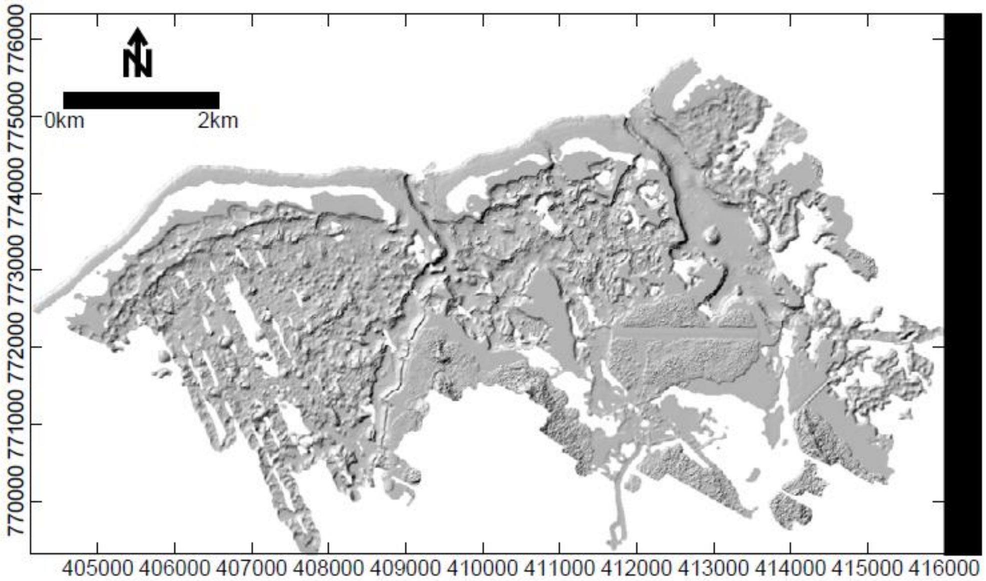

Figure 4.18: Kolonia Harbour bathymetry map (Krüger & Kumar, 2008)

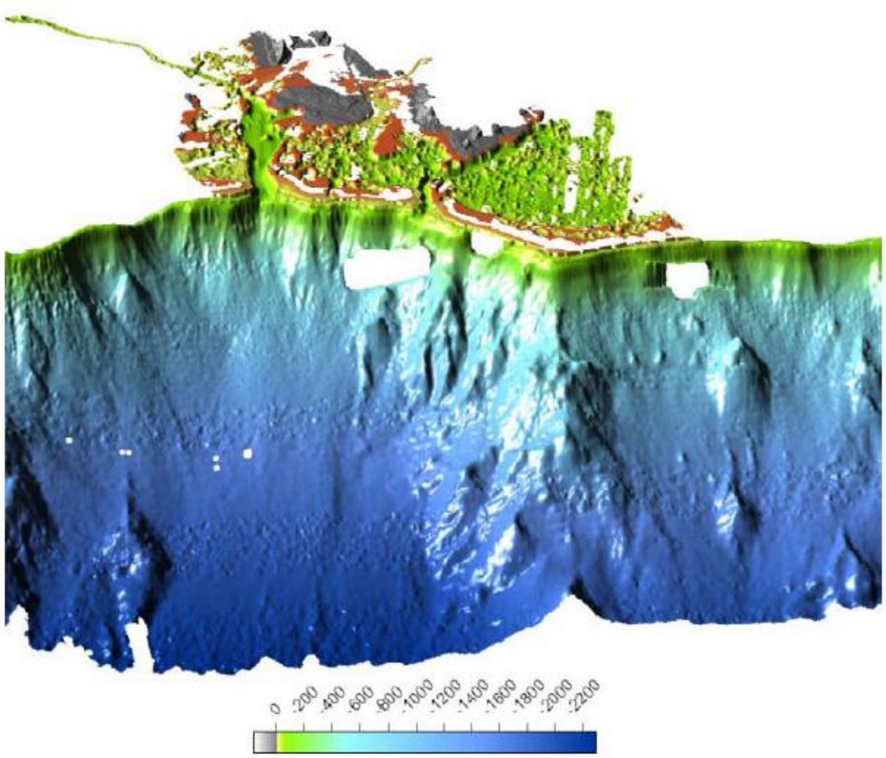

Figure 4.19: Kolonia Harbour in three-dimensional image looking south (Krüger & Kumar, 2008)

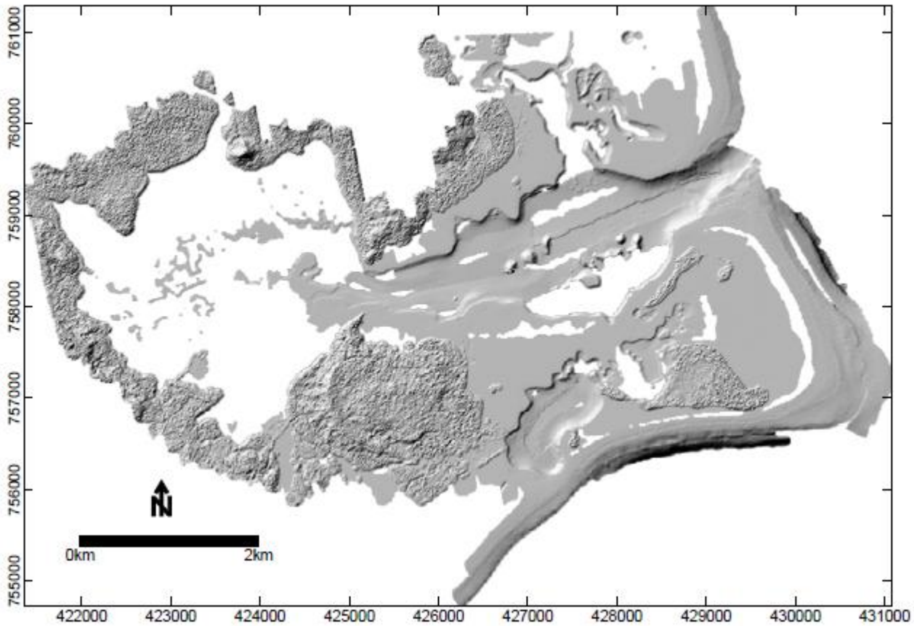

Figure 4.20: Nanmadol and Madolenihmw harbour bathymetry map (Krüger & Kumar, 2008)

Appendix 7

Coral community types and spreadsheet of 28 coral stations

There are seven major coral community 'types' (A-G), which are distributed in relation to depth, incident environmental conditions and exposure, in the twenty eight coral stations (Turak & De Vantier, 2005). The environmental conditions were based on water clarity (low or very clear), current flow (low or high) and wave exposure (low or high) (Table 5.1). Taxonomic compositions were based on abundance and diversity, of most notably *Porites* and *Acropora* (Turak and De Vantier, 2005).

