STAFF WORKING PAPER
SUMMARY OF SELECTED PEARL HARBOR MARINE NATURAL RESOURCES DATA FROM 1999 – 2015 - IN SUPPORT OF PROPOSED PROJECT P 516

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Introduction

Overview. The objective of this Staff Working Paper is to summarize selected data gathered by the author between 1999 and February 2015. During that time period, the author conducted a variety of assessments throughout Pearl Harbor and the Pearl Harbor Entrance Channel. The specific resources which will be addressed in this partial summary are: 1) corals, 2) selected fin fish species and Essential Fish Habitat (EFH), 3) sea turtles, 4) miscellaneous and 5) perceived data gaps. This summary is not intended to reiterate material already presented in the Pearl Harbor INRMP or the many other documents which contain pertinent marine natural resource data; it is intended to summarize unpublished and/or unreported data gathered by the author.

In this document, Pearl Harbor is defined as the area north of Hammer Point, as designated on Nautical Chart No. 19366 (Oahu South Coast Pearl Harbor). The Pearl Harbor Entrance Channel (PHEC) is defined as the area south of Hammer Point between the channel markers on the eastern and western sides of the PHEC and extending to the outermost Channel Marker Buoys (No. 1 on the west side and No. 2 on the east side). Figure 1 illustrates the boundaries of the P 516 project assessment area.

All the data summarized in this document was gathered by the author, with periodic biological support from Donald Marx, and others. Many other studies have been conducted in and adjacent to Pearl Harbor and those works should be reviewed and evaluated relative to the proposed P 516 project. As noted, it is not within the scope of this Staff Working Paper to review or summarize those studies. It should be noted that a significant number of investigations and surveys have been completed within Pearl Harbor which are outside of the physical boundaries designated for this summary, for example West Loch and Pearl City Peninsula.

General Geography and Ecology.

Pearl Harbor consists of three large lochs (West Loch, Middle Loch and East Loch) and a smaller loch (Southeast Loch). Ford Island is located in East Loch. The portion of the harbor adjacent to the west side of Ford Island is generally referred to as the Ford Island Channel, while the waters to the east of Ford Island include the Main Channel, Turning Basin, South Channel and Southeast Loch (Nautical Chart No. 19366). These lochs and the channels within the harbor cover an area of approximately 21 km^2 and are the remnants of drowned river valleys which once merged to a common channel which is now the PHEC. The PHEC, from Hammer Point to the outermost Channel Markers is approximately 3.2 km with a width of 300 m. Based on substrate type Pearl Harbor has two primary ecological zones and the PHEC and its adjacent areas have four. Most investigators have divided the harbor into: 1) a soft bottom zone of unconsolidated sediment and 2) a hard substrate zone made up of either fossilized reefal material, or anthropogenic items (concrete piers and debris, metal sheet piles, wooden piles and sunken objects). Approximately 90% of the Pearl Harbor seafloor is terrigenous mud or calcareous sand. Of course, as one proceeds in a seaward direction the percentage of coarser calcareous sand increases. The fossilized reefal material is present as a shelf in many portions of the harbor. It is generally covered with a thin layer of sand or mud and terminates in a natural drop off or dredged wall to the harbor floor. The PHEC can be broadly divided into four zones: 1) the channel bottom which is entirely unconsolidated sediment with a few widely spaced fossilized reefal/limestone boulders/blocks near the edges, 2) steep slopes and isolated ledges that connect the channel bottom to 3) the reef platform that borders both side of the PHEC and 4) reefs seaward of the reef platform and the outer Channel Markers. See Smith, Deslarzes and Brock (2006) for more detail.

Corals

As of February 2015, fifteen species of Scleractinian corals have been identified within Pearl Harbor. In addition, there are four species whose taxonomy is disputed and which may or may not be present. Table 1 summarizes this information.

Table 1 Scleractinian Corals in Pearl Harbor

Family	Species	Taxonomic Disputes	Presence Confirmed
Acroporidae	1] ***Montipora capitata***	No	Yes
	2a] ***Montipora flabellata***	Yes (1)	Yes
	2b] Montipora dilatata	Yes (1)	No
	2c] Montipora turgescens	Yes (1)	No
	3a] ***Montipora patula***	Yes (2)	Yes
	3b] Montipora verrilli	Yes (2)	No
	4] ***Montipora tuberculosa***	No	Yes
Agariciidae	5] ***Leptoseris incrustans***	No	Yes
	6] ***Pavona varians***	No	Yes
Faviidae	7] ***Cyphastrea ocellina***	No	Yes
	8] ***Leptastrea purpurea***	No	Yes
Pocilloporidae	9a] ***Pocillopora meandrina***	Yes (3)	Yes
	9b] Pocillopora elegans	Yes (3)	No
	10] ***Pocillopora damicornis***	No	Yes
	11] ***Pocillopora ligulata***	No	Yes
	12] ***Pocillopora eydouxi***	No	Yes
Poritidae	13] ***Porites compressa***	No	Yes
	14] ***Porites lobata***	No	Yes
Siderastreidae	15] ***Psammocora explanulata***	No	Yes

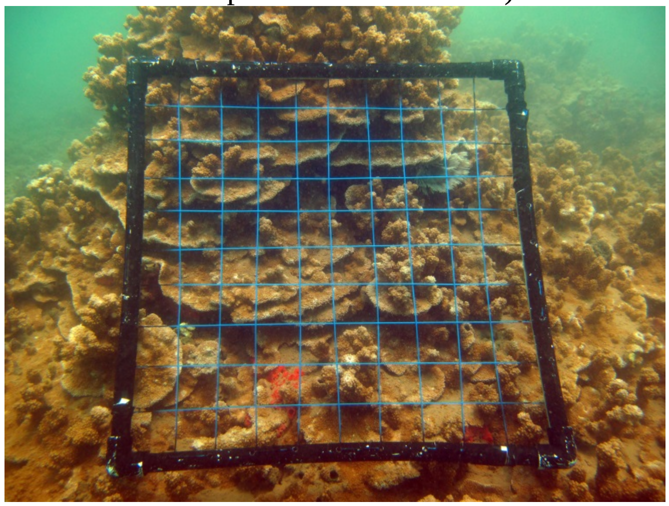
Notes 1, 2 & 3: The taxonomy of many stony coral species is disputed. Because of morphological plasticity and genetic similarities the species numbered 2a-c; 3a-b and 9a-b are regarded as a total of 3 separate species and not seven separate species by many experts.
1). *M. dilatata* and *M. turgescens* are claimed by some to possibly be a single species with *M. flabellata*.
2). J. Margos (1995) and J.E.N.Veron (2000) list *M. tuberculosa* as present in HI, D. Fenner (2005) does not. A specimen of *M. tuberculosa* was collected by the author and examined by staff at the Bishop Museum; it was tentatively confirmed to be *M. tuberculosa*.
3) Some taxonomists claim *P. meandrina*, and P. *elegans* may be a single species. *P. meandrina* has been positively identified.

There are no coral reefs in Pearl Harbor, based upon accepted definitions of coral reefs. There are limited areas of coral bearing substrate, but there are no areas which are framework-or-biogenic morphology producing coral reefs. During exhaustive surveys, performed by Evans et al. (1974), no corals were detected anywhere within Pearl Harbor. Since that time, the number of species and distribution has gradually increased. Coles et al. (1999) identified five species of Scleractinian corals within the harbor; by 2002 Smith (2002) identified eight; by 2005 11 species were confirmed (Smith, Deslarzes and Brock 2006); Smith (unpublished) confirmed a total of 13 species by 2013 and 15 species by 2014. Figure 2 shows the portions of the harbor which the author has surveyed on a roughly quarterly basis since 1999. Table 1 and Figures 3 through 6 list the species and show their known distribution as of February 2015. Note, the numbers designating a particular coral species in Table 1 are the same numbers used in Figures 3 through 6. For example, numeral 1 represents *Montipora capitata* in Table 1 and in Figures 3 through 6.

Montipora capitata ranks first based upon the amount of sea floor covered and by the size of the largest colonies. Specimens in excess of 100 cm in their maximum dimension have been measured at two locations around Ford Island and in West Loch. This species also has the greatest depth range distribution within the harbor, from depths of 2 to 21.5 m. *Leptastrea purpurea* ranks first based upon the frequency of occurrence (largest total number of specimens). This species is also the most widely distributed and was the first known species to recolonize the harbor after Evans's investigations. However, most of the *Leptastrea purpurea* colonies are very small, less than 8 cm in their maximum dimension. *Pocillopora damicornis* ranks second based upon both frequency of occurrence and area of sea floor covered. These three species are known to be able to withstand high levels of turbidity. Plate 1 illustrates these three corals. Species present in the harbor, such as *Pocillopora meandrina* and *Pocillopora eydouxi*, which are generally not resistant to turbid conditions have only been observed on sections of the shoreline that are regularly subject small wind waves and surface chop which prevents sediment buildup. Examples of that situation include Bishop Point and the shoreline between Channel Markers 18 and 20.

The prop wash from frequent ship movements further increases Pearl Harbor's naturally high levels of turbidity. Therefore, the corals which are present in the harbor are clearly adapted to those physical conditions, or are restricted to areas where turbidity is naturally less, such as the Bishop Point example presented above. Between 1999 and 2015 a number of dredging projects have taken place at various sites within the harbor. The author has not observed any visible adverse impacts or changes to corals that were in proximity to those dredging operations within the harbor.

Plate 1. Top *Montipora capitata* southeast side of Ford Island. Middle *Pocillopora damicornis* near Channel Marker 20. Bottom, typical size *Leptastrea purpurea* colony (center of photo to left of serpentine sea cucumber)



True coral reefs are present adjacent to the PHEC. The reefs on the west side are better developed and support higher percentages of sea floor cover by corals. Forty to 45 species of Scleractinian corals are present within the Main Hawaiian Islands. Taxonomists have not reached agreement on the taxonomy, and therefore the presence or absence of some species. At least 23 species are present within the 300 m width of the PHEC **or** the immediately adjacent (≤ 50 m) sides of the PHEC. However, nearly all of those (>99%) are located on the edges of the PHEC and not within the main body of the channel or on its sea floor. Table 2 lists the species which have been field identified in the PHEC or within 50 m of the edges of the designated channel.

Table 2 Scleractinian Corals in the PHEC
(Excluding Taxonomically Disputed Species Listed in Table 1)

F. Acroporidae	**F. Dendrophyllidae**	**F. Pocilloporidae**	**F. Siderastreidae**
Montipora capitata	*Tubastraea coccinea*	*Pocillopora damicornis*	*Psammocora explanulata*
Montipora flabellata	**F. Faviidae**	*Pocillopora meandrina*	*Psammocora nierstraszi*
Montipora patula	*Cyphastrea ocellina*	*Pocillopora eydouxi*	
Montipora tuberculosa	*Cyphastrea agassizi* (AKA *Leptastrea bottae*)	*Pocillopora ligulata*	
F. Agariciidae	*Leptastrea purpurea*	**F. Poritidae**	
Leptoseris incrustans	*Leptastrea bewickensis*	*Porites compressa*	
Leptoseris sp.	**F. Fungiidae**	*Porites lobata*	
Pavona duerdeni	*Fungia scutaria*	*Porites rus*	
Pavona varians			

Sea floor cover by these corals is very strongly dominated by three species: first *Pocillopora meandrina,* second *Montipora capitata* and third *Porites lobata*. Coral development is most extensive seaward of Channel Marker Buoy 4 on the east side and Channel Marker Buoy 3 on the west side of the PHEC. On the west side of the PHEC, between Channel Marker Buoys 3 and 1 is an area referred to as 'turtle reef'. The approximate coordinates for the best developed portions of this reef are: N 21^{o} 18.091' x W 157^{o} 57.588 by N 21^{o} 18.046' x W 157^{o} 57.571'. This portion of the PHEC is the most biologically significant, based upon: 1) physical relief and rugosity, 2) coral diversity and coral cover, 3) fish diversity and density, 4) year round presence of green sea turtles (*Chelonia mydas*) and 5) the frequent presence of sharks, manta rays and spotted eagle rays. There is a natural vertical wall at 'turtle reef', the top ranges from 5 – 6 m deep, and the base is 14 - 15 m deep. There are 15 separate grottos at the base of the wall; the largest measures 3.5 m wide X 4 m deep X 1.2 m high. Green turtles utilize these grottos year round. Whitetip reef sharks (*Triaenodon obesus*) co-occur with the green turtles as well as Blacktip reef sharks (*Carcharhinus melanopterus*) and Blacktip sharks (*Carcharhinus limbatus*). All the Scleractinian coral species which have been sighted in the PHEC have been observed at this location. It also supports the highest coral densities in the zone within 50 m of the PHEC, up to 25% sea floor cover in some areas.

Proceeding to the west, from the top of the vertical wall at turtle reef, classic spur and groove topography extends for several hundred meters. The grooves range from 6 to 9 m in total depth (from the sea surface) while the spurs are generally 1 – 2 m high. Continuing west, this spur and groove topography becomes less pronounced. The sea floor consists of a gently sloping (< 5 ^{o}) fossilized limestone bottom with a thin veneer of coarse sand and widely scattered rock and coral outcrops. Most of the latter are less than one m high. Overall live Scleractinian coral cover is less than 5%. Macro algae and sea grass are present, but are generally not abundant. Parallel to shore at depths of 20 and 30 m there are wave cut benches (formed during lower sea level stands) with scattered grottos. These rocky ledges and grottos support substantial coral growth, particularly *Pocillopora meandrina* and *Pocillopora eydouxi*, large numbers of reef fish and also provide good potential resting habitat for turtles. A similar series of wave cut benches are located to the east of the PHEC extending toward Honolulu Harbor. Coral cover and diversity along these east-side wave cut benches is (qualitatively) judged to be less than half of what is encountered on the west-side.

<u>Selected Fin Fish and EFH</u>

The last detailed quantitative assessment of fishes was presented in "Characterization of Fish and Benthic Communities of Pearl Harbor and Pearl Harbor Entrance Channel" Smith, Deslarzes and Brock (2006). That report concluded that Pearl Harbor and the PHEC is an important habitat for many species of reef fishes and that the mean size and densities of many fishery target species is greater in Pearl Harbor and the PHEC than at most if not all other locations in the Main Hawaiian Islands which have been studied. Based upon qualitative observations and limited quantitative data collected by the author since the 2006 study, it is his opinion that fish stocks have continued to improve in both the harbor and the PHEC. Notable (apparent) changes since the 2006 report include, but are not limited to, the following:

1. *Gnathanodon speciosus* (golden trevally, yellow ulua) have become more numerous and larger. They are most frequently sighted near Waipio Point and in the southern reaches of West Loch. Specimens with an estimated total length (TL) of 80 cm have been frequently encountered and have always been in small schools of four to 10 individuals.
2. *Caranx ignobilis* (giant trevally, white ulua) have also increased in numbers and size. Schools of twenty individuals are routinely sighted at the seaward end of the PHEC near the Fort Kamehameha WWTP outfall pipe. Many of the individual specimens are estimated to be in excess of 100 cm TL.
3. *Caranx sexfasciatus* (bigeye trevally, sasa) are the most abundant (large) member of the Carangidae (Jack) family in the project area. Schools in excess of 100 individuals are often sighted in the outermost portions of the PHEC and solitary individuals or small schools of 8 -10 individuals are often seen inside the harbor, particularly on the east side of Ford Island.
4. *Acanthurus blochii* (ringtail surgeonfish, pualu) numbers appear to have increased more than any other fish species since 2006. Large schools (>25) and large individuals (> 30 cm TL) frequent all parts of Pearl Harbor, including areas adjacent to and under the piers in Southeast Loch. Ringtail surgeonfish are abundant at turtle reef year round.
5. Juvenile parrotfishes (species not confirmed) have shown substantial increases in the PHEC and in the harbor every year since 2006. Adult parrotfish, particularly *Chlorurus perspicillatus* are noticeably more abundant with large specimens commonly observed. Smith, Deslarzes and Brock (2006) estimated that the average weight of *Chlorurus perspicillatus* to be 243 g compared to estimates (made in the same general time period)

of 71 g off Lanai and 87 g at the Atlantis wreck site off Waikiki. This species is present throughout the PHEC and the harbor, but is most abundant at turtle reef, the Beckoning Point degausing facility, Waipio Point and the lower reaches of West Loch and lastly the south east side of Ford Island .

6. *Manta birostris* (manta ray) sightings are more common in the outer portions of the PHEC than prior to 2006. They enter the PHEC when the tide is ebbing. When sighted, there are usually two to five individuals; they range in size from 200 to 300 cm (wing span).

Population structures of the other fish species have remained stable or have increased since 2006, with a single exception. Fewer shark sightings have been made than in the past. However, all the shark species recorded in the 2006 report are still encountered occasionally.

All of the Main Hawaiian Islands, from the high tide line to depths over 100 m have been designated as Essential Fish Habitat (EFH) for one or more managed species. Therefore, all of Pearl Harbor, the PHEC and the adjacent areas being assessed for the proposed project are EFH. No Habitat Areas of Particular Concern (HAPC) have been designated for the project area.

Because of restricted public access and the implementation of advanced environmental safeguards Pearl Harbor and the PHEC are free from and/or experience very reduced impacts from factors which routinely result in adverse impacts to fish and other marine organisms. Table 3 lists some of these key stressors.

Table 3. Common Stressors Which Are Absent or Reduced in Pearl Harbor and the PHEC

Stressors	Stressors
Reef walking	Grounding of personal watercraft
Skin /SCUBA Diving	Untreated sewage discharge personal watercraft
Spear fishing	Improper/inadequate waste water disposal
Trap & net fishing	Improper/inadequate storm water runoff disposal
Hook & line fishing	Illegal dumping of hazardous materials/waste
Jet skiing	Improper/inadequate erosion control
Motorized personal watercraft	Harassment of marine life by beachgoers
Collection of corals & invertebrates for the aquarium trade	Reduced H2O quality from large volumes of sun block

The most important sites, relative to fish biomass, fish diversity and the presence of juvenile and/or adult fishery target species (managed species) are:

1. Turtle reef. Please refer to the previous description of this location.
2. Southeastern most portion of the PHEC and the Fort Kamehameha WWTP outfall pipe. The pipe emerges from the seafloor at a depth of 19 m near the mouth of the PHEC and then extends to the south southeast and terminates at a depth of approximately 49 m. The pipe is 1.2 m in diameter and is supported by large concrete piles at 10 m intervals. There are extensive sea grass beds adjacent to the outfall pipe to depths of 40 m.
3. Waipio Point and submerged debris fields/wrecks in the southern portions of West Loch. The point and areas to the northeast and north west have natural vertical to near vertical walls with abundant small caves and undercut ledges which provide good fish habitat. Several wrecks and debris fields on the eastern and western sides of West Loch Channel also provide important fish habitat.

4. Southeast side of Ford Island. The nearshore area from Building No. 77 (on the east side of Ford Island) to the southern tip of Ford Island at depths of 1-8 m supports substantial coral, natural drop-offs and the abandoned sea plane ramps. The sea plane ramps are undercut to distances of more than 8 m in many locations. These features serve to attract one of the largest and most diverse groups of fish of any location within the harbor.
5. Beckoning Point Degaussing Facility. This is a relatively new facility. It consists of a large complex of steel piles and cross members extending to depths of over 15 m with an overall footprint of approximately 6,400 m^2. The area is serving as a de-facto artificial reef and supports a dense fish population, particularly surgeonfishes.

Sea Turtles

There are seven recognized species of marine turtles. All of these are classified as Threatened or Endangered. Two of these species have been documented from the proposed project area: the Threatened green turtle (*Chelonia mydas*) and the Endangered hawksbill (*Eretmochelys imbricata*). The author, with significant assistance from D. Marx, conducted 500 individual underwater transects to assess sea turtles, between March 2000 and February 2014. Open circuit compressed air scuba was used to conduct the transects and sea turtle densities were estimated per unit time and per unit area surveyed. Most transects were conducted in one of 20 separate study areas (Figure 7). Data collected included species, size, sex, behavior when first sighted, apparent health and distinguishing features. The results of this long-term study are currently in-press. Some of the most relevant findings are listed below:

1. Green turtles have been present year round in the PHEC from 2000 through 2014.
2. The estimated number of green turtles has remained stable or increased slightly; it is estimated that there are approximately 30 individuals which are year round residents in the PHEC.
3. There are few, if any green turtles which are resident within the harbor; however, green turtles have been sighted in most portions of the harbor. The largest number of sightings within the harbor have been in West Loch.
4. Green turtles are not evenly distributed in Pearl Harbor or in the PHEC. The areas in which the largest number of sightings routinely occur are, in descending order: i] turtle reef, ii] the Fort Kamehameha WWTP outfall pipe, iii] the area adjacent to PHEC Channel Marker No. 4, iv] West Loch/Waipio Point.
5. Only two separate hawksbill turtles have been sighted during the entire survey period.
6. Green turtles have been observed both resting and foraging to a depth of 43 m along the WWTP outfall pipe.
7. The incidence of green turtles with fibro-papilloma tumors, and the number of tumors per infected turtle have both declined steadily since 2000.

Miscellaneous

Pearl Harbor and the PHEC are clearly serving as a de-facto preserve. In addition to the return of Scleractinian corals and the presence of a robust fish and green turtle population, Pearl Harbor and the PHEC have seen the return of their namesake, the black lipped pearl oyster (*Pinctada margaritifera*). This oyster was extirpated, or nearly extirpated from the harbor decades ago, but has become increasingly common since the surveys described here began. It is now common in the PHEC and in all of the harbor's lochs. Another once common species has also made a comeback, the striped mantis shrimp (*Lysioquilla maculatus*). It is important to emphasize, that all this has taken place in spite of the fact that during the last 15 years there have been many major dredging and construction projects in the harbor and the PHEC. The evidence strongly supports the position that the organisms which are present have adapted to the naturally high levels of turbidity that the Pearl Harbor estuary is subject to and that the temporary increases in turbidity from construction and dredging have had no significant adverse impacts to marine natural resources.

Data Gaps

There are a number of data gaps which either currently exist, or which will exist in the future. To ensure that these gaps are filled and/or do not develop, it is recommended that the following studies be undertaken and/or continued. These studies are ranked in their perceived order of importance.

1. Reconnaissance level coral surveys should be performed twice per year to assess all portions of the harbor and PHEC which have been assessed in the past. This will ensure that changes to the coral community are documented in a timely fashion.
2. Sea urchin distribution and populations have only been assessed once since 1997. This important group should be quantitatively evaluated and monitored at selected sites in both Pearl Harbor and the PHEC.
3. The invasive alga, gorilla seaweed (*Gracillaria salicornia*), has adversely impacted numerous areas in the Main Hawaiian Island, including Pearl Harbor. Although, the densities of this alga appear to be declining in some parts of the harbor, it has not been adequately assessed. This species has overgrown and killed corals in parts of the harbor. It is recommended that a quantitative study of this alga be combined with the coral surveys.
4. Much of the harbor shoreline is lined with the red mangrove (*Rhizophora mangle*). Mangroves, like many of the large trees in Hawaii are not native. Some stakeholders consider the red mangrove to be invasive and recommend its eradication. However, such efforts ignore the fact that in Pearl Harbor, red mangroves provide many critical functions, including, but not limited to: i] stabilizing the shoreline, ii] providing important habitat for many fish species in their juvenile stages and iii] protecting certain corals from increasing sea surface temperatures. No studies have been done to document the importance of Pearl Harbor's mangroves to fishes and corals. Such a study should be completed prior to any efforts or funding to remove additional mangroves.
5. An updated effort to quantitatively assess selected fin fish species in Pearl Harbor and the PHEC needs to be completed. It has been 10 years since the last survey and an updated evaluation of this important resource is needed.
6. There are wreckage items within the project area that may be of cultural significance. These items are located in the PHEC and West Loch. An evaluation of these sites should be undertaken.
7. Additional coral surveys to the east and west of the PHEC should be performed to better document coral resources in those areas.