A: Acropora – Pocillopora

Coral community A is distributed predominantly on the shallow (< 10 m) depths of exposed barrier reef of Pohnpei (Stations 3, 6, 12, 14, 15, 17, 18, 20, and 27). Environmental conditions are high when exposed to consistent wave energy and there are very clear waters for all stations. Characterizing species of Community A is comprised of diverse coral assemblages which include the acroporids *Acropora abrotanoides*, *A. hyacinthus*, *A. digitifera*, *A. monticulosa*, *A. gemmifera*, *A. nasuta*, the pocilloporids *Pocillopora verrucosa*, *P. eydouxi* and *P. elegans* and faviids *Goniastrea retiformis* and *Favia stelligera.*

B: Agariciid-faviid

Coral community B is distributed predominantly on the exposed outer barrier reef slopes of Pohnpei (Stations 14, 17, 18) but mostly occurring at both deep (45 m and >70 m) and shallow (< 10 m) depth sites of And Atoll channel (30). Environmental conditions are high with varying wave exposure and current flow, all having clear water visibility. Several community B corals inhabit with community A corals, notably the faviid *Favia stelligera* and pocilloporid *Pocillopra verrucosa.* Characterizing species of Community B is comprised of diverse coral assemblages including the agariciids *Pavona varians* and *P. duerdeni*, *Gardineroseris planulata* and *Pachyseris speciosa* and faviids *Leptastrea transversa* and *Echinopora pacificus*. Community B also maintains poritids, notably massive *Porites rus*, and *Porites spp.* corals.

C: Poritids

Coral community C is distributed predominantly in the shallows (<10 m) (Stations 4, 5, 7, 9, 10, 11, 13, 26) and some deep (45 m) depths of the lagoonal reef slopes (Stations 14, 17, 22, 23) of Pohnpei. Environmental conditions are low for wave and current with little activity and low water clarity. Several community C corals inhabit with massive *Porites spp.* of community B corals. Characterizing species of Community C is comprised of diverse coral assemblages which include the poritids *Porites cylindrical, P. rus, P. nigrescens, P. monticulosa* and *P. attenuata.*

D: Fungiid

Coral community D is distributed predominantly in the shallow (<10 m) lagoonal reef slopes of Pohnpei (Stations 12, 14, 19, 21, 24, 25, 28). Environmental conditions are low with small waves, little current flow and all having low water clarity. Characterizing species of Community D comprise diverse coral assemblages which include the fungids *Fungia concinna, F. fungites, F. danai,* and *Herpolitha limax.* Community D also maintains poritids, notably *Porites spp*.

E: Acroporid- faviid

Coral community E is distributed predominantly in deep (>45 m) depths on the sheltered reef slopes of And Atoll and there are none in Pohnpei lagoon. Environmental conditions are low with usually small waves, little current flow, with low water clarity. Characterizing species of Community E comprise diverse coral assemblages, including the acroporids *Astreopora listeria, A. myriophthalma, A. cucullata, A. gracilis, A. granulose, A. carolinina, A. lokani,* and *A. loripes.* Community E also maintains poritids, notably *Porites spp*.

F: Mixed massive-encrusting

Coral community F is distributed on the steep, deep (>45 m) depths of outer reef slopes of Pohnpei (Stations 3, 6, 11, 12, 15, 20, 21, 27). Environmental conditions are high waves and current exposure with high water clarity. Characterizing species of Community F comprises of mixed coral assemblages from massive to encrusting poritids. Community F corals include *Porites spp.*, *Leptoseris and Gardineroseris spp.*, agariciids *Pavona*, the euphyllid *Physogyra Lichtensteini and* faviids, notably *Platygyra daedalea* and *Diploastrea heliopora*.

G: Mixed pectiniid-mussid

Coral community G is distributed on deep (>45 m) depths of lagoonal reef slopes of Pohnpei (Stations 2, 4, 5, 8, 7, 9, 10, 13, 16, 24, 25, 26, 28). Environmental conditions are low waves and current exposure and relatively low water clarity. Characterizing species of community G comprise of mixed coral assemblages from massive to encrusting poritids similar to community F. Some sites (Stations 7, 24, 25, 28,) inhabited various fine-branching and 'bottlebrush' *Acropora* assemblages. Community G corals best differentiated from other communities by widespread presence of encrusting-foliose pectiniids. Community G corals include *Oxypora lacera*, *Pectinia alcycornis and and massive Lichtensteini and Mycedium elephantotis* and massive mussids *Lobophyllia hataii, L. Australomussa rowleyensis*.

Habitat characteristics

Bourgoin and Joseph's (2008) habitat characteristics of the five marine reserves (Stations 1, 2, 10, 24, and 27) within and outside of the Pohnpei Lagoon consist of the following:

1. Dead Coral (DC) - includes massive, branching, foliose, and tabular;
2. Live Coral (LC) - same as dead corals;
3. Other Fauna (OF) - includes sponges, hydroids, ascidians, zoanthids and soft coral.

Coral spreadsheet summary

Site number (S. no.): There are twenty eight stations inside and outside reefs for corals (Turak and De Vantier, 2005). The coral sites consist of site numbers and letters of alphabet: 1a, 1b, 1c, 1d and so forth. This was done to differentiate the MPA stations: 1a=inside MPA, 1b=outside MPA, 1c=inside non-MPA and 1d=outside non-MPA.

Reefs: The reefs are numbered by: 1= inside reef of lagoon and 2=outside reef of lagoon. The reefs as before estimated by Turak and Devantier (2005), Allen (2005), and Bourgoin and Joseph (2008).