Figure 1. Project Area

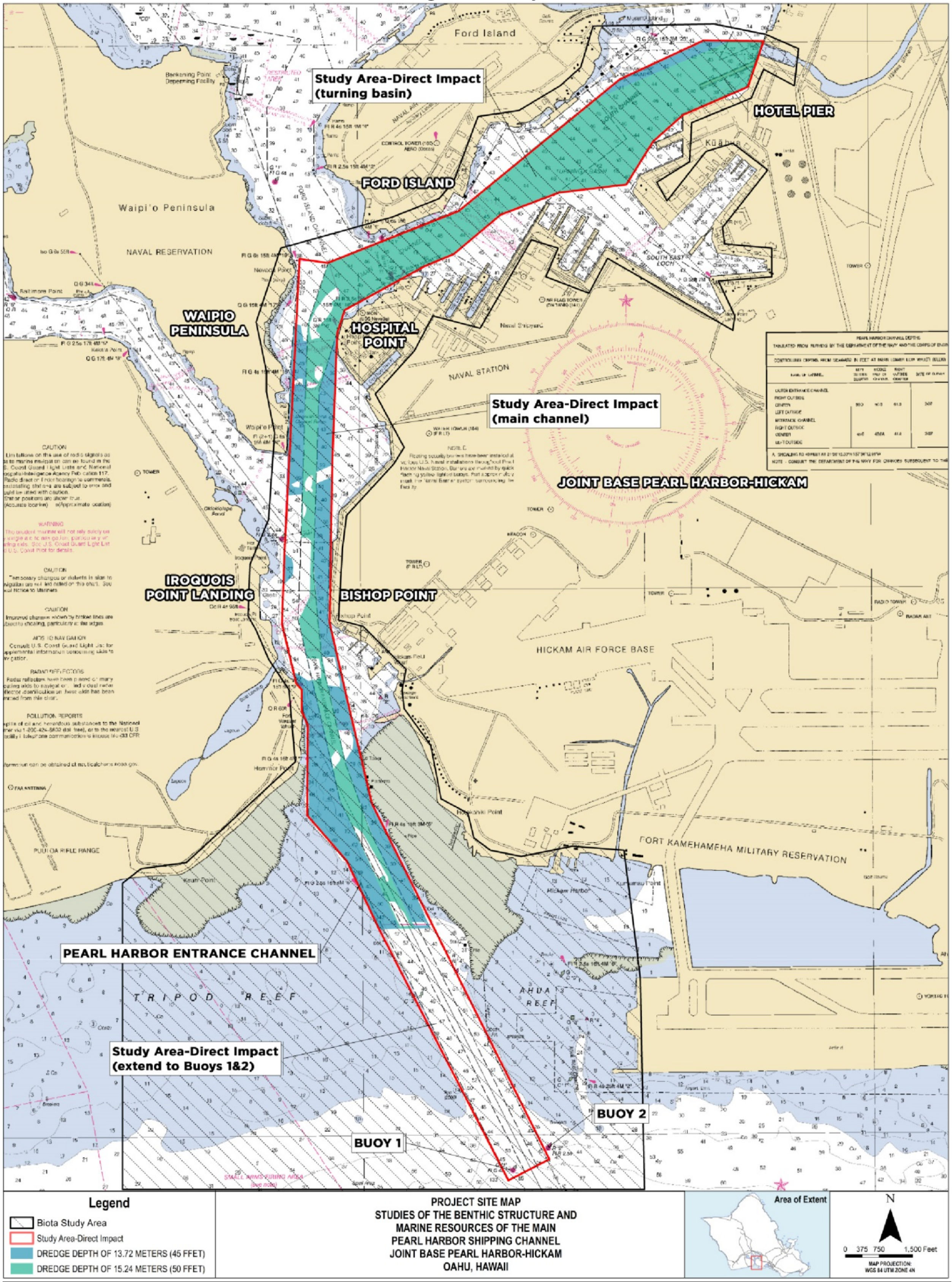


Figure 2. Pearl Harbor Coral Surveys

Pearl Harbor Coral Surveys (Data from 2000-2015)

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Figure 3. Coral Survys - Kuahua Peninsula, Shipyard

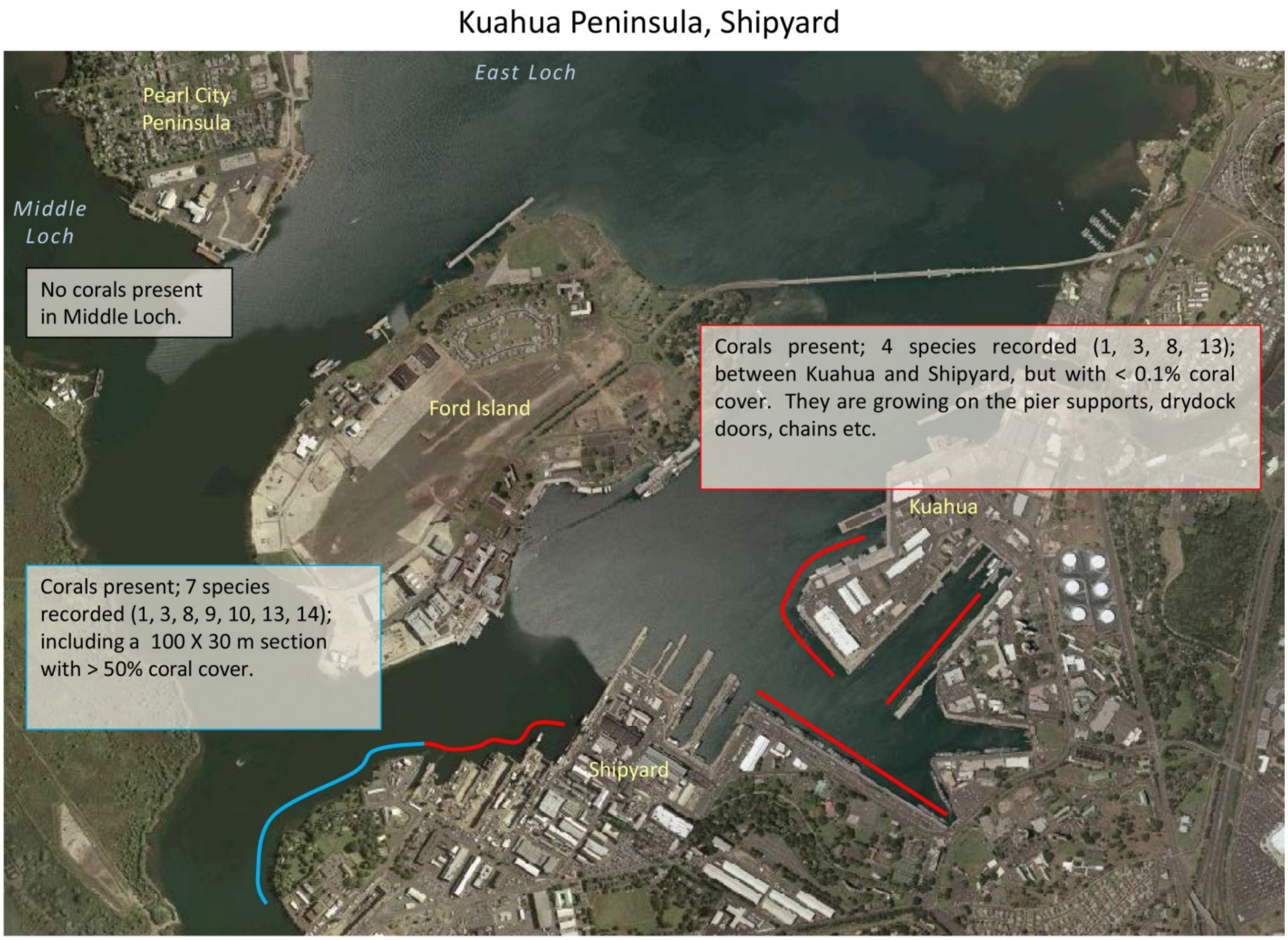

Figure 4. Coral Surveys - Ford Island, Pearl City Peninsula, Aiea Bay

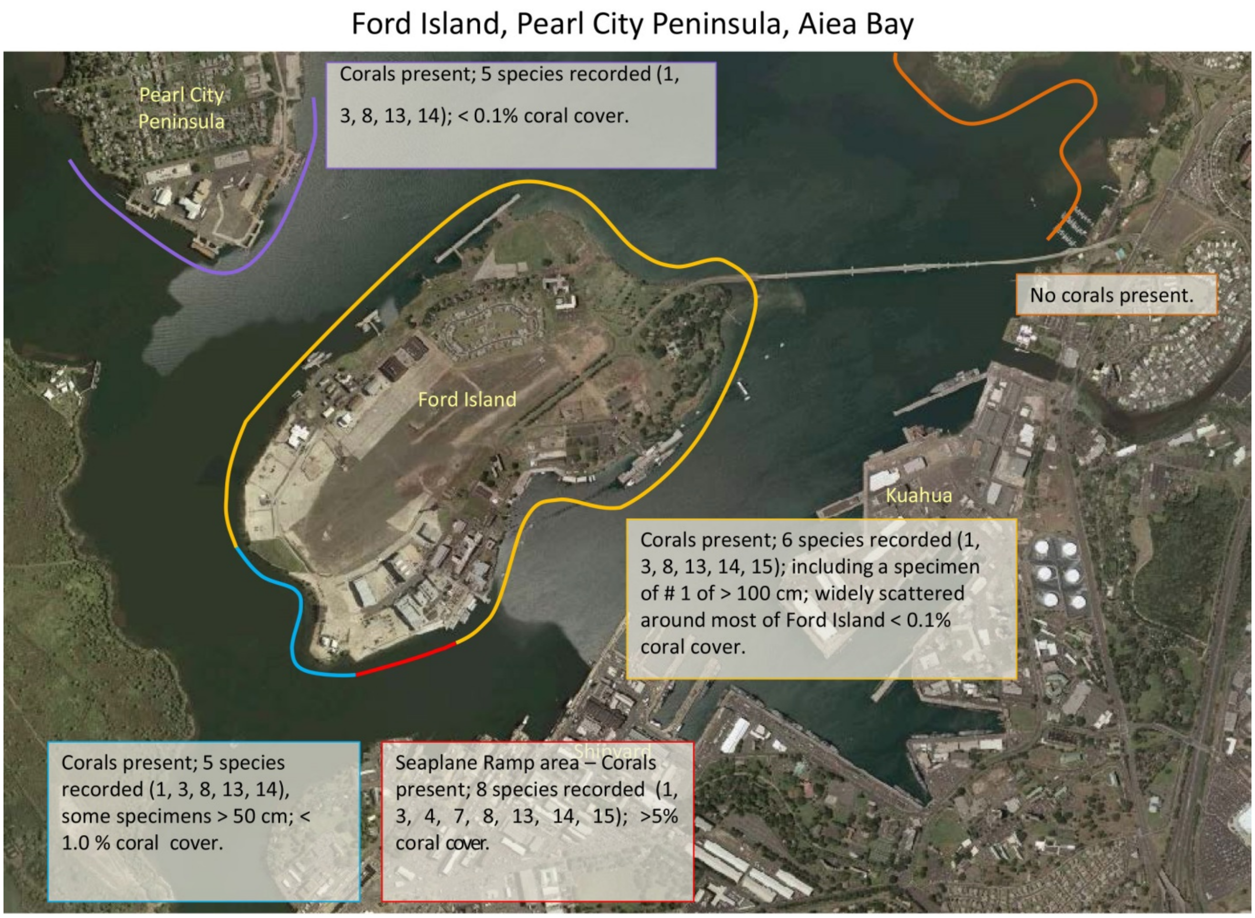

Figure 5. Coral Surveys - West Loch, Waipio Peninsula

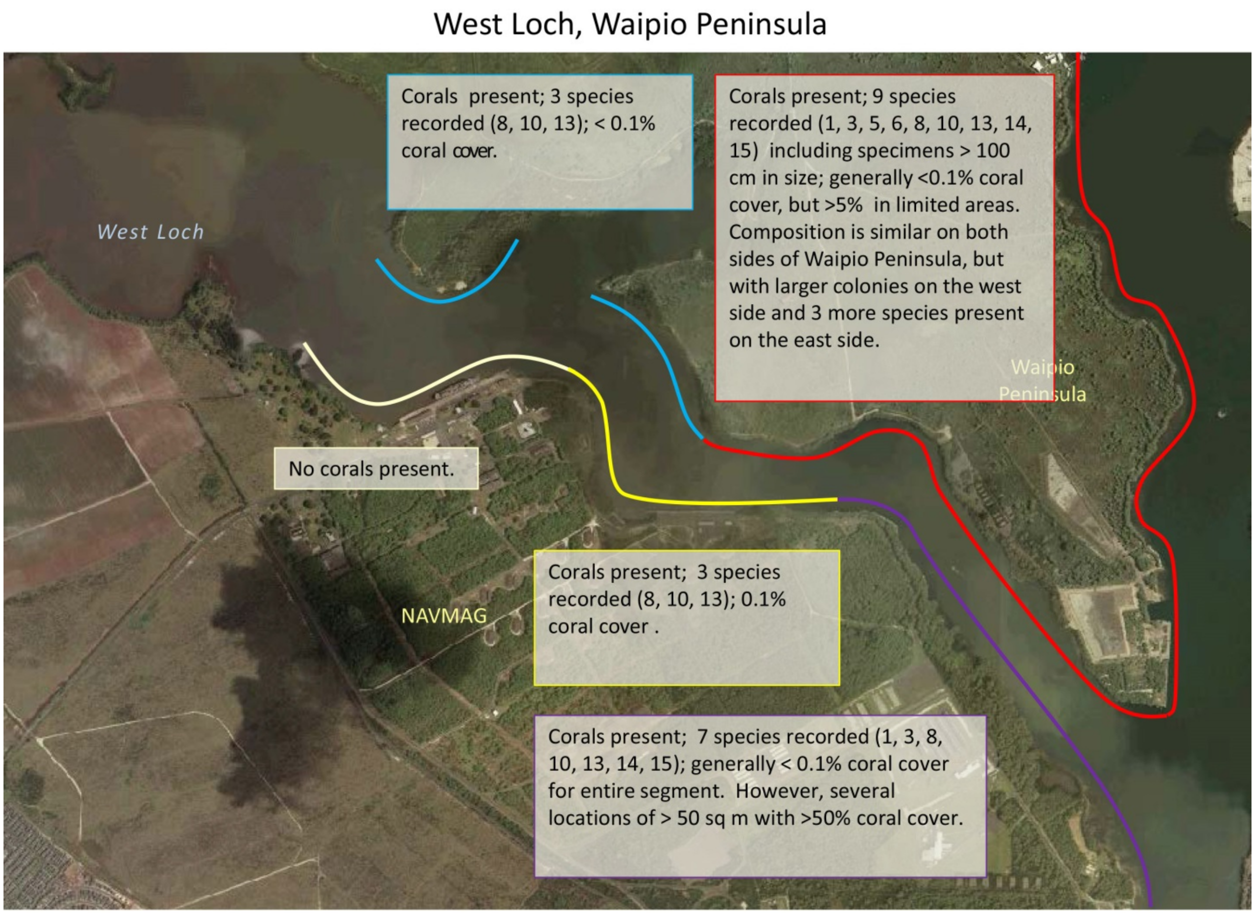

Figure 6. Coral Surveys PHEC

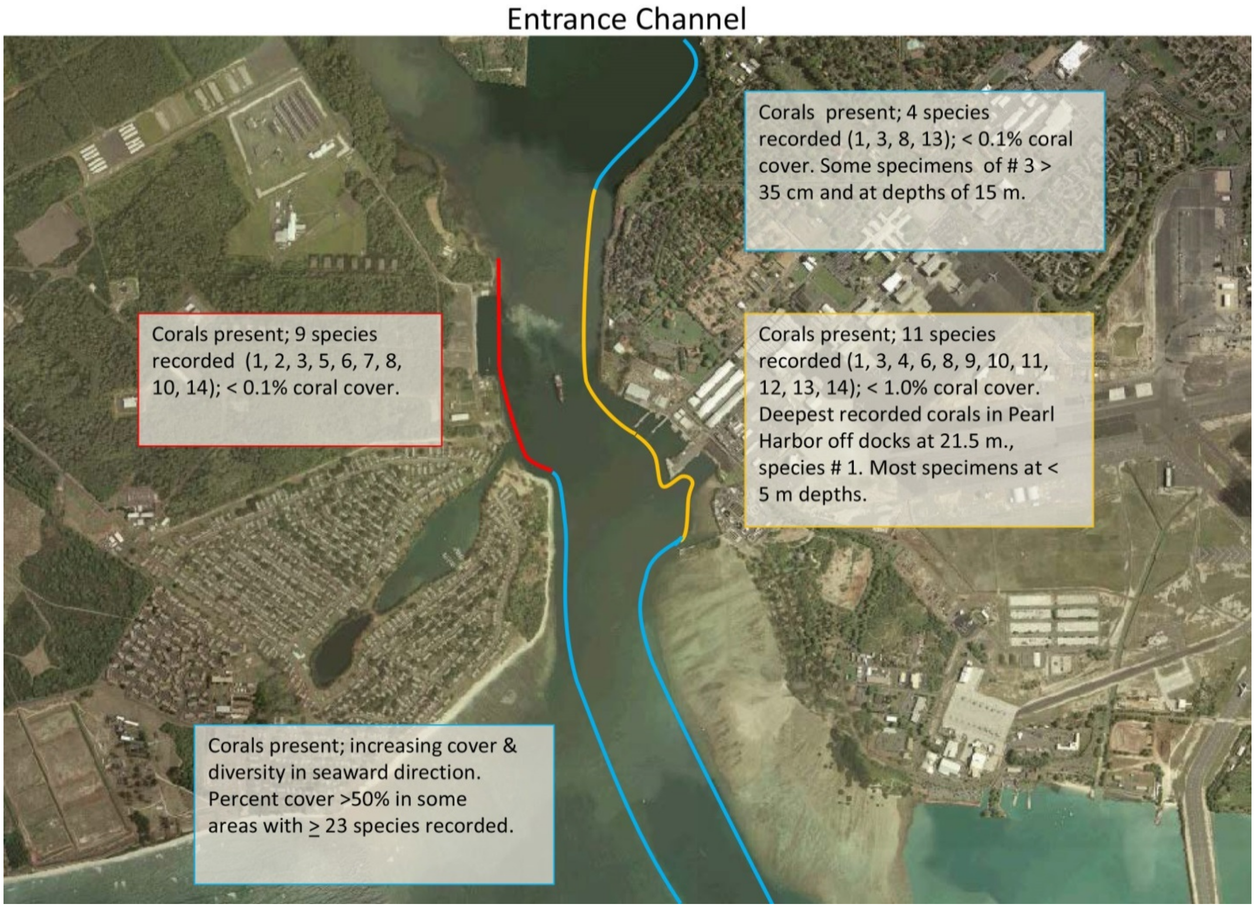

Figure 7. Primary Sea Turtle Survey Segments

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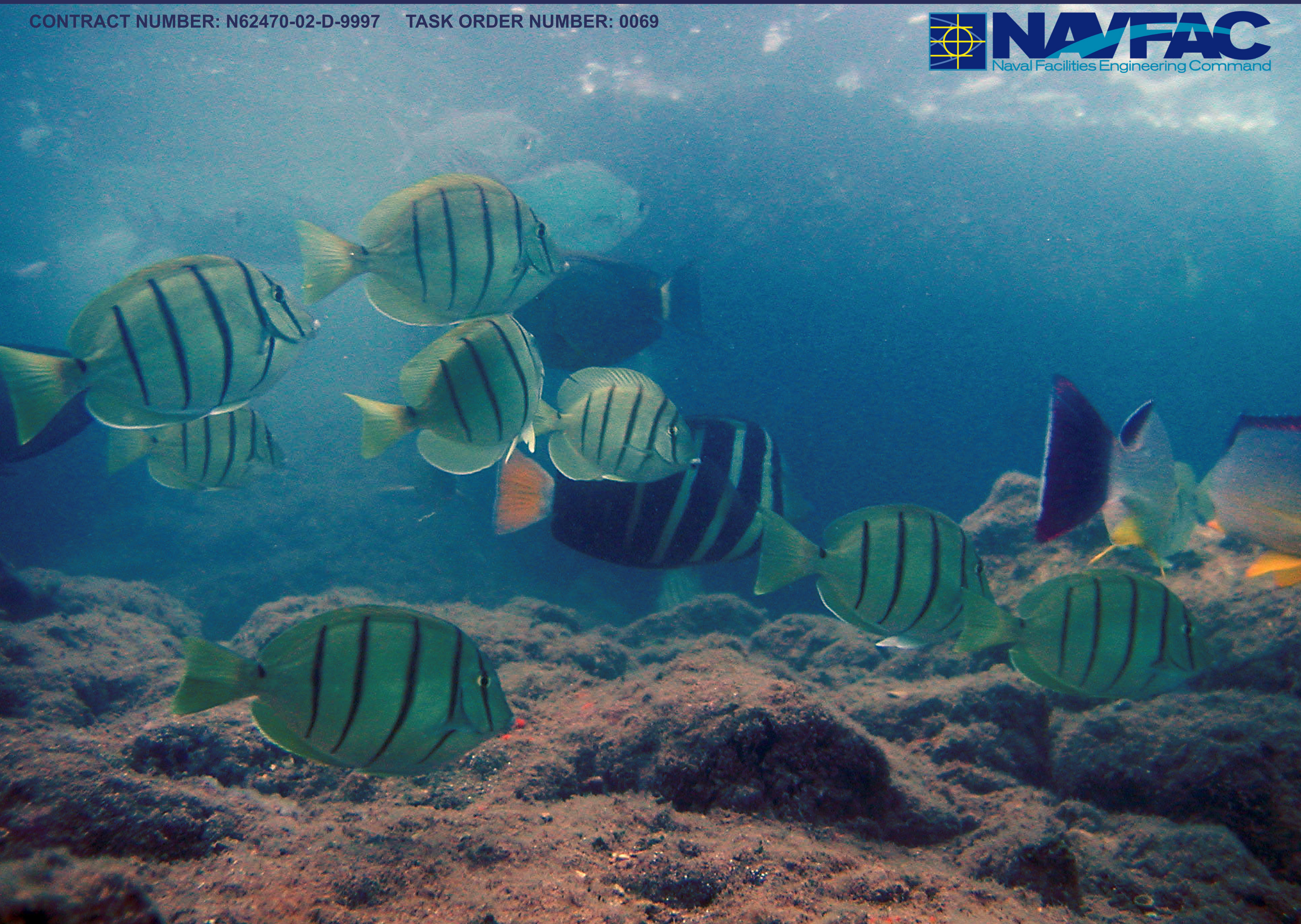
CHARACTERIZATION OF FISH AND BENTHIC COMMUNITIES OF PEARL HARBOR AND PEARL HARBOR ENTRANCE CHANNEL, HAWAI'I

FINAL REPORT - DECEMBER 2006

CONTRACT NUMBER: N62470-02-D-9997 TASK ORDER NUMBER: 0069



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NAVFAC
Naval Facilities Engineering Command

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LIST OF ACRONYMS AND ABBREVIATIONS

%	Percent
°	Degree(s)
°C	Degree(s) Celsius
ANOVA	Analysis of Variance
CCA	Crustose Coralline Algae
cm	Centimeter(s)
cm^2	Square Centimeter(s)
DoN	Department of the Navy
g	Gram(s)
g/m^2	Gram(s) Per Square Meter
GMI	Geo-Marine, Inc.
GPS	Global Positioning System
H	Pearl Harbor
ha	Hectare(s)
kg	Kilogram(s)
km	Kilometer(s)
km^2	Square Kilometer(s)
m	Meter(s)
m^2	Square Meter(s)
m^3/day	Cubic Meter(s) Per Day
NITROX	Enriched Air
PCQM	Point Centered Quarter Method
PHEC	Pearl Harbor Entrance Channel
PQA	Photo-Quadrat Analyzer
psu	Practical Salinity Unit(s)
PVC	Polyvinyl Chloride
QIM	Quadrat Intercept Method
SCUBA	Self Contained Underwater Breathing Apparatus
SD	Standard Deviation
SE	Standard Error
SNK	Student-Newman-Keuls
t	Ton(s)
U.S.	United States

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1.0 INTRODUCTION

1.1 PURPOSE

The objective of this project that took place in September 2005 was to assess the status of selected elements of the marine community in Pearl Harbor and the Pearl Harbor Entrance Channel (PHEC), O'ahu, Hawai'i. **Figures 1-1**, **1-2a**, and **1-2b**, depict the project areas and study sites. Particular emphasis was placed upon assessing fin fishes and sessile macro-benthic communities. Data was also gathered on threatened and endangered species.