Depth: The coral depths are numbered from: 1=shallow and 2=deep. Coral depths were estimated from Turak and De Vantier (2005).

Damaged corals (D.c): A percentage of damage corals are numbered from: 1=less damage, 2=moderate damage and 3=serious damage. The coral damage was estimated by Turak and De Vantier (2005).

Percentage of live coral cover (% of l. coral): The percentage of live coral cover is estimated by Bourgoin and Joseph (2008) as a proportion of the sea floor.

Percentage of dead coral cover (% of d. coral): The percentage of dead coral cover is estimated by Bourgoin and Joseph (2008) as a proportion of the sea floor.

Biodiversity (Bio): The coral biodiversity is estimated from Turak and De Vantier (2005) based on coral areas of biodiversity significance and priority conservation. They are numbered: 1= moderate biodiversity significance and 2=high biodiversity significance. The biodiversity significance can be determined by greatest number of coral species present at a particular site.

Coral community types (CCT): The coral community is described in seven categories and numbered: 1= (A) Shallow Acropora-Pocillopora, 2= (B) Deep Agariciid-faviid, 3= (C) Shallow Poritids, 4= (D) Shallow Fungiid, = (E) Acroporid- faviid, 6= (F) Deep mixed massive-encrusting coral lagoons and 7= (G) Deep mixed pectiniid-mussid. However, each station will have more than one number of corals. Turak and De Vantier (2005) use the seven categories to distinguish the corals depth, current status and health.

Rich sites (R. s.): The rich sites mean rich reef-building coral sites and were estimated by Turak and De Vantier (2005) as the highest number of coral species present (richness) at a site. The coral rich sites are numbered by: 1= less moderately rich, 2= moderately rich, 3= rich and 4= very rich.

Crown of Thorns (COTs): The Crown-of-thorns (COTs) was ordered on the scale of one to three: 1=uncommon, 2=common and 3=outbreak. The numbering scale was from Turak and De Vantier (2005).

Dredging (Dre.): The dredging numbering scale is in the order of proximity to a dredge site: 1=site is far away from dredging at barrier reefs, 2=site close to dredge area at fringing reefs and 3=near active dredge site at mangrove estuaries. Dredging sites compared are identified as old, recent, and newly designated dredge sites around Pohnpei's mangrove estuaries, fringing reefs, and barrier reef. The dredging rating was estimated from my local knowledge of the area.

Sediment input (Sed.): The sediment input into the Pohnpei Lagoon is ordered using a scale of one to three: 1=low, 2=medium and 3=high. The sediment input scale was estimated by personal observations and literature readings (coastal developments in the area, dredging, poor land use practices in upland areas and river outlets).

Marine Protected Areas (MPA): The numbering of the MPAs: 1=not an MPA and 2=MPA.

Coral health (C.h): The overall coral health is estimated by personal observations and estimated high numbers in each coral category. Overall coral health was numbered: 1=poor, 2=moderate and 3=good.

Current (Curr.): The current energy estimates are numbered from: 1=weak, 2=moderate and 3=strong. The currents energy was estimated by Turak and De Vantier (2005).

Wave: The wave energy estimates are numbered from: 1=weak, 2=moderate and 3=strong. Wave energy was estimated by Turak and De Vantier (2005).

Table 5.1: The 28 coral stations including factors and conditions that contribute to the overall coral health and diversity inside and outside the Pohnpei Lagoon (note: - means no data)

Site names	S.no.	Reefs	Depth	D.c	% l. coral	% d. coral	Bio.	CCT	R.s	COTs	Dre.	Sed.	MPAs	C.h	Curr.	Wave
Sapwitik	1a	1	1	2	50%	20%	2	4,7	4	1	1	2	1	3	1	1
	1b	1	2	2	-	-	2	4,7	4	1	1	2	1	3	2	2
	1c	1	1	-	50%	30%	-	4,7	-	-	1	2	1	3	1	1
	1d	1	1	-	-	-	-	4,7	-	-	1	2	1	3	1	1
S of Mwand channel	2a	2	1	1	65%	15%	2	4,7	4	1	1	1	1	3	1	1
	2b	2	2	1	44%	30%	2	4,7	4	1	1	1	1	3	2	1
	2c	2	1	-	45%	18%	-	4,7	-	-	1	1	1	3	1	1
	2d	2	2	-	57%	35%	-	4,7	-	-	1	1	1	3	1	1
Palikir outer slope	3a	2	2	1	-	-	1	1,6	3	2	1	1	2	2	2	2
	3b	2	2	1	-	-	1	1,6	3	2	1	1	2	2	2	2
	3c	2	2	-	-	-	-	1,6	-	-	1	1	2	2	2	2
	3d	2	2	-	-	-	-	1,6	-	-	1	1	2	2	2	2
Insadu reef- Sokeh's	4a	1	1	3	-	-	1	1,6	1	2	2	3	2	1	1	1
	4b	1	1	3	-	-	1	1,6	1	2	2	3	2	1	1	1
	4c	1	2	-	-	-	-	1,6	-	-	2	3	2	1	1	1
	4d	1	1	-	-	-	-	1,6	-	-	2	3	2	1	1	1
Mwahng	5a	1	1	3	-	-	1	3,7	2	1	2	3	2	1	1	1
	5b	1	2	3	-	-	1	3,7	2	1	2	3	2	1	1	1
	5c	1	1	-	-	-	-	3,7	-	-	2	3	2	1	1	1
	5d	1	1	-	-	-	-	3,7	-	-	2	3	2	1	1	1
Tawake N channel	6a	2	1	1	-	-	1	1,6	3	1	1	1	2	2	2	2
	6b	2	2	1	-	-	1	1,6	3	1	1	1	2	2	2	2
	6c	2	2	-	-	-	-	1,6	-	-	1	1	2	2	2	2

Site names	S.no.	Reefs	Depth	D.c	% l. coral	% d. coral	Bio.	CCT	R.s	COTs	Dre.	Sed.	MPAs	C.h	Curr.	Wave
	6d	2	2	-	-	-	-	1,6	-	-	1	1	2	2	2	2
Koaloawao	7a	1	1	2	-	-	2	7	3	1	1	2	2	2	2	2
	7b	2	2	2	-	-	2	7	3	1	1	2	2	2	2	2
	7c	1	1	-	-	-	-	7	-	-	1	2	2	2	2	2
	7d	1	1	-	-	-	-	7	-	-	1	2	2	2	2	2
Tomworo near mangroves	8a	1	1	3	-	-	2	3,7	1	1	1	3	2	2	1	1
	8b	1	2	3	-	-	2	3,7	1	1	1	3	2	2	1	1
	8c	1	1	-	-	-	-	3,7	-	-	1	3	2	2	1	1
	8d	1	1	-	-	-	-	3,7	-	-	1	3	2	2	1	1
Parerm Island E	9a	1	1	1	-	-	1	3,7	2	1	1	1	2	2	1	1
	9b	1	2	1	-	-	1	3,7	2	1	1	1	2	2	1	1
	9c	1	1	-	-	-	-	3,7	-	-	1	1	2	2	1	1
	9d	1	1	-	-	-	-	3,7	-	-	1	1	2	2	1	1
Dehpehk pah	10a	1	1	3	72%	15%	1	3,6	1	2	1	2	1	1	1	1
	10b	1	2	3	-	-	1	3,6	1	2	1	2	1	1	1	1
	10c	1	1	-	75%	10%	-	3,6	-	-	1	2	1	1	1	1
	10d	1	1	-	-	-	-	3,6	-	-	1	2	1	1	1	1
Areu Island- Auetek Point	11a	1	1	3	-	-	1	1,7	2	1	2	2	2	1	1	1
	11b	1	2	3	-	-	1	1,7	2	1	2	2	2	1	1	1
	11c	1	1	-	-	-	-	1,7	-	-	2	2	2	1	1	1
	11d	1	1	-	-	-	-	1,7	-	-	2	2	2	1	1	1
Nahpali channel N side	12a	2	1	2	-	-	2	3,7	4	1	1	1	2	3	2	2

Site names	S.no.	Reefs	Depth	D.c	% l. coral	% d. coral	Bio.	CCT	R.s	COTs	Dre.	Sed.	MPAs	C.h	Curr.	Wave
	12b	2	2	2	-	-	2	3,7	4	1	1	1	2	3	2	2
	12c	2	2	-	-	-	-	3,7	-	-	1	1	2	3	2	2
	12d	2	2	-	-	-	-	3,7	-	-	1	1	2	3	2	2
Ninleu-old dredge hole	13a	1	1	2	-	-	1	1,2	1	1	2	3	2	2	1	1
	13b	1	2	2	-	-	1	1,2	1	1	2	3	2	2	1	1
	13c	1	1	-	-	-	-	1,2	-	-	2	3	2	2	1	1
	13d	1	1	-	-	-	-	1,2	-	-	2	3	2	2	1	1
Mwand Pass N outer	14a	2	1	2	-	-	1	1	4	3	1	1	1	2	2	2
	14b	2	2	2	-	-	1	1	4	3	1	1	1	2	2	2
	14c	2	2	-	-	-	-	1	-	-	1	1	1	2	2	2
	14d	2	2	-	-	-	-	1	-	-	1	1	1	2	2	2
Aru channel N	15a	2	1	2	-	-	1	7	3	2	1	1	2	2	2	2
	15b	2	2	2	-	-	1	7	3	2	1	1	2	2	2	2
	15c	2	2	-	-	-	-	7	-	-	1	1	2	2	2	2
	15d	2	2	-	-	-	-	7	-	-	1	1	2	2	2	2
Tolapal inner	16a	1	1	1	-	-	1	1,2	1	1	2	3	2	1	1	1
	16b	1	2	1	-	-	1	1,2	1	1	2	3	2	1	1	1
	16c	1	1	-	-	-	-	1,2	-	-	2	3	2	1	1	1
	16d	1	1	-	-	-	-	1,2	-	-	2	3	2	1	1	1
Nan Madol outer S slope	17a	2	1	1	-	-	2	1,2	4	1	1	1	1	3	2	2
	17b	2	2	1	-	-	2	1,2	4	1	1	1	1	3	2	2
	17c	2	1	-	-	-	-	1,2	-	-	1	1	1	3	2	2
	17d	2	2	-	-	-	-	1,2	-	-	1	1	1	3	2	2

Site names	S.no.	Reefs	Depth	D.c	% l. coral	% d. coral	Bio.	CCT	R.s	COTs	Dre.	Sed.	MPAs	C.h	Curr.	Wave
Penieu S outer slope	18a	2	1	1	-	-	1	4,7	3	1	1	1	2	3	2	2
	18b	2	2	1	-	-	1	4,7	3	1	1	1	2	3	2	2
	18c	2	2	-	-	-	-	4,7	-	-	1	1	2	3	2	2
	18d	2	2	-	-	-	-	4,7	-	-	1	1	2	3	2	2
Lohd village patch	19a	1	1	2	-	-	1	4,7	2	1	1	2	2	2	1	1
	19b	1	2	2	-	-	1	4,7	2	1	1	2	2	2	1	1
	19c	1	1	-	-	-	-	4,7	-	-	1	2	2	2	1	1
	19d	1	1	-	-	-	-	4,7	-	-	1	2	2	2	1	1
S Pehleng- SW outer slope	20a	2	1	2	-	-	1	1,7	2	1	1	1	1	2	2	2
	20b	2	2	2	-	-	1	1,7	2	1	1	1	1	2	2	2
	20c	2	2	-	-	-	-	1,7	-	-	1	1	1	2	2	2
	20d	2	2	-	-	-	-	1,7	-	-	1	1	1	2	2	2
Kepdautoal inside entrance	21a	1	1	2	-	-	2	6,7	4	1	1	2	2	3	2	2
	21b	1	2	2	-	-	2	6,7	4	1	1	2	2	3	2	2
	21c	1	1	-	-	-	-	6,7	-	-	1	2	2	3	2	2
	21d	1	1	-	-	-	-	6,7	-	-	1	2	2	3	2	2
N of Toltik Island	22a	1	1	1	-	-	1	3	1	1	1	2	2	2	1	1
	22b	1	2	1	-	-	1	3	1	1	1	2	2	2	1	1
	22c	1	1	-	-	-	-	3	-	-	1	2	2	2	1	1
	22d	1	1	-	-	-	-	3	-	-	1	2	2	2	1	1
Patch reef SW side	23a	1	1	2	-	-	1	3	1	2	1	2	2	2	1	1
	23b	1	2	2	-	-	1	3	1	2	1	2	2	2	1	1
	23c	1	1	-	-	-	-	3	-	-	1	2	2	2	1	1