Within this broad context, the authors attempted to address the following questions:

1. Have there been any changes in the fish and benthic communities since the Evans (1974) investigations?
2. How do fish communities and fish stocks in Pearl Harbor compare to other locations around O'ahu and in the Main Hawaiian Islands?
3. What is the status of stony corals in Pearl Harbor and the PHEC? How does this compare with the findings of Evans (1974) and Smith (2000, 2002)?
4. What changes have occurred in Turtle/Tripod Reef coral community between 2002 and 2005?
5. How did the construction of the Fort Kamehameha Outfall Replacement affect stony coral distribution in the trenched portion of the outfall corridor, located within the PHEC?
6. Are corals recruiting to the pile supported portions of the Fort Kamehameha Outfall and what other macrobenthic species are present on the outfall pipe and pile supports?
7. What marine threatened and endangered species occur within Pearl Harbor, the PHEC, and along the pile supported portion of the outfall, seaward of the PHEC?

1.2 ENVIRONMENTAL SETTING

1.2.1 Pearl Harbor

Pearl Harbor is located on the island of O'ahu, one of the eight Main Hawaiian Islands. O'ahu was formed by two volcanoes, the Waianae volcano to the west and Koolau volcano to the east. A broad coastal plain extends to the south, between the two volcanoes; Pearl Harbor is a landlocked estuary situated on this plain. It covers an area of approximately 21 square kilometers (km^2) and consists of three main lochs (West Loch, Middle Loch, and East Loch) and a smaller loch (Southwest Loch). These lochs are the remnants of drowned river valleys which connect to a common channel leading to the Pacific Ocean (Coles et al. 1997; Dollar and Brock 2001). The total length of the Pearl Harbor shoreline is approximately 58 kilometers (km).

The boundary between Pearl Harbor and the PHEC is considered to be Hammer Point (**Figure 1-2a**). The area seaward of Hammer Point, to the outermost channel markers buoys, is defined as the PHEC. The PHEC is approximately 3.2 km long and 300 meters (m) wide.

Water depths within Pearl Harbor average 9 m, with a maximum depth of 28 m. A fossilized reef platform forms the eastern and western edges of the PHEC; much of this platform is less than 3 m deep. The central portions of the PHEC range from 15 to 20 m deep (**Figure 1-2a**).

The Pearl Harbor watershed drains roughly 22 percent (%) of the island of O'ahu, or approximately 347 km^2. Seven perennial streams enter Pearl Harbor; however, 70% of the natural fresh water discharge is from springs, the largest of which is Waimanu-Waiau spring complex (Englund et al. 2000). These springs are the largest in the Hawaiian Islands and one of the largest of the Pacific islands (Englund et al. 2000). Grovhoug (1992) estimated the median flow from the Waimanu-Waiau springs to be 121,120 cubic meters per day (m^3/day). Stream flows into Pearl Harbor are heavily influenced by the springs and both the spring and stream discharge vary dramatically during the year. The total fresh water input into Pearl Harbor was calculated to be 189,250 to 378,500 m^3/day during the dry summer season and rainy winter months, respectively (Grovhoug 1992).

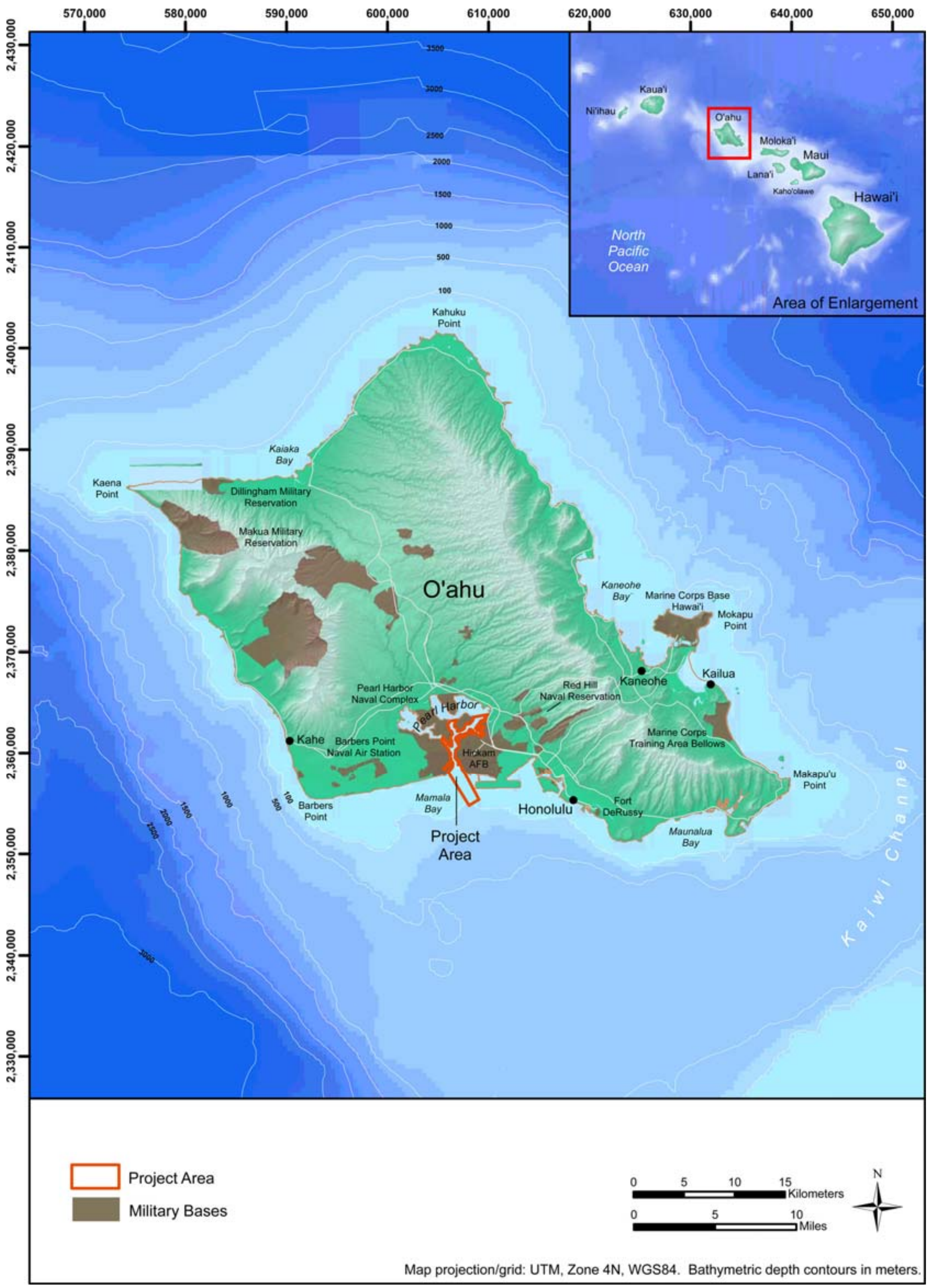
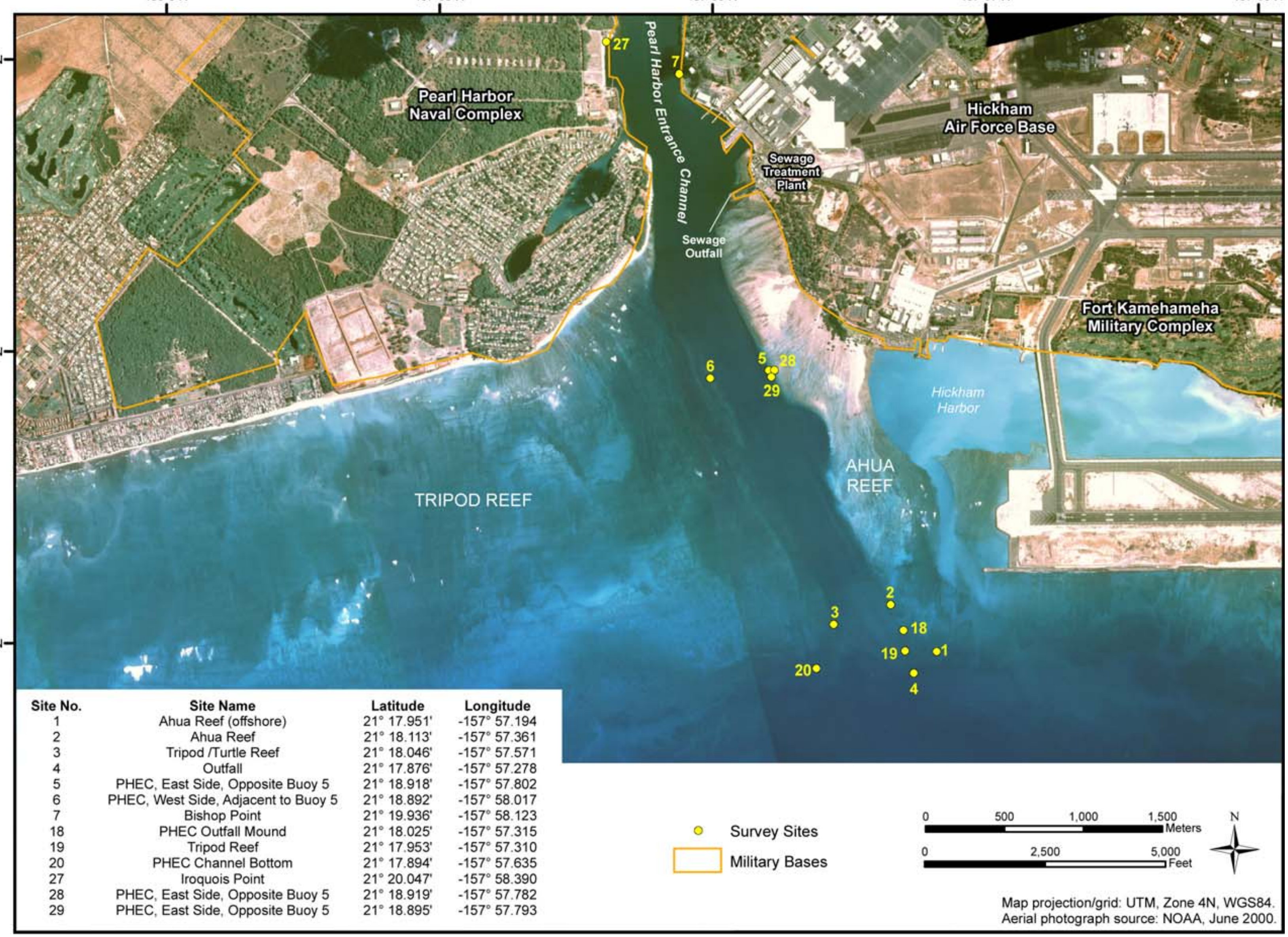


Figure 1-1. Location map of Pearl Harbor, Hawai'i and the project area (Source data: NOAA 2002; Sandwell et al. 2004).



Site No.	Site Name	Latitude	Longitude
1	Ahua Reef (offshore)	21° 17.951'	-157° 57.194
2	Ahua Reef	21° 18.113'	-157° 57.361
3	Tripod /Turtle Reef	21° 18.046'	-157° 57.571
4	Outfall	21° 17.876'	-157° 57.278
5	PHEC, East Side, Opposite Buoy 5	21° 18.918'	-157° 57.802
6	PHEC, West Side, Adjacent to Buoy 5	21° 18.892'	-157° 58.017
7	Bishop Point	21° 19.936'	-157° 58.123
18	PHEC Outfall Mound	21° 18.025'	-157° 57.315
19	Tripod Reef	21° 17.953'	-157° 57.310
20	PHEC Channel Bottom	21° 17.894'	-157° 57.635
27	Iroquois Point	21° 20.047'	-157° 58.390
28	PHEC, East Side, Opposite Buoy 5	21° 18.919'	-157° 57.782
29	PHEC, East Side, Opposite Buoy 5	21° 18.895'	-157° 57.793

Figure 1-2a. Location of study sites within Pearl Harbor, and the Pearl Harbor Entrance Channel, Hawai'i (Source data: NCCOS 2005).

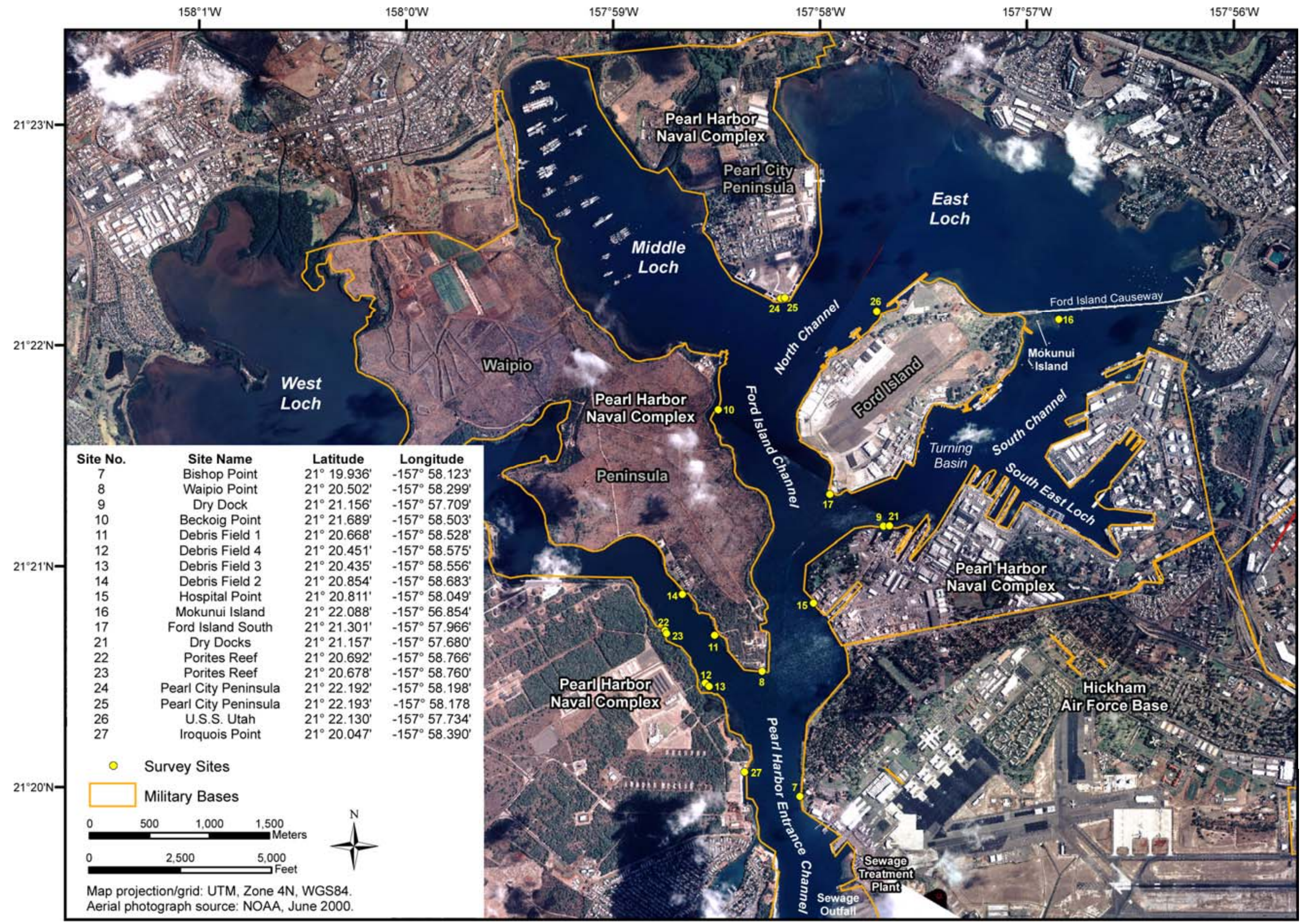


Figure 1-2b. Location of study sites within Pearl Harbor, and the Pearl Harbor Entrance Channel, Hawai'i (Source data: NCCOS 2005).

Turbidity within Pearl Harbor is an important factor affecting the distribution of organisms. B-K Dynamics (1972) estimated that Pearl Harbor’s streams introduce approximately 386 tons (t) of sediment per day into Pearl Harbor.

Due to the shape of Pearl Harbor and the relatively narrow Pearl Harbor mouth, water exchange between Pearl Harbor and the open ocean is slow. Grovhoug (1992) estimated that the residence time for bottom waters is up to six days and for surface waters one to three days. The conditions in the PHEC are significantly different. Although no actual measurements are available, the complete exchange of water within the PHEC (as defined in this study) probably takes place on a daily basis.

Water temperatures within Pearl Harbor range from 23 to 29 degrees Celsius (^{o}C) and salinity ranges from 10 to 37 practical salinity units (psu) (Coles et al 1997). Buske and Evans (1974) found a single thermocline and single halocline within Pearl Harbor at depths of 1.5 and 5.5 m, respectively. As expected in an area with substantial freshwater input, surface salinities are lower than those near the Pearl Harbor bottom, except in the case of underwater springs where strong mixing and upwelling can occur. In the PHEC oceanic influences become progressively stronger as one proceeds seaward from Hammer Point, and the differences noted above diminish.

Recent Human Activity and Anthropogenic Impacts—Prior to 1910 Pearl Harbor was a more confined, and probably more estuarine environment (Coles et al. 1997). A 5 m deep limestone sill functioned as a natural barrier between the present Pearl Harbor and the PHEC. In 1911 a deeper entrance channel was dredged, and over the next several decades Pearl Harbor became a hub of United States (U.S.) Naval activities in the Pacific. Much of the Pearl Harbor coastline was modified and substantial portions of all the Lochs were dredged. In addition to dredging, native Hawaiian fish ponds were filled and other shoreline areas were reclaimed with fill and dredge spoil. At the same time the Navy was developing Pearl Harbor as a major base, the surrounding lands were undergoing rapid changes as well. Mechanized sugar cane cultivation, the extensive use of fertilizers and pesticides, industrialization and residential development all contributed to increased sedimentation and pollution of Pearl Harbor. The American Sugar Company intentionally introduced the red mangrove (*Rhizophora mangle*) on Molokai in 1902. Although the mangroves were reported in Pearl Harbor by 1917, they did not spread rapidly within Pearl Harbor until the 1940s when mechanized agriculture caused the deltaic accumulation of sediments along the harbor shoreline. Today, substantial portions of the undeveloped shoreline are lined with this tree.

Human-induced impacts on water quality and natural resources reached their peak during the 1940 to 1970 period. During that time the Pearl Harbor environment became polluted and degraded by sewage (over 100 sewer outfalls), agricultural waste (including pesticides and fertilizers), sedimentation from land development, and industrial waste (including corrosion products, oil, and brewery waste) (Evans et al. 1972). In the early 1970s, sewage outfalls from the Navy discharged an average of 24,000 m^3/day and City and County of Honolulu sewage outfalls discharged an average of 34,000 m^3/day (Evans et al. 1972) into Pearl Harbor.

Several mass mortalities of marine life in Pearl Harbor were recorded during the 1970s. In June 1972, large numbers of invertebrates were killed in Middle Loch, in the vicinity of the City and County of Honolulu’s Pearl City Sewage Treatment Plant (DoN 2001). In July of the same year, an estimated 34 million oysters, primarily located in West Loch, died from a parasitic infection. Substantial fish kills were also reported in the 1970s; the kills were attributed to red tide caused by the dinoflagellate *Cochlodinium catenatum* (DoN 2001).

1.2.2 Ecological Zonation within Pearl Harbor

Pearl Harbor has two primary ecological zones based upon substrate type: a soft bottom zone comprised of unconsolidated sediment and a hard substrate zone comprised of fossilized reefal material or anthropogenic items, such as steel sheet piles, concrete piers, wooden piles, and sunken items (Dollar and Brock 2001).

Roughly 90% of the Pearl Harbor seafloor is classified as unconsolidated sediment; it is primarily terrigenous mud and calcareous sand. The proportion of terrigenous mud relative to coarse, calcareous sand decreases in a seaward direction from the inner Pearl Harbor toward the PHEC. The unconsolidated sediment layer in the inner Pearl Harbor is believed to be more than several meters thick in most areas of Pearl Harbor that are deeper than 10 m. Surrounding much of the Pearl Harbor shoreline there is a submerged limestone/fossilized reef platform, which is covered by a relatively thin layer of mud and/or sand. At its outer edges, the limestone platform ends in a natural or dredged wall, or slopes more gradually to the Pearl Harbor seafloor. In addition to these natural substrates, substantial portions of the Pearl Harbor shoreline are lined with concrete, steel walls, and sheet piles. Substantial quantities of wooden, metallic, and concrete debris are scattered throughout Pearl Harbor (Smith pers. obs.). This debris includes the remnants of piers, barges, navigation aids, and materials from the December 7, 1941 Pearl Harbor attack. This human-made material currently plays an important ecological role, as will be discussed later in this report.

1.2.3 Ecological Characteristics of the Pearl Harbor Entrance Channel

There are four distinct ecological zones in and immediately adjacent to the PHEC: the channel seafloor, the fossilized reef platform, the vertical wall between the reef platform and the channel seafloor, and the reefs seaward of the PHEC. The largest component of this study area was the channel itself. The channel is approximately 300 m wide and 3.2 km long; it consists almost entirely of unconsolidated sediment, which becomes increasingly coarse in a seaward direction. The channel seafloor is generally flat; small widely dispersed patches of seagrass occur and stony coral cover is less than 0.5%. A second distinct zone flanks both sides of the PHEC and consists of a fossilized reef platform. Depths on this platform range from approximately 1 to 20 m, the deeper end being located at the seaward end of the channel. Most of the fossilized reef platform is less than 4 m deep and is routinely subject to high wave energies. For the majority of the channel's length, there is a steep 25 to 45 degree (°) slope that joins the fossilized reef platform to the PHEC seafloor; however, there are also significant segments where there is a vertical wall joining the fossilized reef platform to the channel seafloor. Along the western side of the PHEC, most of these vertical walls appear to be natural, while those on the eastern side appear to be a mix of natural and dredged walls. The fourth ecological zone is located both seaward of and adjacent to the PHEC. It consists of poorly to modestly developed spur and groove coral reefs and fossilized reef platform areas. The spur and groove topography is best developed on the western side of the channel in depths of approximately 7 to 9 m. In this area the spurs range from 6 to 30 m in width and the grooves range from 3 to 14 m in width; spur height average is 1.5 m (Smith 2002). Along the eastern side of the PHEC, near the Pearl Harbor end of the channel, the fossilized reef platform is dotted with microatolls formed by *Porites lobata* (Scoffin and Stoddart 1978; Marine Research Consultants, Inc. 2001). Coral cover is highest on the western side of the PHEC (Marine Research Consultants, Inc. 2001; Smith pers. obs.).