Site names	S.no.	Reefs	Depth	D.c	% l. coral	% d. coral	Bio.	CCT	R.s	COTs	Dre.	Sed.	MPAs	C.h	Curr.	Wave
	23d	1	1	-	-	-	-	3	-	-	1	2	2	2	1	1
Nahtik 'plug' reef	24a	1	1	2	25%	16%	2	4,7	4	1	1	2	1	3	1	1
	24b	1	2	2	35%	22%	2	4,7	4	1	1	2	1	3	1	1
	24c	1	1	-	30%	10%	-	4,7	-	-	1	2	1	3	1	1
	24d	1	1	-	23%	40%	-	4,7	-	-	1	2	1	3	1	1
Tomwara N	25a	1	1	2	-	-	2	4	2	1	1	2	2	2	1	1
	25b	1	2	2	-	-	2	4	2	1	1	2	2	2	1	1
	25c	1	1	-	-	-	-	4	-	-	1	2	2	2	1	1
	25d	1	1	-	-	-	-	4	-	-	1	2	2	2	1	1
Awetik mangroves	26a	1	1	2	-	-	1	3,7	3	1	1	2	2	2	1	1
	26b	1	2	2	-	-	1	3,7	3	1	1	2	2	2	1	1
	26c	1	1	-	-	-	-	3,7	-	-	1	2	2	2	1	1
	26d	1	1	-	-	-	-	3,7	-	-	1	2	2	2	1	1
Black Coral SPAGS outer	27a	2	1	1	50%	12%	1	1,3	3	1	1	1	1	3	2	2
	27b	2	2	1	30%	25%	1	1,3	3	1	1	1	1	3	2	2
	27c	2	2	-	64%	18%	-	1,3	-	-	1	1	1	3	2	2
	27d	2	2	-	20%	30%	-	1,3	-	-	1	1	1	3	2	2
Pahnsedlap	28a	1	1	2	-	-	2	4,7	4	1	1	2	2	3	1	1
	28b	1	2	2	-	-	2	4,7	4	1	1	2	2	3	1	1
	28c	1	1	-	-	-	-	4,7	-	-	1	2	2	3	1	1
	28d	1	1	-	-	-	-	4,7	-	-	1	2	2	3	1	1

Appendix 8

Fish data summary and spreadsheet for 38 fish stations

The fish data spreadsheet in Table 5.2 consists of 38 fish stations inside and outside the Pohnpei Lagoon. The numbering system of the fish stations follows the twenty eight coral stations with new fish stations from stations 37, 38, 43, 44, 46, 47, 48, 51, and 52 (Figure 5.2). This new fish station numbering follows fish stations were part of Allen's (2005) fish stations on the outer low-lying atolls of And and Pakin. The fish spreadsheets are explained below:

> **Site number (S. no.):** There are thirty eight stations inside and outside reefs for fish monitoring (Allen, 2005). The coral sites consist of site numbers and letters: 1a, 1b, 1c, 1d and so forth. This was done to differentiate the MPA stations: 1a=inside MPA, 1b=outside MPA, 1c=inside non-MPA and 1d=outside non-MPA.
>
> **Reefs:** The reefs are numbered by: 1= inside reef of lagoon and 2=outside reef of lagoon. The inside and outside reef sites were numbered by Turak and Devantier (2005), Allen (2005), and Bourgoin and Joseph (2008).
>
> **Depth:** The coral depths are numbered from: 1=shallow and 2=deep. Coral depths were estimated from Turak and De Vantier (2005).
>
> **Crown of Thorns (COTs):** The Crown-of-thorns (COTs) were ordered on the scale of one to three: 1=uncommon, 2=common and 3=outbreak. The numbering scale was from Turak and De Vantier's (2005) COT table counts of COTs sighted at stations.
>
> **Dredging (Dre.):** The dredging numbering scale is in the order of proximity to a dredge site: 1=site is far away from dredging, 2=site close to dredge area and 3=near active dredge site. Dredging sites are compared from old, recent, and newly designated dredge sites around Pohnpei's mangrove estuaries, fringing reefs, and barrier reef. The ordering is also hypothetically guessed as the researcher has not received dredged data requested from Pohnpei State Office of Environmental and Protection Agency.

Sediment input (Sed.): The sediment input into the Pohnpei Lagoon is ordered by a scale of one to three: 1=low, 2=medium and 3=high. The input scale was estimated from my personal observations and literature readings (coastal developments in the area, dredging, poor land use practices in upland areas and river outlets) as for the last section.

Marine Protected Areas (MPA): The numbering of the MPAs: 1=not an MPA and 2=MPA.

Fish abundance (Fish abun.): The REA fish abundance is numbered from: 1=low, 2=medium and 3=high. The fish abundance was estimated by Allen (2005).

Fish counts (Fish co.): The MPA fish counts are for the five MPAs from Bourgoin and Joseph (2008). The four fish sites are as follows: 1a=inside reef MPA, 1b=outside reef MPA, 1c=inside reef non-MPA and 1d=outside reef non-MPA. There are a total of twenty fish dataset for the five MPAs.

Fish populations (Fish pop.): The REA fish counts were for inside and outside reefs for the thirty eight fish stations (inside and outside reefs) estimated by Allen (2005).

Fishing: The fishing was number: 1= no fishing at site and 2= fishing at site. This was estimated by my personal experience and observations of the area. However, a few of the non-fishing areas, especially the MPAs, do sometimes get poached.

Currents (Curr.): The current energy estimates are numbered from: 1=weak, 2=moderate and 3=strong. The currents energy was estimated by Turak and De Vantier (2005) and by my personal observations/experiences of the area.