1.3 STUDY SITES

Selected marine resources, including corals, fishes and sea turtles, were assessed at 18 sites within Pearl Harbor and 11 sites in or adjacent to the PHEC (**Figures 1-2a** and **1-2b**; **Table 1-1**). The assessments were conducted within relatively small areas and resulted in detailed site-specific information. Marine resources assessed here were encountered on hard substrates, unconsolidated substrates (gravel to soft bottom), and artificial substrates (wood, concrete, and metal structures) (**Table 1-1**).

Stephen Smith, Navy Technical Representative, designated the locations of the study sites. Geographical coordinates of study sites were recorded using a Global Positioning System (GPS) (**Table 1-1**). Fish and benthic communities were assessed in areas previously surveyed by Evans (1974), and Smith (2000 and 2002). Study sites were located in the PHEC environs (including Ahua Reef and Tripod Reef), and at selected shoreline sites within Pearl Harbor (**Figures 1-2a** and **1-2b**).

Table 1-1. List of study sites and their location in Pearl Harbor (PH) and Pearl Harbor Entrance Channel (PHEC). PHEC sites extended from south of PH to the mouth of the PHEC. Pearl Harbor sites extended from the mouth of PHEC, up the main channels, and into the Lochs. [AS = Artificial Substrate; HB = Hard Bottom; SB = Soft Bottom; US = Unconsolidated Substrate]

Site #	Site (GMI Team)	Type	Location	Site #	Site (Navy Team)	Type	Location
1	**Ahua Reef Offshore** PHEC	HB	21°17.951 N 157°57.194 W	16	**Mokunui Island** (Ford Island Causeway, east side of Ford Island) PH	US HB	21°22.088 N 157°56.854 W
2	**Ahua Reef** PHEC	HB	21°18.113 N 157°57.361 W	17	**Ford Island South** (South end by seaplane ramp) PH	US	21°21.301 N 157°57.966 W
3	**Turtle/Tripod Reef** PHEC	HB	21°18.046 N 157°57.571 W	18	**PHEC, Outfall Aggregate Mound**	AS	21°18.025 N 157°57.315 W
4	**Outfall** PHEC	AS	21°17.876 N 157°57.278 W	19	**PHEC, Channel Bottom**	US	21°17.953 N 157°57.310 W
5	**PHEC, East Side, Opposite Buoy 5**	HB	21°18.918 N 157°57.802 W	20	**Tripod Reef** (Offshore Deep) PHEC	HB	21°17.894 N 157°57.635 W
6	**PHEC, West Side, Adjacent to Buoy 5**	US	21°18.892 N 157°58.017 W	21	**Dry Docks** PH	US	21°21.157 N 157°57.680 W
7	**Bishop Point** (Channel Wall) PH	US HB	21°19.936 N 157°58.123 W	22	**Porites Reef, West Loch, Channel Bottom** PH	SB	21°20.692 N 157°58.766 W
8	**Waipio Point** PH	HB US	21°20.502 N 157°58.299 W	23	**Porites Reef, West Loch** PH	SB	21°20.678 N 157°58.760 W
9	**Dry Docks** (Facing crane P63) PH	HB	21°21.156 N 157°57.709 W	24	**Pearl City Peninsula** PH	US	21°22.192 N 157°58.198 W
10	**Beckoning Point** (Waipio Peninsula, East) PH	US SB	21°21.689 N 157°58.503 W	25	**Pearl City Peninsula** PH	SB	21°22.193 N 157°58.178 W
11	**Debris Field 1** (Entrance West Loch, East, submerged pier) PH	AS	21°20.668 N 157°58.528 W	26	**USS Utah** PH	AS	21°22.130 N 157°57.734 W
12	**Debris Field 3** (Entrance West Loch, West, Barge) PH	AS	21°20.854 N 157°58.683 W	27	**Iroquois Pt Landing** PH	AS SB	21°20.047 N 157°58.390 W
13	**Debris Field 3** (Entrance West Loch, West) PH	US	21°20.435 N 157°58.556 W	28	**PHEC, East Side, Opposite Buoy 5**	US	21°18.919 N 157°57.782 W
14	**Debris Field 2** (Entrance West Loch, East, Barge) PH	AS	21°20.451 N 157°58.575 W	29	**PHEC, East Side, Opposite Buoy 5**	HB	21°18.895 N 157°57.793 W
15	**Hospital Point** PH	US	21°20.811 N 157°58.049 W				

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2.0 MATERIALS AND METHODS

A combination of standard underwater survey methods was used to assess the fish and benthic communities within the study area. Each of these methods is described below. All observations were made using open circuit self contained underwater breathing apparatus (SCUBA), using compressed air or enriched air (NITROX).

2.1 PERCENT COVER ASSESSMENTS

Quantitative benthic visual assessments of sessile and motile organisms (including turf algae, macroalgae, sponges, stony corals, and echinoderms) were done using two methods. One was a combination of line intercept and quadrat methods (English et al. 1994; Conand et al. 1999, 2000; Hill and Wilkinson 2004), hereafter referred to as the quadrat intercept method (QIM). The other technique was the point centered quarter method (PCQM) (Cottam and Curtis 1956; Dix 1961; Risser and Zedler 1968; Randall et al. 1988; Paulay et al. 2001).

Quadrat Intercept Method (QIM)—The percent cover of sessile and motile organisms was estimated within 50 centimeters (cm) by 50 cm quadrats randomly placed along randomly located transect lines. Each transect measured 20 m in length and was marked using a fiberglass measuring tape stretched out close to the benthic substrate. To increase the accuracy of the coverage estimates (actual percent cover within a quadrat), the quadrat was divided into one hundred 5 cm by 5 cm squares using 0.2 cm diameter plastic trimmer line threaded through pre-drilled holes. A photo was also taken of each quadrat as a permanent record, when turbidity conditions made this feasible.

The surveyed substrate was confined to a narrow depth range and in some cases to relatively small artificial substrates. Where possible, transects were set along random compass headings. Random transect headings (000-360) were generated from a table of random numbers (Rohlf and Sokal 1969). In areas where random headings could not be used (e.g., vertical substrates), transects were haphazardly placed while avoiding pseudo-replication. Eight quadrats were set at random distances along each transect (Hill and Wilkinson 2004). The random distances (00-20) were determined using a table of random numbers (Rohlf and Sokal 1969).

Point Centered Quarter Method (PCQM)—Smith (1999, 2002, unpublished data) previously utilized the PCQM at selected portions of the PHEC. Two of these locations, a segment of the Fort Kamehameha outfall corridor and Turtle/Tripod Reef (**Figure 1-2b**) were reassessed using the PCQM. To reduce the potential for investigator bias/error, Smith repeated these transects. General procedures of the PCQM were as follows:

a) Base points established during surveys in 1999 and 2002 were relocated. The 1999 points were relocated using GPS; the 2002 Turtle/Tripod Reef transect had been demarcated with steel pins, in addition to GPS. Those pins were simply relocated.
b) A transect line was established beginning at the base point and extended for 100 m along a predetermined depth contour.
c) Additional points were established at 20 m intervals along the transect line. At the base point, and at each 20 m point, the transect line was bisected at a 90° angle, thus creating four quarters around each point.
d) The distance from the point to the edge of the closest stony coral colony was then measured and recorded and the coral identified to the lowest possible taxa.
e) The identification of stony corals was based on Maragos (1995), Devaney and Eldredge (1977), and Veron (2000).
f) The greatest dimension of the colony, parallel to the substrate, was recorded.

Most of the coral colonies measured had a roughly circular 'footprint' on the seafloor. The greatest dimension, measured parallel to the seafloor, was considered to be a diameter from which the area of the seafloor covered by the colony could be determined. The actual area for colonies not having a circular footprint was either over- or under-estimated, depending on the shape of the colony. However, the most commonly encountered corals, within the areas where the PCQM was used were *Pocillopora meandrina, Pocillopora damicornis* and *Pocillopora eydouxi* all of which have generally circular growth patterns in this area.

2.2 FORT KAMEHAMEHA WASTERWATER OUTFALL PIPE

The waste water treatment plant at Fort Kamehameha located along the east side of the PHEC has a deep ocean outfall that currently disposes treated effluent into the open coastal waters of Mamala Bay. The outfall became operational on January 7, 2005 (DoN 2005). The pipe is made of polyvinyl chloride (PVC) and the piles are made of concrete.

A 50 m long section of the pile-supported segment of the outfall was surveyed between pile number 15 and pile number 20 (**Figure 2-1**). The inside diameter of the pipe is 1.2 m. The piles are on 9.5 m centers. The construction of the pile-supported segment began on September 12, 2003 and was completed on November 21, 2003. Our survey of the outfall pipe and piles took place on September 13, 2005, roughly two years following installation.

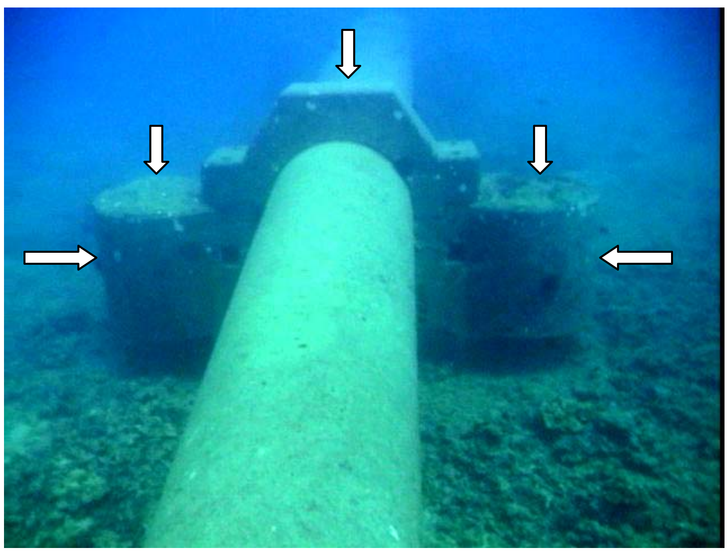

Figure 2-1. Fort Kamehameha wastewater outfall pipe and pile in a 27 m water depth, Pearl Harbor Entrance Channel, Mamala Bay, Hawai'í. Arrows point to where photo quadrats of the pile substrate were taken.

The surveyed portion of the outfall pipe was located at a depth of 27 m between the terminus of the trenched/buried portion of the outfall and the outfall diffuser. The sessile benthic taxa found on the sunlit (top) part of the pipe and piles were assessed using 18 random photo quadrats and a video transect. The video camera was moved perpendicularly over the outfall pipe in such a way that the entire width of the pipe was contained within the recorded image. Photo quadrats were taken vertically 1.5 m above the pipe. Each photo quadrat measured approximately 581 square centimeters (cm^2). A bubble level attached to the upper face of the underwater housing allowed the diver to position the camera in a vertical position above the reef. The benthos on the piles was recorded using five photo quadrats per pile: two images of the sides of the pile and three images of the top of the pile (**Figure 2-1**). Photo quadrats were taken at each pile.

Live percent cover on the pipe and piles was estimated from the photo quadrats using the point count method (Aronson et al. 1994). Each photo quadrat was viewed on a personal computer and superimposed with random dots. The organism or substrate found below each dot was identified and recorded. The total observations (point counts) of a given species/substrate served as the basis for the percent cover estimate. Based on previous experience in lower cover environments, we used 50 random dots per photo quadrat to estimate percent cover. The analysis of photo quadrats was done using the Geo-Marine, Inc. (GMI) software application Photo-Quadrat Analyzer (PQA). The software prepared individual images for analysis by superimposing independent sets of random dots on each image.

Statistical comparisons of live percent cover, colony size, and colony density were done for the different substrate types and exposures using the paired two-tailed t test (Zar 1984). Data sets used in each of the comparisons were tested for homogeneity of variances using Bartlett’s test. When data were found to be non-homoscedastic, they were arcsine transformed before applying the t test (Zar 1984).

2.3 Fish and Macroinvertebrate Belt Transects

Thirty-two transects were completed at 17 locations to sample fish and diurnally exposed macroinvertebrate communities (**Table 2-1**). The latitude-longitude coordinates at each of the 17 sites were established using a hand-held GPS (Garmin 176-C). All transects were situated parallel to shore (or channels) and each individual transect was run along approximately the same depth contour except for two transects duplicating surveys conducted in the early 1970's.

In the PHEC seven transects were sampled at six different locations (**Table 2-1**). Inside of Pearl Harbor, there were 25 transects at 11 different locations (**Table 2-1**). At some locations, more than one transect was carried out; in these cases, transects were established at different depths.

Fish Belt Transects—On arrival at a given station, a visual fish census was undertaken first to estimate the abundance of fishes. This was conducted within a 25 m by 4 m corridor and all fishes within this area to the water's surface were counted. Data collected included species, numbers of individuals and an estimate of their length; the length data were later converted to standing crop estimates using linear regression techniques (Ricker 1975). A single diver equipped with SCUBA, transect line, slate and pencil entered the water, counted and noted all fishes in the prescribed area (method modified from Brock 1954). The 25 m transect line was laid out as the census progressed, thereby avoiding any previous underwater activity in the area which could frighten wary fishes. Fish abundance and diversity are often related to small-scale topographical relief over short linear distances. A long transect may bisect a number of topographical features (e.g., cross coral mounds, sand flats, and algal beds), thus sampling more than one community and obscuring distinctive features of individual communities. To alleviate this problem, a short transect (25 m in length) has proven adequate in sampling many Hawaiian benthic communities (Brock and Norris 1989).

Besides frightening wary fishes, other problems with the visual census technique include the underestimation of cryptic species such as moray eels (Muraenidae) and nocturnal species (e.g., squirrelfishes, Holocentridae; bigeyes, Priacanthidae). This problem is compounded in areas of high relief and coral coverage affording numerous shelter sites. Species lists and abundance estimates are more accurate for areas of low relief, although some fishes with cryptic habits or protective coloration (e.g., scorpionfish, Scorpaenidae; flatfishes, Bothidae) might still be missed. Obviously, the effectiveness of the visual census technique is reduced in turbid water and species of fishes that move quickly and/or are very numerous may be difficult to count and to estimate sizes. Additionally, bias related to the experience of the diver conducting counts should be considered in making any comparisons between surveys. In spite of these drawbacks, the visual census technique probably provides the most accurate non-destructive method available for the assessment of diurnally active fishes (Brock 1982).

Macroinvertebrate Belt Transects—After the assessment of fishes, an enumeration of epibenthic invertebrates (excluding corals) was undertaken using the same transect line as established for fishes. Exposed invertebrates usually greater than 2 cm in some dimension (without disturbing the substrate) were censused in a 4 m by 25 m area. This sampling methodology is quantitative for only a few invertebrate groups (e.g., some echinoids and holothurians, mollusks, a few crustaceans, and polychaetes). Most coral reef invertebrates (other than corals and some sponges) are cryptic or nocturnal in their habits making accurate assessment of them in areas of topographical complexity very difficult.

Table 2-1. Fish and macroinvertebrate sampling site numbers, substrate classification, station identifier, and site descriptions. Note that Stations A through F were established in the Pearl Harbor Entrance Channel while all others were in the confines of Pearl Harbor. [PHEC = Pearl Harbor Entrance Channel, SB = Soft Bottom, W = Wall, DF = Debris Field]

Site #	Fish Substrate Classification	Fish Station	Description
1		A	Entrance Channel east side (locID#4)
	PHEC		Transect #1, 14 m deep, hard substrate
2		B	Ahua reef between buoys 2 & 4 (locID#7)
	PHEC		Transect #2, 6 m deep, hard substrate
3		C	Turtle/Tripod Reef (locID#6a)
	PHEC		Transect #3, 9 to 12 m deep, along wall
4		D	Outfall Pipe/Stanchions (locID#1)
	PHEC		Transect #4, 8 to 8 m deep, sand substrate
5		E	Entrance Channel E opposite buoy 5 (locID#8)
	PHEC		Transect #5, 6 to 8 m deep, along wall
6		F	Entrance Channel W adjacent buoy 5 (locID#9)
	PHEC		Transect #6, 6 to 8 m deep, hard substrate
	PHEC		Transect #7, 11 m deep, rubble slope
7		G	Bishop Pt. N side channel wall (locID#10)
	W		Transect #8, 3 to 6 m deep, along wall
	SB		Transect #9, 12 m deep, rubble slope
8		H	Waipio Pt. by concrete platform E side (locID#13)
	W		Transect #10, 6 m deep, along wall
	SB		Transect #11, 12 m deep, rubble/mud slope
9		I	Drydock by Crane P63 (locID#18)
			Transect #12, 2 m deep, hard substrate
	W		Transect #13, 5 to 6 m deep, along wall
	SB		Transect #14, 12 m deep, rubble/mud slope
10		J	Beckoning Pt. east side (locID#14)
	SB		Transect #15, 1 to 1.5 m deep, sand slope with *Graciliaria salicornia*, Grovhoug transect
	SB		Transect #16, 1 to 12 m deep, down rubble/sand slope, Grouhoug transect
	SB		Transect #17, 3 to 5 m deep, sand/rubble slope
	SB		Transect #18, 9 to 12.5 m deep, mud substrate
11		K	Debris Field (Finger Pier) (locID#20)
	DF		Transect #19, 8.5 to 9 m deep, old finger pier ~50m long
12		L	Debris Field (metal box in shallow water)
	DF		Transect #21, 2 m deep, sand/rubble substrate around box
13		M	Debris Field (barge) (locID#22)
	DF		Transect #20, 9 to 12 m deep, barge
14		N	Debris Field (barge) (locID#4)
	DF		Transect #22, 3 to 5 m deep, barge
15		O	Hospital Pt. by concrete discharge
	W		Transect #23, 6 m deep, E side along wall, Grovhoug transect
	W		Transect #24, 6 m deep, W side along wall, Grovhoug transect
	SB		Transect #25, 11 to 12 m deep, rubble/sand
16		P	Mokunui Is. by Ford Is. Bridge (locID#16)
	W		Transect #26, 6 m deep, along mauka wall, Grovhoug transect
	W		Transect #27, 6 m deep, along makai wall, Grovhoug transect
			Transect #28, 3 to 11 m deep, over slope, Grovhoug transect
			Transect #29, 1.5 to 2.4 m deep, on top, mix of sand, rubble, hard substrate
	SB		Transect #30, 12 m deep, mud substrate
17		Q	Ford Is. makai end (locID#31)
			Transect #31, 1 to 2.4 m deep, mix of sand, rubble, concrete
	SB		Transect #32, 5 to 6 m deep, rubble/limestone slope

This, coupled with the fact that the majority of these cryptic invertebrates are small, necessitates the use of methodologies that are beyond the scope of this survey (e.g., Brock and Brock 1977). Recognizing constraints on time and the scope of this survey, the invertebrate censusing technique used here attempted only to assess those few macroinvertebrate species that are diurnally exposed.

2.4 Threatened and Endangered Species Belt Transects

The threatened green sea turtle (*Chelonia mydas*) is commonly sighted within the PHEC, and occasionally sighted within Pearl Harbor. Only three other protected marine species have been recorded within Pearl Harbor or the PHEC: the endangered hawksbill sea turtle (*Eretmochelys imbricata*), the endangered Hawaiian monk seal (*Monachus schauinslandia*), and the endangered humpback whale (*Megaptera novaeangliae*). Single sightings of the first two species were made by Smith on March 14, 2002 and August 9, 2005. Residents of the Iroquois Point housing area have periodically reported a single monk seals hauled out on the Iroquois Point beach. These sightings were made between 2001 and September 2006. This area is approximately 200 m west of the western edge of the study area. The Pearl Harbor Master reported the presence of an adult humpback and a calf in East Loch on March 21, 1998. The whale sighting is considered to be an extraordinarily unusual event. The team was prepared to identify sea turtles and monk seals and to record as much information as possible. This information would include:

- Activity when first sighted (swimming, resting, foraging, being cleaned)
- Carapace length for sea turtles (<0.5 m; >0.5 m – 1.0 m; >1.0 m)
- Total length for monk seal
- Presence/absence of fibropapilloma tumors for turtles
- Presence/absence of other distinguishing features, such as tags, or scars.

In addition to recording the presence of these protected species at each study site, a census of green sea turtles was made by Smith. During the month following our field work, each study site was visited for a period of 15 minutes. Each sighting was recorded as a separate event, unless more than one individual could be seen at once, and/or individuals could be positively identified based upon distinguishing characteristics. Therefore, if four separate green sea turtles were seen simultaneously, and then they disappeared, this was recorded as four individuals. If a single turtle was seen four times during a dive, and it could not be determined if it was the same individual, this was recorded as four sightings. During the course of the 2005 surveys, only green sea turtles were observed.

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3.0 RESULTS

3.1 BENTHIC COMMUNITIES

Benthic data were collected at a total of 19 of the 29 sites within the PHEC and Pearl Harbor (including two survey locations at Iroquois Point). The number of transects, number of quadrats, and substrate type for each site are listed in **Table 3-1**.

Table 3-1. List of sites where benthic communities were assessed within the Pearl Harbor Entrance Channel (PHEC) and Pearl Harbor (H) and their corresponding site numbers, locations, sample sizes; and underlying substrates.

Site	Site #	Location	Number of Benthic Transects	Number of Quadrats	Substrate Type
Ahua Reef Offshore	1	PHEC	4	32	Hard Bottom
Ahua Reef	2	PHEC	4	32	Hard Bottom
Tripod Reef	3	PHEC	4	31	Hard Bottom
Ft. Kamehameha Outfall	4	PHEC	1	18	Artificial Substrate
PHEC, Opp. Buoy 5	5	PHEC	4	32	Hard Bottom
PHEC, West at Buoy 5	6	PHEC	4	32	Unconsolidated Substrate
Bishop Point	7	H	4	32	Hard Bottom/Unconsolidated Substrate
Waipio Point	8	H	4	32	Hard Bottom/Unconsolidated Substrate
Dry Dock	9	H	4	32	Hard Bottom
Beckoning Point	10	H	4	32	Soft Bottom
Debris Field 1	11	H	4	31	Artificial Substrate
Debris Field 3 bis Barge	12	H	3	19	Artificial Substrate
Debris Field 3	13	H	3	24	Unconsolidated Substrate
Debris Field 2	14	H	4	15	Artificial Substrate
Hospital Point	15	H	3	24	Unconsolidated Substrate
Mokunui	16	H	3	24	Hard Bottom/Unconsolidated Substrate
Porites Reef - deep	22	H	4	32	Soft Bottom
Porites Reef - shallow	23	H	4	32	Soft Bottom
Iroquois Point	27a	H	4	32	Soft Bottom
Iroquois Point - wall	27b	H	4	32	Artificial Substrate

3.1.1 Fort Kamehameha Outfall Pipe and Piles

Pipe—The quantitative assessment of the benthos on the sunlit portion of a 50 m section of the Fort Kamehameha outfall pipe was based on random photographic quadrats taken on September 13, 2005, two years following the pipe emplacement. The video transect of the pipe gave an overall non-quantitative perspective of the sessile organisms having grown on the pipe.

Overall, the sunlit portion of the section of the outfall pipe surveyed was almost entirely covered by turf algae (mean percent cover: 99.2% ± 1.3 Standard Deviation [SD], n = 17) (**Table 3-2**). Few areas of small hard coral (scleractinian) colonies (0.5% ± 1.3 SD), small patches of crustose coralline algae (0.1% ± 0.5 SD), and small areas colonized by encrusting sponges (0.1% ± 0.5 SD) were located in the study area. While hardened calcium carbonate polychaete tubes were observed on the sunlit portion of the pipe, they were too few to be accounted for in terms of percent cover using the point count method. The density of coral colonies was relatively low and highly variable: 0.8 coral colonies per random quadrat (± 1.2 SD, n =

Table 3-2. Percent cover (%) of hard corals, encrusting sponges, turf algae, and crustose coralline algae in 17 random photographic quadrats of a 50 m section of the sunlit side of the Fort Kamehameha outfall pipe between the micro-tunneled shoreline and the outfall diffuser. Data were collected on September 13, 2005, two years after pipe installation. [SD = Standard Deviation; CCA = Crustose Coralline Algae]

Statistic	Hard Corals	Encrusting Sponges	Turf Algae	CCA
Mean	0.5	0.1	99.2	0.1
SD	1.3	0.5	1.3	0.5

17) (which corresponded to a density of 14.2 coral colonies per square meters [m^2] ± 21.3 SD). Corals were represented by at least three species from two genera, *Porites sp.* and *Montipora sp.* The diameters of corals ranged from 0.7 to 3.7 cm (mean diameter: 1.9 cm ± 1.1 SD, *n* = 20). Patches of crustose coralline algae measured on average 1.1 cm (± 1.7 SD; *n* = 10).

Piles—The sessile benthos was assessed on five piles located within a 50 m section of the outfall pipe. Much like the sunlit portion of the outfall pipe, the majority of the sessile benthic cover consisted of turf algae (89.0% ± 12.7 SD, *n* = 24). The remaining sessile cover included highly variable cover values of hard corals, encrusting sponges, crustose coralline algae, and sessile bivalves (**Table 3-3**). Comparing the mean cover made of corals, encrusting sponges, crustose coralline algae, and sessile bivalves between the tops (4.5% ± 3.4 SD, *n* = 15) and the sides (21.7% ± 15.3 SD, *n* = 9) of the piles, we found that the sides of the piles supported significantly greater cover that the tops of the piles ($t_{0.05\ (2),\ 22}$ = 4.18; *P* = 0.001). There was no significant difference in percent live cover (corals, encrusting sponges, crustose coralline algae, and sessile bivalves) between the east-exposed and west-exposed sides of the piles ($t_{0.05\ (2),\ 7}$ = -1.50; *P* = 0.18).

Table 3-3. Percent cover (%) of hard corals, bivalves, encrusting sponges, turf algae, and crustose coralline algae in 24 photographic quadrats of five piles supporting the Fort Kamehameha outfall pipe. Data were collected on September 13, 2005, two years after pipe installation. [SD = Standard Deviation; CCA = Crustose Coralline Algae]

Statistic	Hard Corals	Bivalves	Encrusting Sponges	Turf Algae	CCA
Mean	0.3	0.6	7.1	89.0	3.0
SD	1.0	1.9	11.4	12.7	4.8

The mean diameter of hard corals on the piles was 1.6 cm (± 0.9 SD, *n* = 31). The patches of crustose coralline algae measured on average 1.9 cm (± 2.5 SD, *n* = 78). The density of corals was highly variable: 1.8 individuals per random quadrat (± 1.8 SD, *n* = 24) (which corresponded to 30.1 individuals/m^2 ± 31.8 SD).

3.1.2 Natural and Artificial Seafloor Substrates (Excluding Outfall Pipe)

3.1.2.1 Quadrat Intercept Method Transects

Using QIM transects, percent substrate cover (including biotic and abiotic categories) was assessed at each of the sites (**Figure 3-1**). Live cover categories included live coral, zoanthid, sponge, oyster, echinoid, annelid, crustacean, and tunicate cover (**Figure 3-2**). Mean total live cover, averaged for all

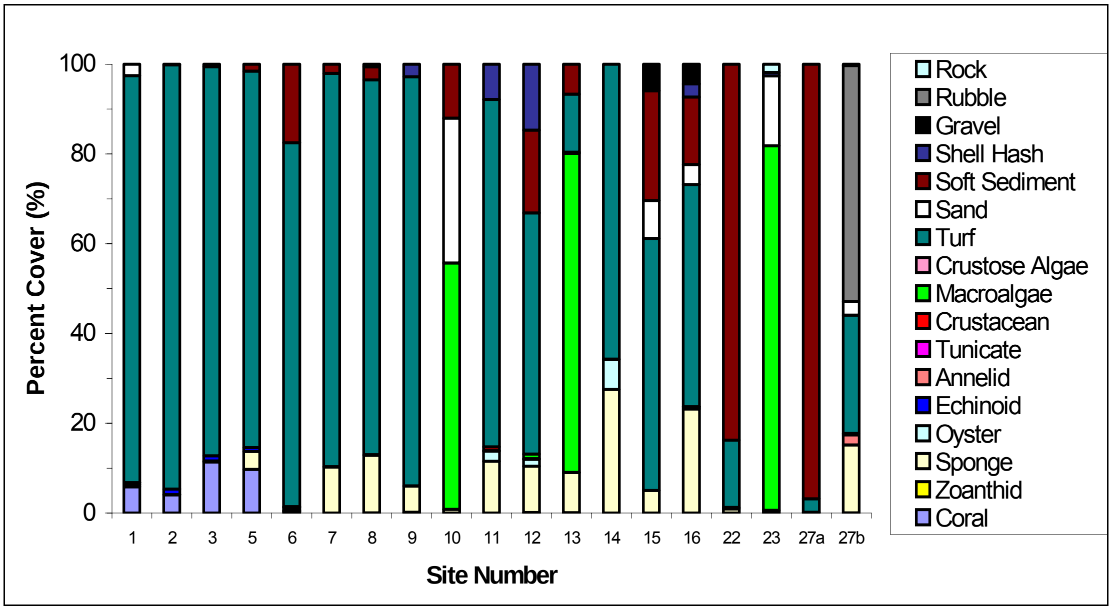

Figure 3-1. Percent cover of substrates and biota (sessile and motile) in Quadrat Intercept Method transects at Pearl Harbor Entrance Channel and Pearl Harbor sites.

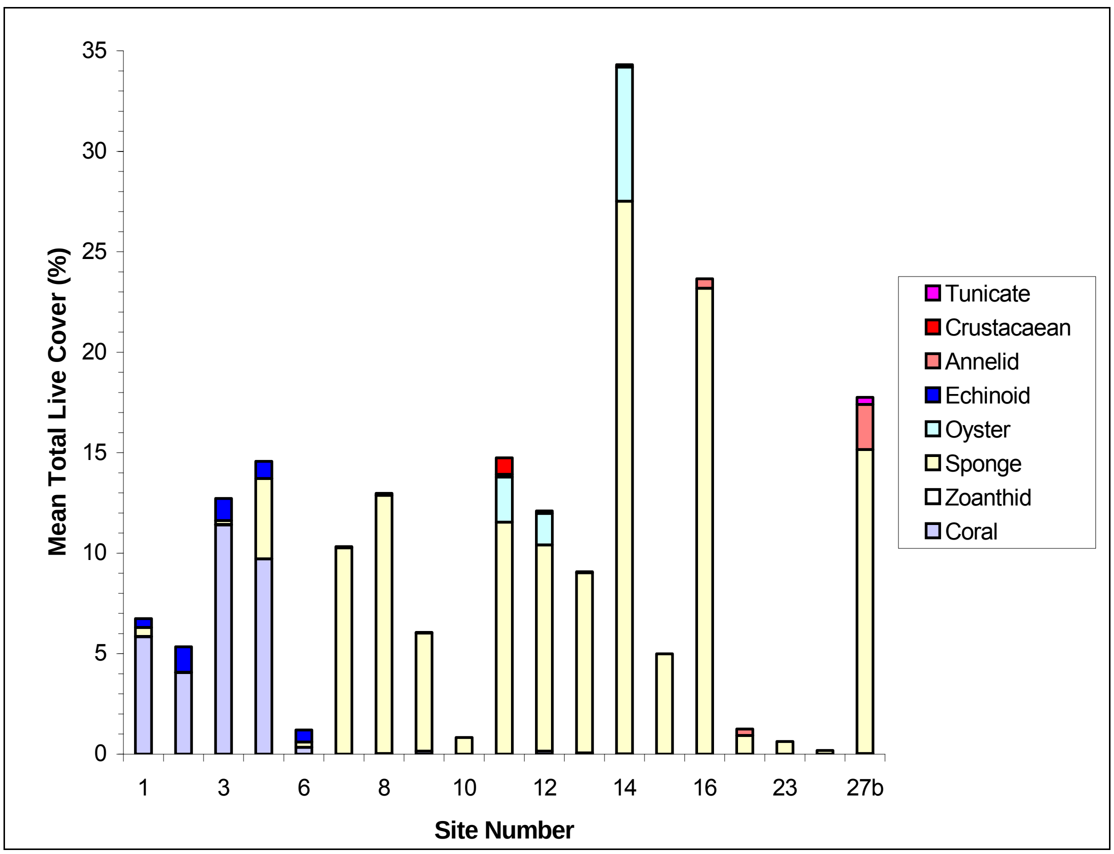

Figure 3-2. Mean total live cover of sessile and motile organisms in Quadrat Intercept Method transects at Pearl Harbor Entrance Channel and Pearl Harbor sites.

sites, was 9.97% (± 8.81 SD). Live coral and sponge cover were highly variable contributing 1.68% (± 6.28 SD) and 7.27% (± 8.12 SD), respectively. The greatest amount of live coral cover among sites was recorded at Turtle/Tripod Reef, located south of the PHEC: 11.42% (± 1.71 Standard Error [SE]). Debris Field 2 had the highest mean total live cover at 34.31% (± 7.21 SE) with 27.5% (± 3.66 SE) attributed to sponge cover.

Live cover was dominated by turf algae. Mean turf cover was 73.43% (± 20.11 SD), excluding sites where macroalgae were present and/or sites with soft bottom substrates where turf algae could not adhere (Beckoning Point, Porites Reef – deep; Porites Reef – shallow, Iroquois Point, and Debris Field 3). Crustose coralline algae were recorded in a total of three quadrats at only three sites (Debris Field 3, Hospital Point, and Mokunui) with percent cover in these quadrats ranging from 1% to 6%.

Three sites in Pearl Harbor (Beckoning Point, Debris Field 3, and Porites Reef - shallow) supported substantial macroalgal cover (gorilla seaweed, *Gracilaria salicornia,* Rhodophyta) overlying either unconsolidated or soft bottom substrates. At Beckoning Point, there was 54.91% (± 11.74 SE) *G. salicornia* cover. At Debris Field 3 and Porites Reef – shallow, the *G. salicornia* cover amounted to 71.08% (± 7.09 SE) and 81.22% (± 10.81 SE), respectively.

Figures 3-3 and **3-4** present mean total live cover for PHEC and Pearl Harbor sites. At PHEC sites, live cover consisted mainly of corals (scleractinians) and echinoderms. Sponges dominated live cover in Pearl Harbor sites. All of the Pearl Harbor sites had less than 0.2% mean live coral (scleractinian) cover. PHEC sites had a mean live coral cover of 6.28% (± 4.43 SD) which was higher than that found in Pearl Harbor but still highly variable.

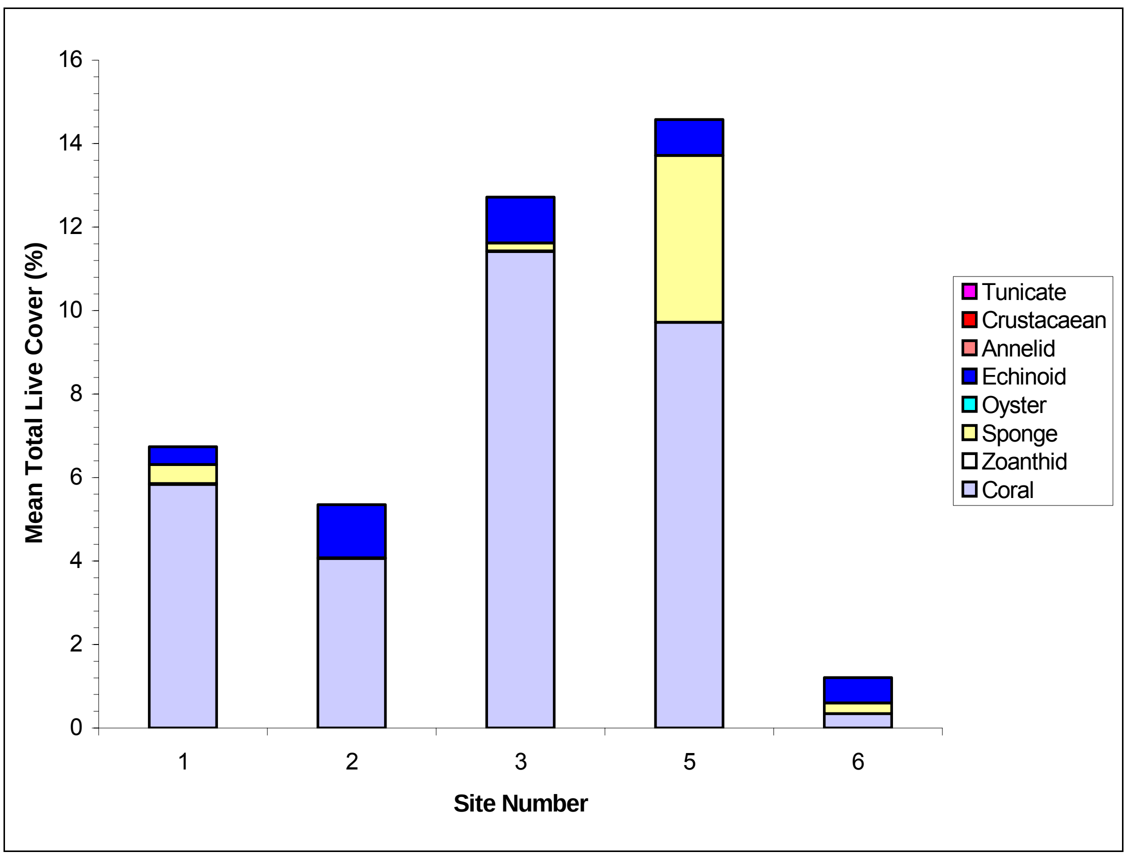

Figure 3-3. Mean total live cover by sessile organism category in Quadrat Intercept Method transects at Pearl Harbor Entrance Channel sites.

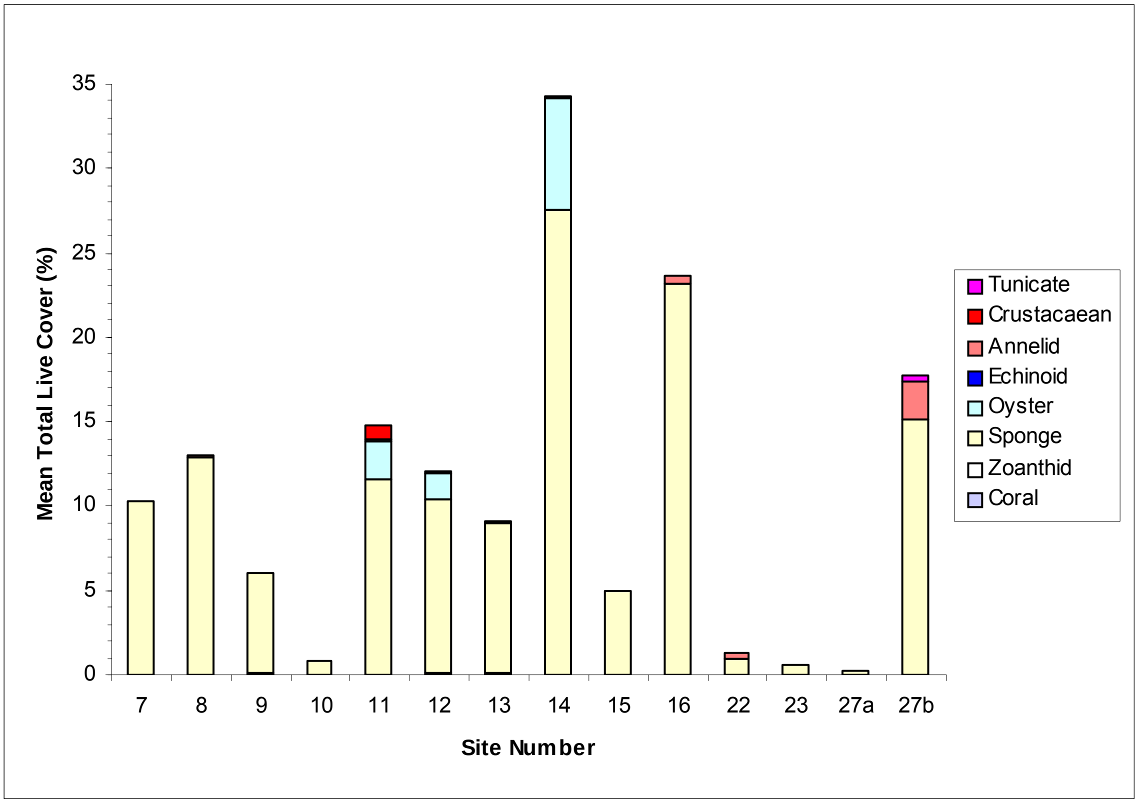

Figure 3-4. Mean total live cover by sessile organism category in Quadrat Intercept Method transects at Pearl Harbor sites.

Of the PHEC sites, site 6 (west side of channel at Buoy 5) had less live coral cover (0.34% ± 0.15 SE) than the rest of the PHEC sites (Sites 1, 2, 3, and 5), most likely due to a difference in substrate type. The substrate at site 6 was unconsolidated while there was hard bottom at the other PHEC sites. Sponges covered more area in Pearl Harbor sites (0.98% ± 1.70 SD) than PHEC sites (9.51% ± 8.36 SD).

The introduced eastern oyster, *Crassostrea virginica*, was recorded at three sites in Pearl Harbor (debris fields at sites 11 through 14), all located in the West Loch and all consisting of artificial substrate. The eastern oyster was recorded in 16 of the 65 quadrats surveyed at these three sites. Percent cover values were highly variable and ranged from 6.67% (± 6.67 SE) at Site 14 (Debris Field 2) to 1.56% (± 1.11 SE) at Site 12 (Debris Field 3 bis Barge).

The featherduster worm, *Sabellastarte spectabilis*, was recorded in 10 of the 14 study sites in Pearl Harbor. Barnacles were recorded on an artificial substrate at Site 11 (Debris Field 1) located in Pearl Harbor. Echinoids were only recorded at PHEC sites (Sites 1, 2, 3, 5, and 6) and their mean live cover was 0.85% (± 0.34 SD) cover.

Substrate types (hard bottoms, soft bottoms, unconsolidated substrates, and artificial substrates) and associated live cover were further examined. Of the four substrate categories, artificial substrate supported the greatest amount of live cover (19.73% ± 9.99 SD). Sponge cover was recorded on all substrate types but was particularly prominent on artificial substrates, where it represented 75% of the live cover (16.11% ± 7.87 SD), and on unconsolidated substrates where sponges represented 93% of the live cover (4.74% ± 4.36 SD) (**Figure 3-5**). Soft bottom substrates supported low live cover (0.72% ± 0.44 SD) compared to other substrate types; most of the live cover consisted of sponges. Compared to other substrates, hard bottoms supported less live cover (9.09% ± 4.24 SD). Yet, hard bottoms supported more coral cover (6.24% ± 4.50 SD) than artificial substrates (0.05% ± 0.07 SD).

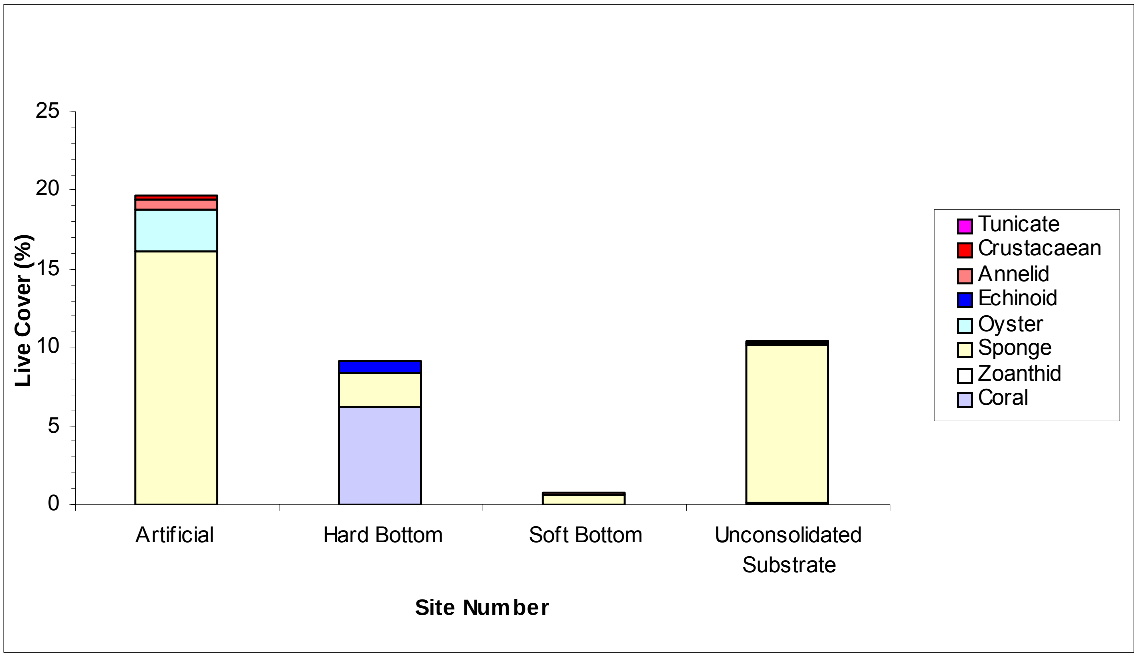

Figure 3-5. Mean total live cover by substrate type in benthic transects at 19 sites in Pearl Harbor.

3.1.2.2 Point Centered Quarter Method Transects

Two separate locations, which had been previously surveyed using PCQM transects, were re-evaluated during this project. The first location had been surveyed in July and August of 2000, as part of the Fort Kamehameha Outfall Extension Project. This site was re-evaluated using only the PCQM. The second location, Turtle/Tripod Reef, had been initially surveyed in August of 2002. At that time permanent markers were installed to facilitate future monitoring. Both of these PCQM surveys were initially conducted by Smith; to minimize investigator bias, the 2005 measurements were also done by Smith. During this project, Turtle/Tripod Reef was also assessed using QIM transects.

Outfall Corridor—In support of the Fort Kamehameha Outfall Replacement Project, in 2000, 17 PCQM transects were completed, covering a linear distance of 2,100 m, 85% of which were at a depth of 15 m. The seafloor in this area consisted of coarse sand and rubble. Surveys Smith conducted in 2000 were completed prior to any construction activity. The current study replicated a segment of the 2000 survey by completing 140 m of the PCQM transects at a depth of 15 m in the coarse sand and rubble zone.

The 2000 survey area was eventually trenched in 2003. After the outfall pipe was placed in the trench it was buried and covered with heavy aggregate, concrete pillows, and lastly with the naturally occurring sand and rubble which had been removed to form the trench (and piled adjacent to it for reuse). At the time of the 2005 survey, the area of the seafloor that was assessed had the same general appearance that it had in 2000.

In 2005, *Pocillopora meandrina* comprised 75% of all the colonies measured and the mean colony size was 17 cm^2. The other species which were identified within and/or adjacent to the PCQM transects were: *Montipora capitata, Montipora flabellata, Pavona duerdeni, Porites lobata* and *Porites* sp. The mean area within which all coral colonies were located was 9.9 m^2; the percentage of the seafloor covered by coral was 0.02%.