Wave: The wave energy estimates are numbered from: 1=weak, 2=moderate and 3=strong. Wave energy was estimated by Turak and De Vantier (2005) and by my personal observations/experiences of the area.

Table 5.2: The 38 fish site stations including factors and conditions that contribute to the overall health of reef fish diversity inside and outside the Pohnpei Lagoon. (note: - means no data)

Site names	S.no.	Reefs	Depth	COTs	Dre.	Sed.	MPAs	Fish abun.	Fish co.	Fish pop.	Fishing	Curr.	Wave
Sapwitik	1a	1	1	1	1	2	1	2	1248	142	1	1	1
	1b	1	2	1	1	2	1	2	640	142	1	2	2
	1c	1	1	-	1	2	1	2	2231	-	1	1	1
	1d	1	1	-	1	2	1	2	1272	-	1	1	1
S of Mwand channel	2a	2	1	1	1	1	1	3	1248	150	1	1	1
	2b	2	2	1	1	1	1	3	640	150	1	2	1
	2c	2	1	-	1	1	1	3	2231	-	1	1	1
	2d	2	2	-	1	1	1	3	1272	-	1	1	1
Palikir outer slope	3a	2	2	2	1	1	2	-	-	146	2	2	2
	3b	2	2	2	1	1	2	-	-	146	2	2	2
	3c	2	2	-	1	1	2	-	-	-	2	2	2
	3d	2	2	-	1	1	2	-	-	-	2	2	2
Insadu reef- Sokeh's	4a	1	1	2	2	3	2	-	-	106	2	1	1
	4b	1	1	2	2	3	2	-	-	106	2	1	1
	4c	1	2	-	2	3	2	-	-	-	2	1	1
	4d	1	1	-	2	3	2	-	-	-	2	1	1
Mwahng	5a	1	1	1	2	3	2	-	-	76	2	1	1
	5b	1	2	1	2	3	2	-	-	76	2	1	1
	5c	1	1	-	2	3	2	-	-	-	2	1	1
	5d	1	1	-	2	3	2	-	-	-	2	1	1
Tawake N channel	6a	2	1	1	1	1	2	-	-	145	2	2	2

Site names	S.no.	Reefs	Depth	COTs	Dre.	Sed.	MPAs	Fish abun.	Fish co.	Fish pop.	Fishing	Curr.	Wave
	6b	2	2	1	1	1	2	-	-	145	2	2	2
	6c	2	2	-	1	1	2	-	-	-	2	2	2
	6d	2	2	-	1	1	2	-	-	-	2	2	2
Koaloawao	7a	1	1	1	1	2	2	-	-	-	2	2	2
	7b	1	2	1	1	2	2	-	-	-	2	2	2
	7c	1	1	-	1	2	2	-	-	-	2	2	2
	7d	1	1	-	1	2	2	-	-	-	2	2	2
Tomworo near mangroves	8a	1	1	1	1	3	2	-	-	-	2	1	1
	8b	1	2	1	1	3	2	-	-	-	2	1	1
	8c	1	1	-	1	3	2	-	-	-	2	1	1
	8d	1	1	-	1	3	2	-	-	-	2	1	1
Parerm Island E	9a	1	1	1	1	1	2	-	-	117	2	1	1
	9b	1	2	1	1	1	2	-	-	117	2	1	1
	9c	1	1	-	1	1	2	-	-	-	2	1	1
	9d	1	1	-	1	1	2	-	-	-	2	1	1
Dehpehk pah	10a	1	1	2	1	2	1	2	1248	120	1	1	1
	10b	1	2	2	1	2	1	2	640	120	1	1	1
	10c	1	1	-	1	2	1	2	2231	-	1	1	1
	10d	1	1	-	1	2	1	2	1272	-	1	1	1
Areu Island- Auetek Point	11a	1	1	1	2	2	2	-	-	127	2	1	1
	11b	1	2	1	2	2	2	-	-	127	2	1	1
	11c	1	1	-	2	2	2	-	-	-	2	1	1
	11d	1	1	-	2	2	2	-	-	-	2	1	1
Nahpali channel N side	12a	2	1	1	1	1	2	-	-	145	2	2	2

Site names	S.no.	Reefs	Depth	COTs	Dre.	Sed.	MPAs	Fish abun.	Fish co.	Fish pop.	Fishing	Curr.	Wave
	12b	2	2	1	1	1	2	-	-	145	2	2	2
	12c	2	2	-	1	1	2	-	-	-	2	2	2
	12d	2	2	-	1	1	2	-	-	-	2	2	2
Ninleu-old dredge hole	13a	1	1	1	2	3	2	-	-	-	2	1	1
	13b	1	2	1	2	3	2	-	-	-	2	1	1
	13c	1	1	-	2	3	2	-	-	-	2	1	1
	13d	1	1	-	2	3	2	-	-	-	2	1	1
Mwand Pass N outer	14a	2	1	3	1	1	1	-	-	-	2	2	2
	14b	2	2	3	1	1	1	-	-	-	2	2	2
	14c	2	2	-	1	1	1	-	-	-	2	2	2
	14d	2	2	-	1	1	1	-	-	-	2	2	2
Aru channel N	15a	2	1	2	1	1	2	-	-	158	2	2	2
	15b	2	2	2	1	1	2	-	-	158	2	2	2
	15c	2	2	-	1	1	2	-	-	-	2	2	2
	15d	2	2	-	1	1	2	-	-	-	2	2	2
Tolapal inner	16a	1	1	1	2	3	2	-	-	-	2	1	1
	16b	1	2	1	2	3	2	-	-	-	2	1	1
	16c	1	1	-	2	3	2	-	-	-	2	1	1
	16d	1	1	-	2	3	2	-	-	-	2	1	1
Nan Madol outer S slope	17a	2	1	1	1	1	2	-	-	149	2	2	2
	17b	2	2	1	1	1	2	-	-	149	2	2	2
	17c	2	1	-	1	1	2	-	-	-	2	2	2
	17d	2	2	-	1	1	2	-	-	-	2	2	2
Penieu S outer slope	18a	2	1	1	1	1	2	-	-	-	2	2	2