Turtle/Tripod Reef—In 2002, this site supported the densest concentration of stony corals within or adjacent to Pearl Harbor or the PHEC. At Turtle/Tripod Reef corals grew in tiers or layers, and the PCQM transects yielded percent cover estimates that exceeded 100%. This was caused by branching colonies of *Pocillopora meandrina* and *Pocillopora eydouxi* underlain by well-developed encrusting forms of *Porites lobata, M. capitata,* and *M. flabellata*. As a result of these growth patterns, the PCQM cover estimates made in 2002 were 188%. The 2005 results were dramatically different; the PCQM-estimated live coral cover was 15%; the QIM transects yielded an 11% coral cover estimate. The majority of large colonies of *P. meandrina, P. eydouxi,* and *P. lobata* located on Turtle/Tripod Reef were dead in 2005. Most *P. lobata* colonies seen in 2002 were encrusting growth forms. Those which were still alive in 2005 were predominately head-forming colonies. Most of the dead colonies of all species were structurally intact yet heavily overgrown with crustose coralline algae. Based upon their appearance and condition of the corallites, the corals appeared to have been dead for about two years. Mean colony size, spacing and dominance rankings, based upon frequency of occurrence and the percentage of the seafloor occupied are shown in **Table 3-4**. It should be noted that neither the PCQM, nor most other benthic survey methods, provide an estimate of the volumetric displacement of coral colonies. If volumetric displacement had been assessed, the upright, branching colonies of *P. meandrina* and *P. eydouxi* would have displaced *P. lobata* as the dominant coral in the survey area. It was also observed that there were large numbers of coral recruits and juvenile corals (less than 3 cm in diameter) growing within and adjacent to the PCQM transect corridor.

Table 3-4. Comparison of the coral population status at Turtle/Tripod Reef in 2002 and 2005 based on Point Centered Quarter Method (PCQM) and Quadrat Intercept Method (QIM) data. [P = *Porites* sp.; PL = *Porites lobata*; PM = *Pocillopora meandrina*; M = *Montipora* sp.; MCF = *Montipora capitata* and *Montipora flabellata*]

Date	Method	Quarters With Coral (%)	Mean Colony Size (cm^2)	Mean Area Including Coral Colony (cm^2)	Coral Cover (%)	Dominant Species by Occurrence	Dominant Species by Cover
Jul & Aug 2002	PCQM	100	423	225	>100	PL PM MCF	PL PM MCF
Sep 2005	PCQM	100	154	1024	15.0	PL MCF PM	MCF PM PL
Sep 2005	QIM	NA	—	—	11.4	PM P M	PM P M

3.2 FISH COMMUNITIES

In total, 90 species of fishes from 26 families were recorded; 64 species were found at the seven transects carried out along the PHEC and 48 species inside of Pearl Harbor at transect numbers 8 through 32 (**Table 3-5**; **Appendix 1**). None of the fish species encountered in this survey were unusual or rare but the sizes of many individuals of some species were unusually large.

In general, coral reef fishes are usually more abundant in areas where shelter is more available. To demonstrate this hypothesis, transects were grouped according to the relative abundance of shelter at each and the abundance of fishes was compared. Transects were assigned to one of four categories: PHEC sites (all with reasonably well-developed cover and all subjected to less environmental stress than in Pearl Harbor sites) and Pearl Harbor sites on (a) soft substrate with low local cover, (b) along channel walls providing some shelter and (c) in debris fields where shelter is high. The fish community parameters measured included the number of species, the abundance of each species and the estimated standing crop of fish present at transect site. These data are summarized in **Table 3-6**. Seven transects (numbers 1 through 7) were conducted in the PHEC, ten on sediment substrates (transect numbers 9, 11, 14 through 18, 25, 30, 32), seven along walls in Pearl Harbor (numbers 8, 10, 13, 23, 24, 26, 27) and four in

Table 3-5. List of fish species observed within Pearl Harbor and the Pearl Harbor Entrance Channel in this study.

Species	Family	Common Name
Acanthurus blochi	Acanthuridae	ringtail surgeonfish
Acanthurus dussumieri	Acanthuridae	eyestripe surgeonfish
Acanthurus nigrofuscus	Acanthuridae	brown surgeonfish
Acanthurus nigroris	Acanthuridae	blue-lined surgeonfish
Acanthurus olivaceus	Acanthuridae	orangeband surgeonfish
Acanthurus triostegus	Acanthuridae	convict tang
Acanthurus xanthopterus	Acanthuridae	yellowfin surgeonfish
Ctenochaetus strigosus	Acanthuridae	spotted surgeonfish
Naso brevirostris	Acanthuridae	spotted unicornfish
Naso hexacanthus	Acanthuridae	sleek unicornfish
Naso lituratus	Acanthuridae	orangespine unicornfish
Naso unicornis	Acanthuridae	bluespine unicornfish
Zebrasoma flavescens	Acanthuridae	yellow tang
Zebrasoma veliferum	Acanthuridae	Pacific sailfin tang
Apogon kallopterus	Apogonidae	iridescent cardinalfish
Foa brachygramma	Apogonidae	weed cardinalfish
Pranesus insularum	Atherinidae	Hawaiian islands silverside
Aulostomus chinensis	Aulostomidae	trumpetfish
Rhinecanthus rectangulus	Balistidae	wedgetail triggerfish
Sufflamen bursa	Balistidae	scythe triggerfish
Caranx ignobilis	Carangidae	giant trevally
Caranx melampygus	Carangidae	bluefin trevally
Decapterus macarellus	Carangidae	mackerel scad
Gnathanodon speciosus	Carangidae	golden trevally
Scomberoides laysan	Carangidae	double-spotted queenfish
Chaetodon auriga	Chaetodontidae	threadfin butterflyfish
Chaetodon ephippium	Chaetodontidae	saddle butterflyfish
Chaetodon lunula	Chaetodontidae	raccoon butterflyfish
Chaetodon lunulatus	Chaetodontidae	oval butterflyfish
Chaetodon miliaris	Chaetodontidae	millet butterflyfish
Chaetodon multicinctus	Chaetodontidae	pebbled butterflyfish
Chaetodon quadrimaculatus	Chaetodontidae	fourspot butterflyfish
Chaetodon unimaculatus	Chaetodontidae	teardrop butterflyfish
Forcipiger flavissimus	Chaetodontidae	longnose butterflyfish
Chanos chanos	Chanidae	milkfish
Paracirrhites arcatus	Cirrhitidae	arc-eye hawkfish
Paracirrhites forsteri	Cirrhitidae	blackside hawkfish
Diodon hystrix	Diodontidae	porcupinefish
Elops hawaiiensis	Elopidae	ten-pounder or ladyfish
Asterropteryx semipunctatus	Gobiidae	starry goby
Bathygobius fuscus	Gobiidae	dusky frillgoby
Gnatholepis anjerensis	Gobiidae	no common name
Psilogobius mainlandi	Gobiidae	Hawaiian shrimp goby
Myripristis amaenus	Holocentridae	brick soldierfish
Sargocentron punctatissimum	Holocentridae	speckled squirrelfish
Bodianus bilunulatus	Labridae	saddleback hogfish
Cheilinus bimaculatus	Labridae	twospot wrasse
Coris gaimard	Labridae	yellowtail coris

Table 3-5 (Continued). List of fish species observed within Pearl Harbor and the Pearl Harbor Entrance Channel in this study.

SPECIES	FAMILY	COMMON NAME
Coris venusta	Labridae	elegant coris
Gomphosus varius	Labridae	bird wrasse
Halichoeres ornatissimus	Labridae	ornate wrasse
Labroides phthirophagus	Labridae	Hawaiian cleaner wrasse
Oxycheilinus unifasciatus	Labridae	ringtail wrasse
Pseudocheilinus octotaenia	Labridae	eightstripe wrasse
Pseudojuloides cerasinus	Labridae	smalltail wrasse
Stethojulis balteata	Labridae	belted wrasse
Thalassoma duperrey	Labridae	saddle wrasse
Thalassoma purpureum	Labridae	surge wrasse
Lutjanus fulvus	Lutjanidae	blacktail snapper
Cantherhines dumerili	Monacanthidae	yelloweye filefish
Cantherhines sandwichiensis	Monacanthidae	Sandwich isle filefish
Mugil cephalus	Mugilidae	flathead mullet
Mulloides flavolineatus	Mullidae	yellowstripe goatfish
Mulloides vanicolensis	Mullidae	yellowfin goatfish
Parupeneus bifasciatus	Mullidae	doublebar goatfish
Parupeneus cyclostomus	Mullidae	goldsaddle goatfish
Parupeneus multifasciatus	Mullidae	manybar goatfish
Parupeneus porphyreus	Mullidae	whitesaddle goatfish
Echidna nebulosa	Muraenidae	snowflake moray
Gymnothorax flavimarginatus	Muraenidae	yellow-edged moray
Gymnothorax meleagris	Muraenidae	whitemouth moray
Parapercis schauinslandi	Parapercidae	redspotted sandperch
Pomacanthus imperator	Pomacanthidae	emperor angelfish
Abudefduf abdominalis	Pomacentridae	green damselfish
Abudefduf sordidus	Pomacentridae	blackspot sergeant
Chromis vanderbilti	Pomacentridae	Vanderbilt's chromis
Dascyllus albisella	Pomacentridae	Hawaiian dascyllus
Plectroglyphidodon imparipennis	Pomacentridae	brighteye damselfish
Plectroglyphidodon johnstonianus	Pomacentridae	Johnston Island damselfish
Stegastes fasciolatus	Pomacentridae	Pacific gregory
Priacanthus cruentatus	Priacanthidae	glasseye
Calotomus carolinus	Scaridae	stareye parrotfish
Chlorurus sordidus	Scaridae	bullethead parrotfish
Scarus perspicillatus	Scaridae	spectacled parrotfish
Scarus psittacus	Scaridae	palenose parrotfish
Scarus rubroviolaceus	Scaridae	redlip parrotfish
Cephalopholis argus	Serranidae	peacock grouper
Monotaxis grandoculis	Sparidae	humpnose big-eye bream
Sphyraena barracuda	Sphyraenidae	great barracuda
Hippocampus kuda	Syngathidae	spotted seahorse
Saurida gracilis	Synodontidae	slender lizardfish
Arothron hispidus	Tetraodontidae	white-spotted pufferfish
Canthigaster coronata	Tetraodontidae	crown toby
Canthigaster jactator	Tetraodontidae	Hawaiian whitespotted toby
Zanclus cornutus	Zanclidae	Moorish idol

Table 3-6. Summary of biological parameters measured at 28 of the 32 fish belt transects surveyed in this study. These transects are grouped according to substrate type or rugosity and/or by location. Means of parameters are given for each group.

Substratum or Location	Transect Number	Number of Species	Number of Individuals	Biomass (g/m^2)
Entrance Channel				
	1	13	105	14
	2	28	320	215
	3	33	208	414
	4	20	170	126
	5	8	40	2
	6	10	79	7
	7	3	18	3
Means		***16***	***134***	***112***
In Pearl Harbor Soft Substratum				
	9	3	16	1
	11	9	91	66
	14	3	8	55
	15	3	7	3
	16	3	68	2
	17	1	4	>0.1
	18	0	0	0
	25	1	1	18
	30	0	0	0
	32	7	77	35
Means		***3***	***27***	***18***
In Pearl Harbor Along Walls				
	8	14	281	184
	10	14	336	547
	13	8	222	187
	23	17	270	612
	24	13	148	162
	26	3	59	172
	27	6	37	26
Means		***11***	***193***	***270***
In Pearl Harbor Debris Fields				
	19	20	924	1550
	20	16	690	1343
	21	7	314	487
	22	21	2347	490
Means		***16***	***1069***	***968***

debris fields in Pearl Harbor (numbers 19 through 22). Four stations in Pearl Harbor were not included in this analysis; three of these (numbers 28, 29, and 31) were conducted on a mixed substrate (hard and sedimentary materials) and one (transect number 12) on a singular sampled habitat type in Pearl Harbor (shallow smooth limestone). Inclusion of these sites for the analysis below increases variance; thus, they were not considered further.

To test the hypothesis that shelter space or cover is important to the observed distribution of fishes, we compared the means of the three parameters, number of fish species, number of individual fish, and fish biomass, measured at transects in each of the four substrates/locations (i.e., the PHEC, in Pearl Harbor soft substrate, in Pearl Harbor along channel walls, and in Pearl Harbor debris fields). Mean parameter measurements were compared among the four substrates/locations using the nonparametric Kruskal-

Wallis Analysis of Variance (ANOVA) which determines whether significant differences exist and the Student-Newman-Keuls (SNK) Test to show where those differences actually are.

Table 3-7 presents the results of the Kruskal-Wallis ANOVA and the SNK Test for these data. The Kruskal-Wallis ANOVA found significant differences in the means for all three parameters as measured in the four groups. However, the SNK Test did not find a clear statistical separation among the four transect groups for the number of fish species (**Table 3-7**) but both the number of individual fish and standing crop of fish in Pearl Harbor debris fields transects are significantly greater than any of the other three transect groupings. In summary, there were significantly more fish and a significantly greater standing crop of fishes in the sampled debris fields in Pearl Harbor than at other sampled locations.

Table 3-7. Summary of the Kruskall-Wallis ANOVA and Student-Newman-Keuls (SNK) Test applied to the parameters (number of fish species, number of individuals, and estimated standing crop) measured at four groupings of sample sites: entrance channel sites (n=7), debris field sites (n=4), channel wall sites (n=7), and sedimentary (soft) bottom sites (n=10). Letters with the same designation show means that are related; changes in letter designation show where significant differences exist. Overlaps in letters indicate a lack of significant differences; in such cases, only the extremes may be significantly different.

Number of fish species (P >0.002)

Location	Mean	SNK Grouping	
Entrance Channel	16.4	A	
Debris Fields	16.0	A	
Channel Walls	10.7	A	B
Sediment Bottom	3.0	A	
Interpretation	Greater diversity of fish species at the PHEC stations because of distance/lessening impact of sediment/freshwater input at the Pearl Harbor head, however, statistical separation is weak.		

Number of individual fish (P >0.0005)

Location	Mean	SNK Grouping	
Debris Fields	1,068.8	A	
Channel Walls	193.3		B
Entrance Channel	134.3		B
Sediment Bottom	27.2		B
Interpretation	Numbers of fish are significantly greater in the debris fields than over other sampled areas.		

Estimated Standing Crop (P >0.0007)

Location	Mean	SNK Grouping	
Debris Fields	967.5	A	
Channel Walls	270.0		B
Entrance Channel	111.6		B
Sediment Bottom	18.0		B
Interpretation	Significantly greater biomass of fishes at debris field stations over other sampled areas.		

3.3 MACROINVERTEBRATE COMMUNITIES

Table 3-8 presents a list of the species and numbers of individuals of each of those species encountered in the 25 m by 4 m transect areas of each of the 32 fish belt transects. At the foot of **Table 3-8** are the total number of species and individuals found on each transect; transect numbers 1 through 7 (PHEC) had a mean of 5.6 species and 107.6 individuals per transect and the inner Pearl Harbor transect means were 2.2 species and 26.6 individuals per transect. The higher numbers in the PHEC probably reflect the more marine conditions present relative to the inner reaches of Pearl Harbor.

There were no rare macroinvertebrate species at any of the 32 transect sites surveyed in this study; however several species were observed which are infrequently sighted around O'ahu. It should be noted that the pearl oyster (*Pinctada margaritifera*) was seen at two PHEC transects and at three transects in the inner Pearl Harbor. For many years, pearl oysters have been virtually absent from inner Pearl Harbor; the increasing numbers of this species in the inner Pearl Harbor is probably related to the improving environmental conditions of the area in recent years. Large specimens of the horned helmet (*Cassis cornuta*) and Triton's trumpet (*Charonia tritonis*) were seen in the PHEC. These shells are highly prized by collectors and specimens of the sizes recorded (30 cm and 40 cm, respectively) are uncommon. In addition to these sightings, an aggregation of 56 of the uncommon blue-spinned urchin (*Astropyga radiata*) were recorded by Smith in the PHEC in June 2002. The urchins were all physically touching one another and remained in the area for one week and then disappeared.

The presence or absence of specific macroinvertebrate species in this survey is related to the substrate present in the transect area. The presence of hard substrate (limestone or anthropogenic surfaces such as concrete or steel) will usually allow a greater development of visually obvious benthic species than will be found on soft (mud or sand) substrates. However, considering only transects within Pearl Harbor (transect numbers 8 through 32), commercially important crab species (*Portunus sanguinolentus, Podophthalmus vigil, and Thalamita crenata*) were all encountered on transects dominated by unconsolidated sediments. Conversely, *Echinothrix diadema*, the banded urchin (*Echinothrix calamaris)*, brown sea cucumber (*Actinopyge mauritana*), and pink sea cucumber (*Opheodesoma spectabilis*), which are not particularly common in Pearl Harbor, were found on transects dominated by hard substrate.

3.4 THREATENED AND ENDANGERED SPECIES

As previously noted, the only protected marine species sighted during this study was the threatened green sea turtle. Specimens of this species were observed inside Pearl Harbor and within the PHEC (**Table 3-9**).

A total of 58 green sea turtle sightings were made in the PHEC or the adjacent study areas. The total observation time was approximately 135 minutes. The largest number of individuals sighted simultaneously was 13, at Turtle/Tripod Reef. The second largest number was on the Outfall Extension Pipe, where nine individuals were simultaneously counted as they rested between the bottom of the pipe and the seafloor. Insufficient data is available to determine the actual number of separate individuals sighted during this survey. There were only seven sightings within Pearl Harbor and no more than a single individual was ever seen at one time. The total observation time within Pearl Harbor was approximately 270 minutes. Of all the sightings at all locations, 26 were females, 17 were males and the remaining 22 were undetermined. Ten of the green sea turtles seen at Turtle/Tripod Reef and all of the turtles under the outfall pipe were estimated to have carapace lengths over 100 cm, with four specimens estimated to exceed 130 cm. When first observed, eight of the specimens were apparently being cleaned; 33 were resting and 24 were swimming. None of the individuals appeared to be feeding. While conducting a fish transect, one of the field investigators (Evans) recorded a specimen estimated to have a carapace length of 170 cm.

Forty two of the 58 sightings outside Pearl Harbor were either at Turtle/Tripod Reef or underneath the Outfall pipe. All of the cleaning activity was noted at Turtle/Tripod Reef where a cleaning station appears to be located. On three separate dives during this study four turtles were simultaneously observed at this

Table 3-8. Diurnally exposed macroinvertebrates encountered in the 25 m by 4 m census area on each of 32 transects. The first seven transects were established in the Pearl Harbor Entrance Channel and the remainder were carried out inside of the Pearl Harbor on 12-15 September 2005.

	Transect Number																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
MOLLUSCA																																
Conus vexillum																															1	
C. striatus	1																															
C. lividus		1																														
C. ebreus						1																										
C. miles						1																										
C. leopardus					1																											
Pinctada margaritifera					1		1	1				2							1													
Chama elatensis												1	2									3										
Arca ventricosa	7		19		14																											
Spondylus tenebrosus		2	3																													
Octopus cyanea	1					1																										
ANNELIDA																																
Sabellastarte spectabilis					3			30		23		24	8	3	4				11	30	11	28	58	57		24	92	6	111		28	16
Loimia medusa					1																											
Thelepus setosus								1	4		6		9										9									6
ARTHROPODA																																
Corallianassa borradailei		1				6																										
Pseudosquilla ciliate																													1			
Lysiosquilla maculate													1	1				1							1							
Gonodactylus mutates													1																			
Stenopus hispidus										2			2																			
Portunus sanguinolentus									2		1							1							1					2		1
Podophthalmus vigil														1																		
Thalamita integra																													1			
T. crenata																									1							
ECHINODERMATA																																
Echinothrix diadema	5	27	20	12	56	17	26	9		1																						
E. calamaris	1				4	10	17		1																							
Tripneustes gratilla	5	1	7		100	135	55																									
Echinostrephus aciculatum		21	1																													
Echinometra mathaei		174																														
Diadema paucispinum					3																											
Actinopyge mauritana								11																								
Opheodesoma spectabilis																					2	1										
Total Number of Species	**6**	**7**	**5**	**1**	**9**	**7**	**4**	**5**	**3**	**3**	**2**	**3**	**6**	**3**	**1**	**0**	**0**	**2**	**2**	**1**	**2**	**3**	**2**	**1**	**3**	**1**	**1**	**1**	**3**	**1**	**2**	**3**
Total Number of Individuals	**20**	**218**	**50**	**12**	**183**	**171**	**99**	**52**	**7**	**26**	**7**	**27**	**33**	**5**	**4**	**0**	**0**	**2**	**12**	**30**	**13**	**32**	**67**	**57**	**3**	**24**	**92**	**6**	**113**	**2**	**29**	**23**

Table 3-9. Number of green sea turtle observations made underwater at sites surveyed within Pearl Harbor (H) and within or adjacent to the Pearl Harbor Entrance Channel (PHEC). Turtles over 65 cm carapace length were judged to be sexually mature and were recorded as male (M) or female (F). All turtles estimated to be less than 65 cm were recorded as sex unknown (?). Some turtles over 65 cm were also recorded as sex unknown (?) when sex could not be clearly determined.

Site #	Sightings	Confirmed No Of Individuals	Sex	Site #	Sightings	Confirmed No Of Individuals	Sex
1 PHEC	4	2	2 F 2 ?	16 H	0	0	
2 PHEC	1	1	1 ?	17 H	0	0	
3 PHEC	28	13	10 M 10 F 8 ?	18 PHEC	3	2	1 M 2 F
4 PHEC	14	9	5 M 9 F	19 PHEC	1	1	1 M
5 PHEC	3	2	1 F 2 ?	20=3			
6 PHEC	1	1	1 ?	21 H	0	0	
7 H	0	0		22 H	0	0	
8 H	0	0		23 H	0	0	
9 H	0	0		24 H	0	0	
10 H	0	0		25 H	0	0	
11 H	0	0		26 H	0	0	
12 H	2	1	1 F 1 ?	27 H	2	1	2 ?
13 H	0	0		28 PHEC	3	2	3 ?
14 H	3	1	1 F 2 ?	29=5			
15 H	0	0					

station (**Appendix 2**). The following species of fish were observed biting at/cleaning the turtles’ carapaces and or other body parts: 1) Hawaiian whitespot toby (*Canthigaster jactator*), 2) Gold-ring surgeonfish (*Ctenochaetus strigosus*), 3) Hawaiian cleaner wrasse (*Labroides phthirophagus*) and 4) Trumpetfish (*Aulostomus chinensis*) (**Appendix 2**). The authors are not aware of any reports of trumpetfish acting as cleaners; however, a single trumpetfish was observed at the cleaning station on two separate days where it could be clearly seen biting at something at the junction of the carapace and neck of a large male turtle.

All the turtles estimated to have carapace lengths of less than 65 cm had at least one visible fibropapilloma tumor. Approximately 50% of the larger specimens had visible tumors. None of the turtles had any bite marks.