Site names	S.no.	Reefs	Depth	COTs	Dre.	Sed.	MPAs	Fish abun.	Fish co.	Fish pop.	Fishing	Curr.	Wave
	18b	2	2	1	1	1	2	-	-	-	2	2	2
	18c	2	2	-	1	1	2	-	-	-	2	2	2
	18d	2	2	-	1	1	2	-	-	-	2	2	2
Lohd village patch	19a	1	1	1	1	2	2	-	-	-	2	1	1
	19b	1	2	1	1	2	2	-	-	-	2	1	1
	19c	1	1	-	1	2	2	-	-	-	2	1	1
	19d	1	1	-	1	2	2	-	-	-	2	1	1
S Pehleng- SW outer slope	20a	2	1	1	1	1	2	-	-	135	2	2	2
	20b	2	2	1	1	1	2	-	-	135	2	2	2
	20c	2	2	-	1	1	2	-	-	-	2	2	2
	20d	2	2	-	1	1	2	-	-	-	2	2	2
Kepdautoal inside entrance	21a	1	1	1	1	2	2	-	-	113	2	2	2
	21b	1	2	1	1	2	2	-	-	113	2	2	2
	21c	1	1	-	1	2	2	-	-	-	2	2	2
	21d	1	1	-	1	2	2	-	-	-	2	2	2
N of Toltik Island	22a	1	1	1	1	2	2	-	-	-	2	1	1
	22b	1	2	1	1	2	2	-	-	-	2	1	1
	22c	1	1	-	1	2	2	-	-	-	2	1	1
	22d	1	1	-	1	2	2	-	-	-	2	1	1
Patch reef SW side	23a	1	1	2	1	2	2	-	-	87	2	1	1
	23b	1	2	2	1	2	2	-	-	87	2	1	1
	23c	1	1	-	1	2	2	-	-	-	2	1	1
	23d	1	1	-	1	2	2	-	-	-	2	1	1
Nahtik 'plug' reef	24a	1	1	1	1	2	1	1	1248	115	1	1	1

Site names	S.no.	Reefs	Depth	COTs	Dre.	Sed.	MPAs	Fish abun.	Fish co.	Fish pop.	Fishing	Curr.	Wave
Tomwara N	24b	1	2	1	1	2	1	1	640	115	1	1	1
	24c	1	1	-	1	2	1	1	2231	-	1	1	1
	24d	1	1	-	1	2	1	1	1272	-	1	1	1
	25a	1	1	1	1	2	2	-	-	105	2	1	1
	25b	1	2	1	1	2	2	-	-	105	2	1	1
	25c	1	1	-	1	2	2	-	-	-	2	1	1
	25d	1	1	-	1	2	2	-	-	-	2	1	1
Awetik mangroves	26a	1	1	1	1	2	2	-	-	-	2	1	1
	26b	1	2	1	1	2	2	-	-	-	2	1	1
	26c	1	1	-	1	2	2	-	-	-	2	1	1
	26d	1	1	-	1	2	2	-	-	-	2	1	1
Black Coral SPAGS outer	27a	2	1	1	1	1	1	2	1248	138	1	2	2
	27b	2	2	1	1	1	1	1	640	138	1	2	2
	27c	2	2	-	1	1	1	2	2231	-	1	2	2
	27d	2	2	-	1	1	1	1	1272	-	1	2	2
Pahnsedlap	28a	1	1	1	1	2	2	-	-	100	2	1	1
	28b	1	2	1	1	2	2	-	-	100	2	1	1
	28c	1	1	-	1	2	2	-	-	-	2	1	1
	28d	1	1	-	1	2	2	-	-	-	2	1	1
Poaloang Pass	37a	2	1	-	1	1	2	-	-	141	2	2	2
	37b	2	2	-	1	1	2	-	-	141	2	2	2
	37c	2	2	-	1	1	2	-	-	-	2	2	2
	37d	2	2	-	1	1	2	-	-	-	2	2	2
N of Nahpali Pass (outer)	38a	2	1	-	1	1	2	-	-	153	2	2	2

Site names	S.no.	Reefs	Depth	COTs	Dre.	Sed.	MPAs	Fish abun.	Fish co.	Fish pop.	Fishing	Curr.	Wave
	38b	2	2	-	1	1	2	-	-	153	2	2	2
	38c	2	2	-	1	1	2	-	-	-	2	2	2
	38d	2	2	-	1	1	2	-	-	-	2	2	2
Poaloang Pass	43a	2	1	-	1	1	2	-	-	145	2	2	2
	43b	2	2	-	1	1	2	-	-	145	2	2	2
	43c	2	2	-	1	1	2	-	-	-	2	2	2
	43d	2	2	-	1	1	2	-	-	-	2	2	2
North Point	44a	2	1	-	1	1	2	-	-	133	2	2	2
	44b	2	2	-	1	1	2	-	-	133	2	2	2
	44c	2	2	-	1	1	2	-	-	-	2	2	2
	44d	2	2	-	1	1	2	-	-	-	2	2	2
Old harbour entrance	45a	1	1	-	1	1	2	-	-	129	2	2	2
	45b	1	2	-	1	1	2	-	-	129	2	2	2
	45c	1	1	-	1	1	2	-	-	-	2	2	2
	45d	1	1	-	1	1	2	-	-	-	2	2	2
Nahlap	46a	1	1	-	1	1	2	-	-	150	2	2	2
	46b	1	2	-	1	1	2	-	-	150	2	2	2
	46c	1	1	-	1	1	2	-	-	-	2	2	2
	46d	1	1	-	1	1	2	-	-	-	2	2	2
Kehpara pass and outer reef	47a	2	1	-	1	1	1	-	-	171	1	2	2
	47b	2	2	-	1	1	1	-	-	171	1	2	2
	47c	2	2	-	1	1	1	-	-	-	1	2	2
	47d	2	2	-	1	1	1	-	-	-	1	2	2