4.0 DISCUSSION

4.1 Pearl Harbor as a Nature Preserve

The control of Pearl Harbor by the U.S. Navy for a century has limited civilian use. This has made much of Pearl Harbor a de facto aquatic preserve which has allowed resources to exist with little or no fishing pressure exerted upon them. The result is that some fishery resources are relatively abundant, especially species such as the eastern oyster (*Crassostrea virginica*) in West Loch and the flathead mullet (*Mugil cephalus*). The only permitted civilian capture fishery has been for baitfish used as live bait in the skipjack tuna pole-and-line fishery. This fishery has dramatically declined since the closure of the tuna cannery in 1984; similarly the capture of baitfish has also decreased in Pearl Harbor. At present a small amount of fishing occurs in portions of East Loch by military and civilian personnel working on base and some fishing is done around the warm water discharge of the Hawaiian Electric Company facility at Waiau in East Loch. These fishing activities are carried out with hook and line methods. Some illegal trap and gill net fishing is also known to occur, primarily in the upper reaches of East Loch. With the recognition of possible contamination of fish and shellfish in Pearl Harbor due to pollution in the mid-1980's, both the U.S. Navy and the Hawai‘i State Department of Health have posted warnings along shoreline areas to not consume fish taken in Pearl Harbor. More recently with the need for heightened security following the tragic events of 11 September 2001, unauthorized civilian entry and use of the Pearl Harbor resources has decreased. The net result has been little fishing activity occurring in Pearl Harbor.

Similarly, the waters around the entrance channel to Pearl Harbor are likewise controlled by the U.S. Navy. In the past this control has varied which allowed fishing to occur (albeit illegally) around the PHEC during periods when enforcement of security was more relaxed; however, since 11 September 2001, security has been increased and fishing activities have probably ceased in the PHEC. In short, base security has made access to the Pearl Harbor aquatic resources difficult for much of the civilian population, thus again enhancing the Pearl Harbor marine preserve status.

4.2 Benthic Communities

4.2.1 Benthos

Biological collections from Pearl Harbor commenced at the turn of the century but none were very extensive in their efforts. It was not until the work by Evans et al. (1974) and the more recent effort by Coles et al. (1997) have the biological collections been more systematic and representative of Pearl Harbor. Coles et al. (1997) listed 434 taxa (36 algae, 1 spermatophyte, 338 invertebrates, and 59 fish species and higher taxa) collected from 15 stations in Pearl Harbor. In total, 394 of these taxa were from fouling communities, sediment samples or fish observations. The remaining 40 taxa were exclusively from sediment samples. Evans et al. (1974) listed 388 taxa (23 algae, 278 invertebrate and 87 fish) collected or seen in the 1971-73 period. Grovhoug (1992) reported 130 taxa (79 invertebrate and 51 fish) from Pearl Harbor. Brock (1994, 1995) found 96 and 99 taxa, respectively from the six stations sampled in East Loch. All other studies carried out in Pearl Harbor previous to those above have reported ten or fewer taxa. The present study has noted 16 large diurnally-exposed macroinvertebrate species on the 25 transects in Pearl Harbor and 18 species on the seven transects carried out in the PHEC. Relative to the studies cited above these species totals appear to be low. However, the above studies focused on many of the small, generally cryptic species and utilized grabs, box cores, traps, and nets to collect specimens. Therefore, the taxonomic lists are considerably longer.

The list of species given in Coles et al. (1997) is the most complete to date. However, many species in the list are recorded as “off Pearl Harbor” or “Fort Kamehameha reef flat.” It is recognized that many motile species (such as fish and crabs) may move in and out of Pearl Harbor as adults, or larvae of some may recruit to Pearl Harbor having originated from areas outside. Sampling biological communities seaward of Pearl Harbor should result in a much longer species list simply because the conditions are more marine and less estuarine in a seaward direction.

Military activities dominated and affected much of Pearl Harbor's environment for the 1900 to 1960 period. During much of that time most of the surrounding hinterland was in sugar production. Commencing in the 1950's and continuing over the next 30 years, the hinterland changed from agriculture to urban and commercial/retail uses as Honolulu's population grew. These changes affected the inputs occurring to Pearl Harbor. Since much of the urbanization has been completed (i.e., landscaping matured, hardened surfaces, and drainage in place), sediment inputs have probably decreased as have the input of certain agricultural pollutants. However, pollution/pollutants typically associated with urbanized areas (e.g., motor oil and grease from automobiles and roads) has probably increased. Increased governmental regulation of pesticides in recent years has led to a banning of products that persist in the environment and the introduction of more environmentally-friendly products (i.e., those with short half-lives). In addition, the U.S. Navy initiated an active program to reduce pollution to Pearl Harbor. From an aquatic biological perspective, the result has been one of species disappearance during the period of time when pollution was probably greater (i.e., less regulated) and the reappearance of these species with the improvement of the Pearl Harbor aquatic environment. Two examples are noted below.

The early improvements of the Pearl Harbor environment resulted in the increased abundance of commercially important species such as the spanner crab (*Ranina ranina*) and the striped mantis shrimp (*Lysiosquilla maculatus*). Fishing for striped mantis shrimp is not well-known among Hawai'i's fishermen today, but many years ago this species was a highly prized species to catch attaining a length in excess of 30 cm. The striped mantis shrimp has, however, not been seen or collected in Pearl Harbor since 1923 (see Coles et al. 1997). In this study, the striped mantis shrimp was encountered on transect numbers 13, 14, 18, and 25 (**Table 3-6**) and thus was reasonably well represented in this study.

The second group of organisms that were conspicuously absent in the extensive biological survey in the early 1970's (Evans et al. 1974) was the corals. Evans et al. (1974) suggested that the environmental conditions had deteriorated to such an extent that corals could not tolerate the conditions in Pearl Harbor and thus were absent. Brock (1994) reported one coral species (*Leptastrea purpurea*) in Pearl Harbor and Coles et al. (1997) noted five species present in Pearl Harbor. During extensive surveys Smith (2002) recorded eight species and the current total of stony coral species is now 11. The reappearance of *Lysiosquilla maculates*, the increasing abundance of stony corals and the number and size of fishes in Pearl Harbor suggest that the environmental conditions have improved.

These improving environmental conditions are probably related to the Navy's efforts to curb pollution entering Pearl Harbor, the maturing of the adjacent urban areas with a subsequent reduction in sediment input and the virtual absence of fishing. However, improving environmental conditions have not necessarily increased to such an extent to allow formerly dominant species to return in high numbers. At one time Pearl Harbor provided a habitat appropriate for pearl oysters. There are two common species in Hawai'i including the black-lipped pearl oyster (*Pinctada margaritifera*) which is used in the pearl aquaculture industry in Tahiti and elsewhere in the South Pacific, and the smaller *Pinctada radiata* which was the most abundant species in Pearl Harbor many years ago (Kay 1979). As noted by Bryan (1915), page 444:

> A species of pearl oyster family occurs at Pearl Harbor. The common species "pa" is often three or four inches or more across....Without a doubt it was the presence of this shell with the iridescent interior, occurring at Pearl Harbor, on O'ahu, that gave that sheet of water its name. Although they belong to the same sub-family, they are not the famous pearl shell of the South Pacific islands. However, a pearl-bearing species is found in Pearl Harbor and at certain other places about the group in the deeper water offshore, and pearls were found to some extent by the natives, but the pa was chiefly used by them for making fishhooks and to some extent in making the curious shell-eyes for their wooden gods.

Pinctada radiata was recorded by numerous studies in Pearl Harbor up through 1938 (Dall et al. 1938) and apparently was not seen again in Pearl Harbor until Coles et al. (1997) noted this species at one site in the vicinity of *The Machinist*, which is part of the inactive fleet near the head of Middle Loch. In his 1999 survey of the warm-water discharge from Hawaiian Electric Company's electrical generation plant at Waiau, Brock (pers. obs.) found many dead *P. radiata* valves (shells) in an area where the discharge currents had recently removed the overlying mud exposing many hundreds of these oyster shells in a small section of the old reef flat at Waiau. The apparent abundance of these shells suggests that *P. radiata* was extremely abundant at one time in Pearl Harbor.

Both Coles et al. (1997) and Evans et al. (1974) recorded the black-lipped pearl oyster in Pearl Harbor, but this species is not at all common. Our survey noted the black-lipped oyster in transects 8, 12 and 19 in Pearl Harbor as well as at transect 5 and 7 in the PHEC. However, it continues to be an uncommon species in Pearl Harbor.

The question arises as to why these species are near absent today in Pearl Harbor? Again, changes in water quality or habitat destruction may have all played a role in the near demise of these *Pinctada* species in the waters of Pearl Harbor. Other possible factors related to the decline in pearl oysters in Pearl Harbor may be (1) the arrival of a parasite or disease specific to these oysters from another locality in the Pacific transported by vessel traffic or (2) similarly, due to another sessile species non-native to Hawaiian waters becoming established and simply outcompeting the native oysters. However, no single species appears to have come to dominate subtidal hard substrate in Pearl Harbor which is required by the adult oysters but rather, an assemblage of sessile species including many species of sponges, polychaete worms, mollusks (vermetids and bivalves), arthropods (barnacles), and urochordates (tunicates). Many of these are known or suspected alien species and in Pearl Harbor are among the most abundant sessile forms. These aliens may simply be competitively superior space occupiers relative to the formerly common pearl oysters. However, only time will tell that with the continuing recent improvement in environmental quality, Pearl Harbor may once again become a habitat suitable for the growth of pearl oysters.

4.2.2 Sessile Benthos on the Fort Kamehameha Outfall Pipe and Piles

The assessment of the benthos on a section of the Fort Kamehameha outfall pipe and piles presented here was conducted about two years (732 days) following the completion of the outfall construction. As mentioned earlier, most of the biotic cover found on the pipe and piles consisted of turf algae (99% on the pipe and 89% on the piles). The remainder of the live cover consisted mainly of hard corals, encrusting sponges, crustose coralline algae (CCA), and sessile bivalves. Differences between the piles and the pipe included the presence of sessile bivalves on the piles and significantly more live cover (excluding turf algae) on the piles compared to the pipe. The mean live cover (excluding turf algae) on the sides of the piles was significantly greater than that on the pipe ($t_{0.05(2),24} = 7.60$; $P = 0.001$). The same was true for a comparison between the mean cover on the tops of the piles versus the pipe ($t_{0.05(2), 30} = 4.15$, $P = 0.001$). The source of the cover differences was CCA and encrusting sponge cover; both were significantly greater on the piles compared to the pipe (CCA comparison: $t_{0.05(2),39} = 2.96$; $P = 0.005$; encrusting sponge comparison: $t_{0.05(2),39} = 3.38$, $P = 0.005$). There was no significant difference in the cover of corals between substrates ($t_{0.05(2),39} = 0.70$, $P = 0.49$). Further, the size of hard corals (largest diameter) was statistically identical on the two substrates ($t_{0.05(2), 45} = 1.69$, $P = 0.10$). The sizes (largest diameter) of CCA patches were not significantly different between substrate types ($t_{0.05(2), 86} = 0.94$, $P = 0.37$) yet the density of patches of CCA was significantly greater on the piles than on the pipe ($t_{0.05(2),39} = 4.09$, $P = 0.001$).

Of the several factors potentially influencing the local level and composition of biofouling (including substrate type, orientation of the substrate, nutrient enrichment, temperature, and predation and herbivory), substrate type, nutrient enrichment and predation and herbivory may explain why fouling in 2005 was greater on the piles than on the pipe. Biofouling of the pipe and piling began 483 days before the outfall pipe was used. During this pre-sewage disposal period fouling organisms may have preferred the concrete over the PVC substrate (note that corals do recruit on PVC surfaces; Birkeland et al. [1981]). From the day the outfall became operational, fouling organisms on the piles and pipe were exposed to the same level of nutrient enrichment. The increase in nutrients probably favored the recruitment and expansion of short-lived organisms (algae and filter feeders) which in turn could have had a negative effect on coral recruitment (Birkeland 1977). Bivalves were observed on the piles. The differences in cover between pile and pipe were probably not caused by differences in substrate orientation, (i.e., vertical versus horizontal surfaces) since in a 27 m water depth, fouling organisms prefer horizontal and sunlit surfaces (Birkeland et al. 1981). Further, it is unlikely that sewage running through the pipe altered the temperature of the surface of the pipe to the point of influencing the level and type of biofouling.

Amongst the differences in biofouling levels observed here between piles and pipe, the greater cover and density of CCA patches on the piles is noteworthy since it may explain a potential future difference in coral cover between substrates. The presence of CCA will probably enhance future stony coral recruitment (Morse et al. 1996). The more abundant CCA on the piles will probably enhance coral recruitment on the piles versus the pipe. Moreover, the presence of mature coral colonies and CCA on the piles will further accentuate coral recruitment on the piles (Vermeij 2005).

4.3 CURRENT AND PREVIOUS POINT CENTERED QUARTER METHOD FINDINGS AND OTHER OBSERVATIONS

Pearl Harbor—During 2005 much of the perimeter of Pearl Harbor was surveyed to assess the distribution of stony corals and sea turtles. **Figure 1-2b** shows the areas which were surveyed.

No stony corals were observed during 1973 and 1974 at any of the study sites (Evans et al. 1974). Coles (1999) found five stony coral species within Pearl Harbor, including specimens at some of Evans et al. (1974) study sites. Smith (2002) found eight stony coral species with one or more species were present at five of the 11 Evans et al. (1974) study locations. Three additional hard coral species were recorded during the present study (**Table 4-1**).

Table 4-1. Stony coral species recorded within Pearl Harbor.

Coles (1999)	Smith (2002)	Present Study
Montipora patula	*Montipora patula*	*Montipora patula*
	Montipora capitata	*Montipora capitata*
	Montipora flabellata	*Montipora flabellata*
		Leptoseris incrustans
		Pavona varians
Leptastrea purpurea	*Leptastrea purpurea*	*Leptastrea purpurea*
Pocillopora damicornis	*Pocillopora damicornis*	*Pocillopora damicornis*
Pocillopora meandrina	*Pocillopora meandrina*	*Pocillopora meandrina*
Porites compressa	*Porites compressa*	*Porites compressa*
	Porites lobata	*Porites lobata*
		Psammocora explanulata

Coles (1999) listed *Leptastrea purpurea* as the most common coral in Pearl Harbor. By 2002, and continuing through this study, *Pocillopora damicornis was* the dominant scleractinian species based upon frequency of occurrence. Most specimens are less than 10 cm in diameter although larger ones are present (**Figure 4-1**). The second most commonly sighted species was *Leptastrea purpurea.* Many of *L. purpurea colonies* within Pearl Harbor are less than 3 cm in their greatest dimension and are most frequently observed growing on old bottles (**Figure 4-2**). The largest individual colonies measured were *P. compressa* colonies in West Loch. During 2002, specimens with low head shaped growth forms and short fused branches were discovered in West Loch. Although it was difficult to clearly differentiate between the beginning and end of overlapping colonies, some appeared to be more than 100 cm in diameter. Specimens of this size, would probably be more than 50 years old. These sites were revisited during the present study and nearly all the colonies were partially or completely overgrown by gorilla seaweed, *G. salicornia* (**Figures 4-3** and **4-4**).

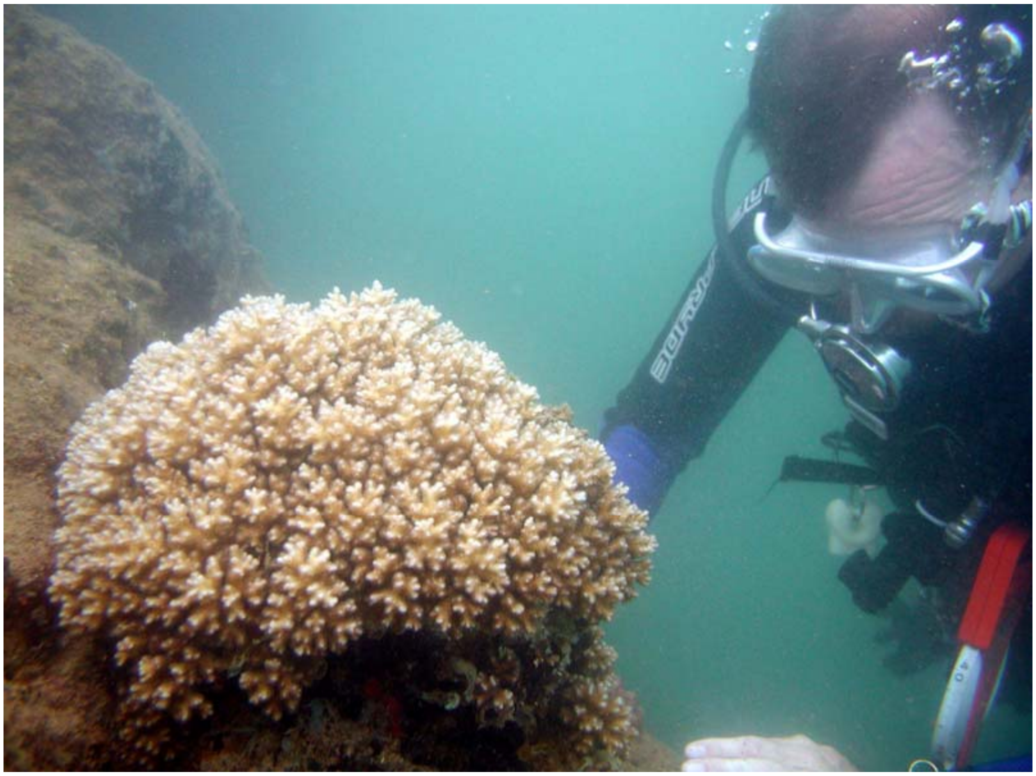

Figure 4-1. Unusually large colony of lace coral (*Pocillopora damicornis*) in Pearl Harbor in 2005.

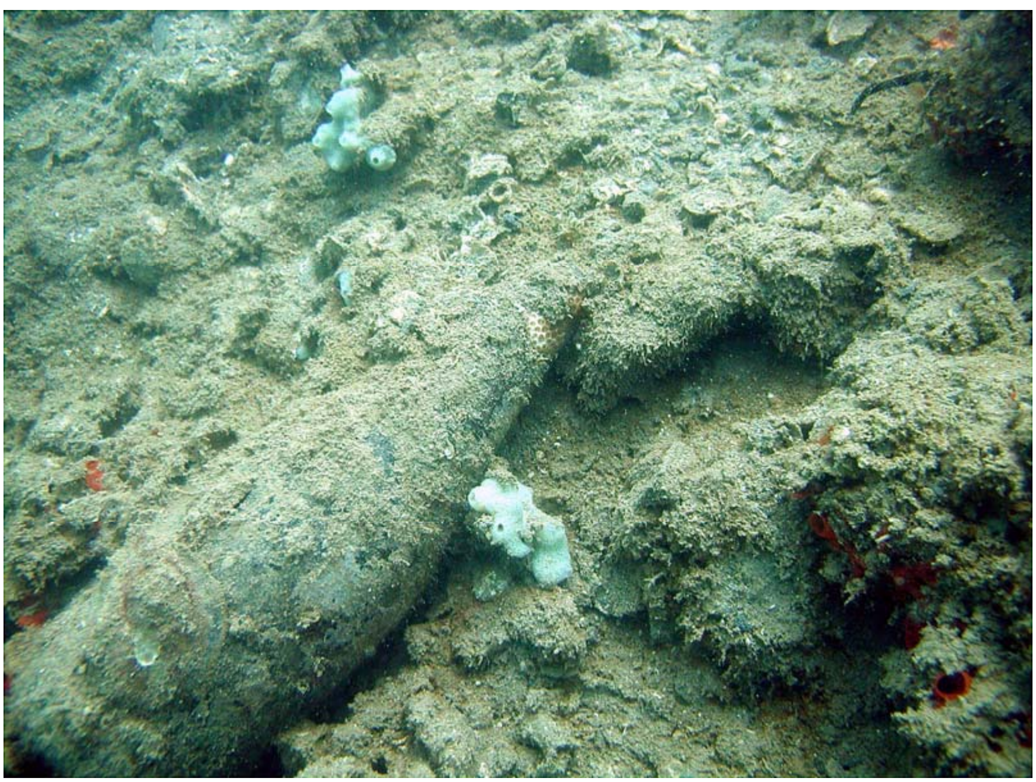

Figure 4-2. Crust coral *Leptastrea purpurea* encrusting a bottle in Pearl Harbor in 2005.

Figure 4-3. Gorilla seaweed, *Gracilaria salicornia*, colonizing the Pearl Harbor shallow nearshore area in 2005.

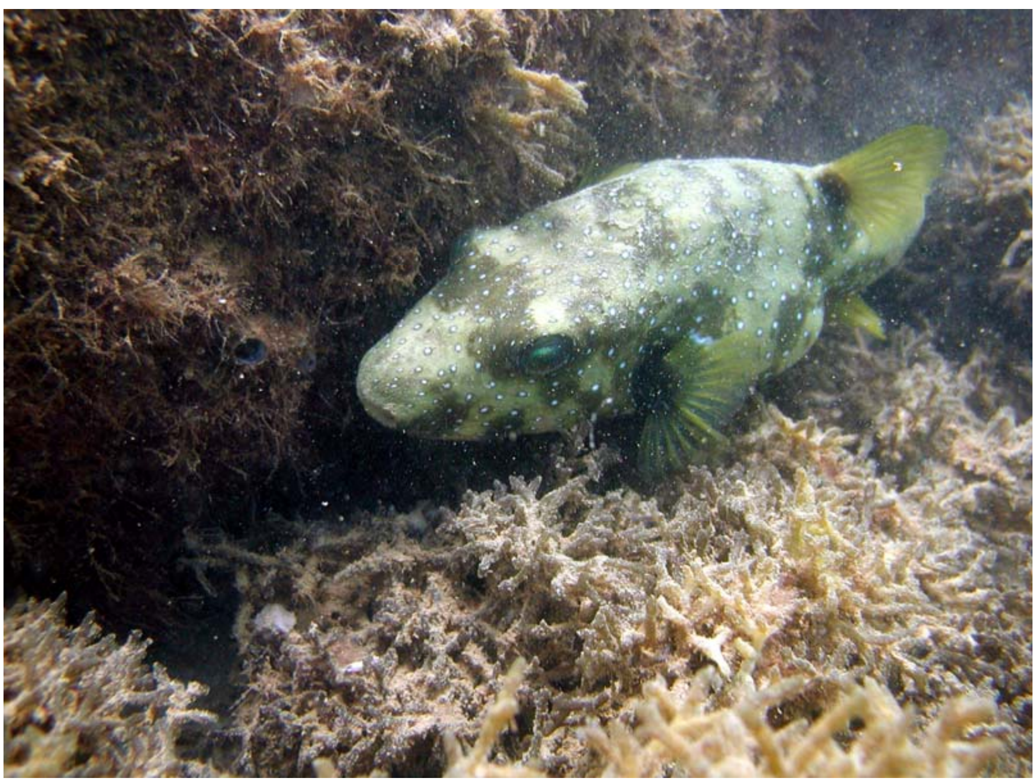

Figure 4-4. White-spotted puffer fish, *Arothron hispidus*, swimming over gorilla seaweed, *Gracilaria salicornia*, colonizing the Pearl Harbor shallow nearshore area in 2005.

Based upon the size of some of *M. capitata, M. patula,* and *P. compressa* specimens, some of these colonies were probably present prior to the 1973 to 1974 surveys conducted by Evans et al. (1974). Nevertheless, the total number of stony corals and diversity of species appears to have increased substantially since Evans et al. (1974). This is a good indication that the marine environmental conditions in Pearl Harbor have improved significantly. Of concern however, is the dramatic increase in *G. salicornia* between 2002 and 2005 (Smith, personal observation). This alga has devastated corals in many areas of Hawai'i and its presence in Pearl Harbor will adversely impact stony coral growth and recruitment, and the general macrobenthic invertebrate diversity and fish stocks (see Section 4.4.1 for a discussion of its apparent impact on fishes).