Site names	S.no.	Reefs	Depth	COTs	Dre.	Sed.	MPAs	Fish abun.	Fish co.	Fish pop.	Fishing	Curr.	Wave
lagoon reef SE corner	48a	1	1	-	1	1	2	-	-	124	2	2	2
	48b	1	2	-	1	1	2	-	-	124	2	2	2
	48c	1	1	-	1	1	2	-	-	-	2	2	2
	48d	1	1	-	1	1	2	-	-	-	2	2	2
about 300 m E of North Pt.	51a	2	1	-	1	1	2	-	-	114	2	2	2
	51b	2	2	-	1	1	2	-	-	114	2	2	2
	51c	2	2	-	1	1	2	-	-	-	2	2	2
	51d	2	2	-	1	1	2	-	-	-	2	2	2
Manta Road	52a	1	1	-	1	1	1	-	-	146	1	2	2
	52b	1	2	-	1	1	1	-	-	146	1	2	2
	52c	1	1	-	1	1	1	-	-	-	1	2	2
	52d	1	1	-	1	1	1	-	-	-	1	2	2

Appendix 9

Questions 1: The relationship between non-Marine Protected Area (MPA) and MPA sites and depth, current, and wave energy.

Table 5.3 MPAs current and wave energy

Waves			Weak	Moderate	Strong
MPA	Depth	Currents			
Not MPA	Shallow	Weak	11	0	0
		Moderate	0	6	0
		Strong	0	0	0
	Deep	Weak	3	0	0
		Moderate	1	9	0
		Strong	0	0	0
MPA	Shallow	Weak	39	0	0
		Moderate	0	27	0
		Strong	0	0	0
	Deep	Weak	13	0	0
		Moderate	0	43	0
		Strong	0	0	0

Question 2: The relationship between no fishing and fishing sites by coral health, currents, and wave energy.

Table 5.4: Fishing and non-fishing sites

Waves			Weak	Moderate	Strong
Fishing	Coral Health	Currents			
No fishing	Poor	Weak	4	0	0
		Moderate	0	0	0
		Strong	0	0	0
	Moderate	Weak	0	0	0
		Moderate	0	1	0
		Strong	0	0	0
	Good	Weak	10	0	0
		Moderate	1	12	0
		Strong	0	0	0
Fishing	Poor	Weak	16	0	0
		Moderate	0	0	0
		Strong	0	0	0
	Moderate	Weak	32	0	0
		Moderate	0	36	0
		Strong	0	0	0
	Good	Weak	4	0	0
		Moderate	0	36	0
		Strong	0	0	0

Question 3: The relationship between sedimentation input from dredging distance proximity at non-Marine Protected Areas (MPA) and MPAs.

Table 5.5: Sediment input

Sediment Input			Low	Medium	High
MPA	Coral Health	Dredging			
Not MPA	Poor	Proximal	0	4	0
		Intermediate	0	0	0
		Distal	0	0	0
	Moderate	Proximal	4	0	0
		Intermediate	0	0	0
		Distal	0	0	0
	Good	Proximal	14	8	0
		Intermediate	0	0	0
		Distal	0	0	0
MPA	Poor	Proximal	0	0	0
		Intermediate	0	4	12
		Distal	0	0	0
	Moderate	Proximal	33	24	4
		Intermediate	0	0	4
		Distal	0	0	0
	Good	Proximal	33	8	0
		Intermediate	0	0	0
		Distal	0	0	0

Appendix 10

Questions 1: The relationship between non-Marine Protected Area (MPA) and MPA sites and depth, current, and wave energy.

Table 5.6: MPAS current and wave energy

MPA		Waves	Weak	Moderate	Strong
	Depth	Currents			
Not MPA	Shallow	Weak	7.24	0.00	0.00
		Moderate	0.00	3.95	0.00
		Strong	0.00	0.00	0.00
	Deep	Weak	1.97	0.00	0.00
		Moderate	0.66	5.92	0.00
		Strong	0.00	0.00	0.00
MPA					
	Shallow	Weak	25.66	0.00	0.00
		Moderate	0.00	17.76	0.00
		Strong	0.00	0.00	0.00
	Deep	Weak	8.55	0.00	0.00
		Moderate	0.00	28.29	0.00
		Strong	0.00	0.00	0.00

Question 2: The relationship between no fishing and fishing sites by coral health, currents, and wave energy.

Table 5.7: Fishing and non-fishing sites

Waves			Weak	Moderate	Strong
Fishing	Coral Health	Currents			
No fishing	Poor	Weak	2.63	0.00	0.00
		Moderate	0.00	0.00	0.00
		Strong	0.00	0.00	0.00
	Moderate	Weak	0.00	0.00	0.00
		Moderate	0.00	0.66	0.00
		Strong	0.00	0.00	0.00
	Good	Weak	6.58	0.00	0.00
		Moderate	0.66	7.89	0.00
		Strong	0.00	0.00	0.00
Fishing	Poor	Weak	10.53	0.00	0.00
		Moderate	0.00	0.00	0.00
		Strong	0.00	0.00	0.00
	Moderate	Weak	21.05	0.00	0.00
		Moderate	0.00	23.68	0.00
		Strong	0.00	0.00	0.00
	Good	Weak	2.63	0.00	0.00
		Moderate	0.00	23.68	0.00
		Strong	0.00	0.00	0.00

Question 3: The relationship between sedimentation input from dredging distance proximity at non-Marine Protected Areas (MPA) and MPAs.

Table 5.8: Sediment input

Sediment Input			Low	Medium	High
MPA	Coral Health	Dredging			
Not MPA	Poor	Proximal	0.00	2.63	0.00
		Intermediate	0.00	0.00	0.00
		Distal	0.00	0.00	0.00
	Moderate	Proximal	2.63	0.00	0.00
		Intermediate	0.00	0.00	0.00
		Distal	0.00	0.00	0.00
	Good	Proximal	9.21	5.26	0.00
		Intermediate	0.00	0.00	0.00
		Distal	0.00	0.00	0.00
MPA	Poor	Proximal	0.00	0.00	0.00
		Intermediate	0.00	2.63	7.89
		Distal	0.00	0.00	0.00
	Moderate	Proximal	21.71	15.79	2.63
		Intermediate	0.00	0.00	2.63
		Distal	0.00	0.00	0.00
	Good	Proximal	21.71	5.26	0.00
		Intermediate	0.00	0.00	0.00
		Distal	0.00	0.00	0.00