Outfall Corridor—The habitat in the surveyed portion of the Fort Kamehameha Outfall Corridor was depauperate from the perspective of stony corals, both prior to construction of the outfall and after construction. The seafloor consisted of coarse sand and rubble bottom. Stony corals were sparsely distributed, with most colonies occurring on rubble and being less than 10 cm in their greatest dimension. The percentage of the seafloor covered by coral was 0.13% in 2000 and 0.02% in 2005. Six species were recorded in 2000; five of the six were observed in 2005. The exception was *P. eydouxi* which was not observed in 2005. *Pocillopora meandrina* comprised 59% of all corals measured in 2000 and 75% in the present study. The mean colony size of this species recorded in 2000 was 113 cm^2; mean colony size in 2005 was 17 cm^2. The mean area within which all coral colonies were located was similar between studies: 8.7 and 9.9 m^2 in 2000 and 2005, respectively.

Based on their size frequency distribution, corals present in 2000 within the outfall corridor were probably less than five years old. The estimated age of five years for most of the corals coincides roughly with the periodic occurrence of waves large enough to roll coarse rubble on the seafloor in a water depth of 15 m. The periodicity of such wave impacts has the potential of limiting the size distribution of corals in this particular area (i.e., the outfall corridor).

Further, the mean colony size of 113 cm^2 in 2000, versus only 17 cm^2 in 2005 was not surprising, because all of the coral colonies observed in 2005 recruited to the outfall corridor after September 2003 when trenching was completed. The fact that the area surrounding each colony is nearly the same in the two surveys is believed to indicate that the distribution of rubble, suitably sized for successful coral recruitment, is comparable before and after construction. In other words, trenching for the outfall pipe in that portion of the PHEC has not significantly altered that portion of the PHECs ability to support corals. Substrate composition and stability were the most important limiting factors prior to construction of the outfall extension and remained the most important limiting factors in 2005.

Pearl Harbor Entrance Channel Seafloor—During 2002, Smith conducted PCQM transects covering a total length of 1,680 m. The results of these surveys are presented in **Table 4-2**. It is clear that no portion of the PHEC Channel seafloor supports significant coral growth. It is also clear that as one proceeds in a seaward direction, increasing quantities of stony coral are present. The inner portions of the PHEC are composed of higher percentages of fine sand and mud. While the substrate in the outer portions of the channel is barely marginal for coral development, the substrate in the inner portions is even less well suited for coral recruitment. It should be noted, however, that scattered metallic and concrete debris, some of which resulted from the December 7th, 1941 Pearl Harbor Attack, does support moderate to good coral growth at all points within the PHEC. This debris, therefore, serves to increase the percentage of stony coral cover within the PHEC.

There was very little macroalgae observed on the seafloor of the PHEC during surveys conducted by Smith in 1999, 2000, 2002, or during the present study. Significant portions of the channel bottom are covered by the seagrass *Halophila decipiens.* **Table 4-3** shows the distribution of seagrass recorded during 2002.

Table 4-2. Coral cover in the outfall corridor and seafloor of the Pearl Harbor Entrance Channel in 2000, 2002, and 2005. Data gathered by Smith at depths of 13 to 15 m within the PHEC, adjacent to the permanent Channel Marker Buoys. Odd numbered buoys are located on the West side of the Channel, even numbers are on the East side. [PCQM = Point Centered Quarter Method; * = A single moderate sized colony was encountered growing on a metallic hull section].

Location	Date	Method	Quarters With Coral (%)	Mean Colony Size (cm^2)	Coral Cover (%)
Outfall Corridor	July and Aug 2000	PCQM	62	111	0.13
Outfall Corridor	Sept 2005	PCQM	25	17	0.02
Buoy 1*	April to Sept 2002	PCQM	100	38	1.21
Buoy 3	April to Sept 2002	PCQM	67	531	0.21
Buoy 5	April to Sept 2002	PCQM	1	1,963*	0.24
Buoy 7	April to Sept 2002	PCQM	0	NA	0
Buoy 4	April to Sept 2002	PCQM	4	15	0
Buoy 6	April to Sept 2002	PCQM	0	NA	0

Table 4-3. Seagrass occurrence in the Pearl Harbor Entrance Channel in 2002.

Location	Transect Length (m)	Survey Points	Points with Seagrass	Occurrence (%)
Buoy 1	340	20	0	0
Buoy 2	—	122	0	0
Buoy 3	280	17	12	71
Buoy 4	100	6	6	100
Buoy 5	300	18	10	56
Buoy 6	280	17	0	0
Buoy 7	60	4	3	75

The areas adjacent to Buoys 1, 3, 4, 5, 6 and 7 were qualitatively assessed by Smith and Marx during this survey. The distribution of *H. decipiens* and stony corals was judged to be comparable to that observed in 2002.

During the 2002 coral surveys, Smith conducted PCQM transects on the fossilized reef platform adjacent to the PHEC and the slope/wall connecting this zone to the channel seafloor. The study locations were located beside the Channel Marker Buoys. **Table 4-4** presents the results of those investigations.

Turtle/Tripod Reef—Turtle/Tripod reef is actually a portion of the fossilized reef platform. It has been treated separately because it is physically distinct from all other areas investigated. The reef is approximately 120 m long and has distinct boundaries on all sides and a vertical 9 m drop along most of its eastern edge, with deeply undercut grottos along its base. In 2000 and 2002, the reef supported much denser coral development than any other study site; it also was frequented by substantial numbers of fishes, sharks, rays, and green sea turtles.

Table 4-4. Coral cover on the fossilized reef platform (FRP) and channel slopes/walls in 2002 based on Point Centered Quadrat Method transects.

Location	Quarters with Coral FRP (%)	Quarters with Coral Slope (%)	Mean Colony Size - FRP (cm^2)	Mean Colony Size - Slope (cm^2)	Coral Cover - FRP (%)	Coral Cover - Slope (%)
Buoy 1	100	NA	198	NA	19.00	NA
Buoy 3	100	88	133	158	2.36	0.19
Buoy 5	86	100	177	154	1.40	0.86
Buoy 7	54	0	64	0	0.05	0
Buoy 4	NA	NA	NA	NA	NA	NA
Buoy 6	100	100	314	452	4.30	50.20

Prior to 1982, Grigg (1995) reported that coral cover for well developed reefs off the south coast of O'ahu ranged from 60% to 75%. However, as a result of Hurricane Iwa in 1982 many reefs off O'ahu "…were reduced to rubble" (Grigg 1995). Furthermore, Grigg (1995) stated that as a result of Hurricane Iwa in 1982 and Hurricane Iniki in 1992 "…coral abundance/cover [off the south coast of O'ahu] is low averaging 7 – 29%...Today recovery is underway, but almost all reefs support less than 30% living coral cover…"

Based upon these observations, Turtle/Tripod reef had significantly higher coral cover in 2002 than most south coast O'ahu reefs. The cover in 2005 (11% to 15%) was within the range of coral cover commonly reported by Grigg in 1995. The reduction in coral cover between 2002 and 2005 was probably not the result of wave action, since the colonies were structurally intact in 2005. Part of the reduction of coral cover may have been caused by periods of heavy sedimentation during the outfall construction. Brock and Smith made separate observations of such events at Turtle/Tripod reef from commercial airlines while landing into Honolulu International Airport. *Pocillopora meandrina* and *P. eydouxi* have a very low tolerance for sedimentation and turbid water (Gulko 1998). Although *P. lobata* is resilient to sedimentation and turbidity, most colonies on the reef were encrusting forms which are less able to rid themselves of sediments as compared to head forming colonies.

It is interesting to note, that surveys of the spur and groove reefs immediately to the west of Turtle/Tripod reef conducted in 2002 produced coral cover estimates of 19%. Based upon qualitative observations of this spur and groove zone in 2005 the coral cover in the area appeared unchanged since 2002.

The presence of large numbers of coral recruits and the survival of some of the large specimens of all the dominant species suggests that a recovery is taking place at Turtle/Tripod Reef and that coral cover may return to 2002 levels in the future.

4.4 FISHES OF PEARL HARBOR

In their detailed study of the ecosystems of Pearl Harbor, Grovhoug in Evans et al. (1974) found 87 species of fishes among 46 families. Many of these species are of commercial and recreational importance. Among these are the flathead mullet (*Mugil cephalus*), milkfish (*Chanos chanos*), bonefish (*Albula vulpes*), Hawaiian ten pounder (*Elops hawaiiensis*), threadfin (*Polydactylus sexfilis*), barracuda (*Sphyraena barracuda*), flagtail (*Kuhlia sandvicensis*), chub (*Kyphosus cinerascens*), blotcheye soldierfish (*Myripristis berndti*), glasseye (*Priacanthus cruentatus*), nehu (*Stolephorus purpureus*), blacktail snapper (*Lutjanus fulvus*), goatfishes (*Mulloides flavolineatus, Mulloides vanicolensis*, *Parupeneus porhyreus*, *Parupeneus multifasciatus*, *Parupeneus pleurostigma*, and *Upeneus taeniopterus*), jacks (*Carangoides gymnostethoides*, *Caranx ignobilis*, *Caranx sexfasciatus*, *Gnathanodon speciosus*, *Caranx melampygus, Caranx mate*, and *Scomberoides laysan*), flatfish (*Bothus pantherinus*), parrotfish (*Calatomus carolinus*, *Chlorurus sordidus*), cigar wrasse (*Cheilio inermis*), sergeant major (*Abudefduf abdominalis*), eyestripe surgeonfish (*Acanthurus dussumieri*), convict surgeonfish (*Acanthurus triostegus*), ringtail surgeonfish

(*Acanthurus blochii*), yellowfin surgeonfish (*Acanthurus xanthopterus*), orangebar surgeonfish (*Acanthurus olivaceus*), goldring surgeonfish (*Ctenochaetus strigosus*), bluespine unicornfish (*Naso unicornis*), and spotted unicornfish (*Naso brevirostris*).

The Coles et al. (1997) survey of the biological resources of Pearl Harbor added only a few fishes to the Evans et al. (1974) list. Among the species added of commercial or recreational interest were the brown surgeonfish (*Acanthurus nigrofuscus*) and the striped goatfish (*Upeneus vittatus*). The striped goatfish probably became established in Hawaiian waters through a careless introduction of other fish species from Nuku Hiva, Marquesas in 1955 (Randall 1987). Brock's (1995) annual surveys of the zone of mixing for Hawaiian Electric's Waiau electrical plant has included the native mullet (*Neomyxus leuciscus*).

The present survey noted 64 species of fishes among the seven transects carried out along the PHEC and 48 species at the 25 transects conducted in Pearl Harbor. Several fish species noted in previous studies (Evans et al. 1974; Coles et al. 1997) were not encountered in any of the transects, but were present outside of the transect areas. These include species of commercial and recreational interest such as the flathead mullet (*Mugil cephalus*), milkfish (*Chanos chanos*) and the ten-pounder (*Elops hawaiiensis*). Nine species of fishes encountered in the transects established in Pearl Harbor in this study represent new records as per Coles et al. (1997). These species are the silverside (*Pranesus insularum*), speckled squirrelfish (*Sargocentron punctatissimum*), and brick soldierfish (*Myripristis amaenus*) all at transect 22; stareye parrotfish (*Calatomus carolinus*) at transect 8; redlip parrotfish (*Scarus rubroviolaceus*) and oval butterflyfish (*Chaetodon lunulatus*) at transect 21; mackerel scad (*Decapterus macarellus*) at transects 12 and 19; ringtail wrasse (*Oxycheilinus unifasciatus*) at transects 10, 19 and 21; and spectacled parrotfish (*Scarus perspicillatus*) at transects 8, 10, 12, 19 through 24, 27, 29 and 31. These new records lend further support to the contention that the environmental quality is improving in Pearl Harbor.

A single adult specimen of the emperor angelfish (*Pomacanthus imperator*) was sighted on two separate days near the north eastern tip of Ford Island. It could not be determined if the sightings were of the same, or different individual fish. Hoover (1993) notes only a single record of this species from Hawai'i; Myers (1991) lists two records for Hawai'i. This species was first observed in Hawai'i by Vernon E. Brock in 1948. Since, Richard Brock has observed emperor angelfish on the Sand Island outfall (south shore of O'ahu) at depths from 14 to about 26 m.

Individuals of many fish species encountered in Pearl Harbor are often large or more abundant relative to those seen outside of Pearl Harbor. Carangids or jacks are highly sought by commercial and recreational fishers in Hawai'i. Shomura (1987) estimated that the catch of carangids decreased more than 85% between 1900 and 1986 (to ~40,300 kg) in Hawai'i and these declines appear to be continuing today. Thus, adult carangids are not often seen on Hawai'i's reefs, yet in Pearl Harbor several species including the giant trevally (*Caranx ignobilis*) and the golden trevally (*Gnathanodon speciosus*) as well as other species are frequently seen. One area not sampled in this study but examined by Brock on several occasions over a twenty-year period in Middle Loch, serves as an aggregation point for giant trevally where more than fifty individuals weighing between 5 to 25 kg have always been present; such aggregations are extremely unusual elsewhere around the high Hawaiian Islands. Jacks were present in three fish census areas (transects 14, 25 and 27) during this study; individual fish ranged from 1.8 to 5.4 kg in estimated weight. Fish census surveys carried out along the south shore of Lana'i Island over a ten-year period encompassing 290 transects (depths from 5 to 20 m) encountered one *Gnathanodon speciosus* with an estimated weight of 0.25 kg and no *Caranx ignobilis*. Similarly, 49 transects spanning a seven-year period at the Atlantis Submarine dive site (depths 23 to 30 m) offshore of Waikiki, O'ahu did not record either of these species. Methods used were the same among all transects and were carried out by the same individual (Brock) in all surveys.

The whitesaddle goatfish (*Parupeneus porphyreus*) is esteemed among island consumers commanding the highest ex-vessel price of any inshore fish species in Hawai'i's market and this species has had this distinction for many years (Hawai'i State Division of Aquatic Resources annual fishery catch statistics). Thus, *Parupeneus porphyreus* are targeted by recreational and commercial fishers resulting in their low abundance on Hawai'i's reefs and when seen, most individuals are small (less than 120 grams [g]). No

Parupeneus porphyreus were encountered in the 290 Lana'i Island transects or in the 49 transects conducted at the Atlantis Submarine dive site. In contrast, *Parupeneus porphyreus* were censused on seven of the 23 transects carried out in Pearl Harbor in this study. In total, fifteen individuals were censused having a mean estimated weight of 950 g with the largest individual estimated at 1.8 kg.

Finally, the spectacled parrotfish (*Scarus perspicillatus*) is also esteemed and sought by commercial and recreational fishers. By 1986, the catch was estimated to be less than 5% of what it was in 1900 (Shomura 1987). Again, the abundance and mean size of this fish on Hawai'i's reefs has declined. *Scarus perspicillatus* has separate sexes and this trait was recognized by the old Hawaiians with the males being a strikingly blue/green color and the females a duller red. This species changes sex as individuals grow: they are females first and then become males in the terminal phase. *Scarus perspicillatus* were encountered in 12 of the 23 transects carried out in Pearl Harbor with 311 individuals censused with a mean estimated weight of 243 g and a maximum weight of 1.8 kg. All of these fishes were female and no terminal phase males were seen, suggesting that Pearl Harbor is serving as a nursery and grow-out area for this species. The abundance of *Scarus perspicillatus* in the Pearl Harbor transects is high relative to other sampled Hawaiian reef sites with a mean number of 14 individuals per transect. In contrast, the 290 Lana'i Island transects yielded a total of 529 *Scarus perspicillatus* individuals, ranging in estimated weight from ~1 g to 2.3 kg and had a mean weight of 71 g. *Scarus perspicillatus* was also present at the Atlantis Waikiki site where 567 fish were censused on 49 transects, ranging in estimated weight from 19 g to 3.2 kg and had a mean estimated weight of 87 g.

The active policing of non-military activities in Pearl Harbor especially since the September 2001 events has served to curtail fishing activities in Pearl Harbor. Thus in the absence of fishing, resident fishes are able to attain greater sizes. The data above support this contention and demonstrate the impact that fishing may have on select coral reef fish species as well as suggest that despite the long history of environmental degradation, Pearl Harbor remains an important habitat for many coral reef fish species.

4.4.1 Comparison with the Evans (1974) Study

As noted above, 90 species of fish among 46 families were reported to be present in Pearl Harbor by Evans (1974). The Evans (1974) survey was carried out over a one-year period encompassing seasonal variation with repeated sampling of individual sites utilizing a number of sampling methods. These methods included the use of gill and hand nets, fish traps, hook and line methods as well as underwater visual censuses of resident fishes resulting in a comprehensive picture of the fish communities present in Pearl Harbor at that time. Since the present survey utilized only visual census techniques at each sample site on a single occasion to sample the fish communities, the results from these two surveys are not directly comparable.

Not surprisingly, Evans (1974) noted many species not seen in the present survey because of the duration of their study and the diversity of methods used. Some fish species are wary of divers and are not easily seen in underwater transects but may be easily detected using gill nets or hook and line methods. Examples include the bonefish (*Abula vulpes*) and the scalloped hammerhead shark (*Sphyrna lewini*). Some species are present in Pearl Harbor on a seasonal basis thus may be missed in surveys that do not coincide with their seasonal presence. Female scalloped hammerhead sharks (S*phyrna lewini*) are known to seasonally enter Pearl Harbor to pup (Clarke 1971).

Three areas (Beckoning Point, Hospital Point and Mokunui Islet) examined by Evans (1974) were re-surveyed in the present study. Every effort was made to locate and resample the well-defined locations surveyed in 1974. The Evans (1974) study did not attempt to directly census all fishes seen on a transect but ranked their abundance by species, making direct comparisons difficult. Despite the methodological differences between the Evans (1974) and present study carried out more than 25 years later, some comparisons are made and the results are given in **Table 4-5**. The early study found considerably more fish species present than in the present study at all three sites (**Table 4-5**). However as noted above, the early study used a variety of sampling techniques spanning an entire year so the probability of finding wandering species such as the eagle ray (*Aetobatus narinari*), reef shark (*Carcharhinus limbatus*), milkfish (*Chanos chanos*), several species of jacks, ten-pounder (*Elops hawaiiensis*), halfbeaks

(*Hemirhamphus depauperatus*), hammerhead sharks (*Sphyrna lewini*) is much greater than in the present study which spent no more than ~2.5 hours at each site. It should be noted that during various surveys conducted by Smith within Pearl Harbor between 2000 and 2004 all of the above species were recorded, except for the sharks.

Standing crop estimates were made in both studies and are also summarized in **Table 4-5**. In the present survey, the standing crop estimates are considerably greater at two of the three sites than those from the early (Evans 1974) study. However, the number of species as well as the estimated biomass at Beckoning Point is extremely low in the present study which raises the question of why the difference? The Evans (1974) study found the substrate at Beckoning Point to be a mix of sand, rubble, and coralline (pavement) substrate with some native algal species present in the shallows adjacent to shore. The present study found the subtidal substrate to be almost entirely covered (~98% coverage) by the alien alga, *Gracilaria salicornis* which does not provide suitable shelter for most fishes. As a result, the fish community at that site today is poorly developed. In contrast, estimated standing crops today are considerably greater than found by Evans (1974) at both Hospital Point and adjacent to Mokunui Islet which suggests that the habitat and/or environmental quality has improved at these locations.

Table 4-5. Analysis of fish communities at three locations in Pearl Harbor comparing results of a one-year field study (Evans 1974) to those from single visual census surveys in the present study. Standing crop estimates are given in grams per square meter (g/m^2).

Location	Evans et al. (1974)		Present Study	
	Species	Biomass	Species	Biomass
Beckoning Point	28	748	3	3
Hospital Point	24	14	15	387
Mokunui Islet	42	153	—	—

4.4.2 Observations of Sharks and Rays in the PHEC

During various surveys conducted by Smith in 1999, 2000, 2002 and 2004 the following shark species were sighted in the PHEC: Blacktip reef shark (*Carcharhinus melanopterus*; 10 sightings), whitetip reef shark (*Triaenodon obesus*; eight sightings), sandbar shark (*Carcharhinus plumbeus*; two sightings), Galapagos shark (*Carcharhinus galapagensis;* one sighting), tiger shark (*Galeocerdo cuvier;* one sighting), and scalloped hammerhead (*Sphyrna lewini*; one sighting). The largest sharks sighted were the Galapagos and tiger sharks, each estimated to be 3.5 m total length. Other large elasmobranchs Smith recorded in the PHEC include manta rays (*Manta* sp.) and spotted eagle rays (*Aetobatus narinari*); all the individuals sighted were large adults. Within Pearl Harbor, juvenile spotted eagle rays, approximately 25 cm across the pectoral fins were sighted in East Loch.

4.5 The Role of Shelter in Structuring Fish Communities

Inspection of the fish transect data from sample sites in the PHEC as well as within Pearl Harbor points to higher abundances of fishes in Pearl Harbor particularly at sites where cover or shelter is available. During this study, transects carried out over soft substrate in Pearl Harbor yielded three species, 27 individuals and a standing crop of 18 g/m^2. In contrast, along Pearl Harbor walls there were 11 species, 193 individuals, and a standing crop of 270 g/m^2. Further, the debris fields comprised 16 species, 1,069 individuals, and a standing crop of 968 g/m^2. The significantly greater development of fish communities in the debris fields is probably related to (1) the protection from fishing pressure created by Pearl Harbor security (i.e., the "de facto" preserve) and (2) the relatively greater amount of shelter afforded by the debris (the "artificial reef effect").

Studies conducted on coral reefs in Hawai‘i and elsewhere have estimated fish standing crops to range from 20 to 200 g/m^2 (Brock 1954; Brock et al. 1979). Eliminating the direct impact of man due to fishing pressure and/or pollution, the variation in standing crop appears to be related to the variation in the local topographical complexity of the substrate. Space, structural diversity, and cover are important factors governing the distribution of coral reef fishes (Risk 1972; Sale 1977). Thus habitats with high structural complexity affording considerable shelter space usually harbor a greater estimated standing crop of coral reef fish. Conversely, transects conducted in structurally simple habitats (e.g., sand flats) usually result in a lower estimated standing crop of fish (0.2 to 20 g/m^2). Goldman and Talbot (1975) noted that the upper limit to fish biomass on coral reefs is about 200 g/m^2. Hawaiian studies (Brock and Norris 1989) suggest that with the manipulation (increasing) of habitat space or food resources (Brock 1987), local fish standing crops may approach 2,000 g/m^2. Thus under certain circumstances, coral reefs may be able to support much larger standing crops of fishes than previously realized.

These studies suggest that if structural diversity, and hence fish biomass are low in a given locality, the addition of structural relief in the form of artificial reefs usually results in an increase in the biomass of fish present. Fishery managers have capitalized on these attributes building artificial reefs to enhance local fisheries usually for consumptive purposes. The greater relief and shelter present in the sampled debris fields in this study is probably responsible for the significantly greater development in those fish communities over other sampled locations in Pearl Harbor.

4.6 Threatened and Endangered Species

Green sea turtles are the only protected species which are routinely encountered within the study area. In a three month field study conducted in 1999, Smith concluded that the PHEC supported a resident population of green sea turtles. Smith used five methods to estimate the number of turtles; the resident population was estimated to range from 32 to 41 individuals. The present study did not attempt to duplicate the 1999 effort. However, the authors believe that the PHEC still supports a modest resident population of these threatened sea turtles and that the total population is at least as large as it was estimated to be in 1999. The PHEC provides both preferred resting habitat and preferred forage. The amount of preferred algal forage does not appear (subjectively) to have changed since the 1999 observations. Resting habitat has increased, if one includes the areas under the pile supported portions of the Fort Kamehameha Outfall Extension.

At most study sites within Pearl Harbor, green sea turtles were never recorded. This observation is consistent with those made during previous Pearl Harbor surveys. There are no significant quantities of preferred forage within Pearl Harbor. Preferred resting habitat is also limited. With the possible exception of the lower reaches of West Loch, the authors believe that few if any green sea turtles are resident within Pearl Harbor. Those individuals which are sighted, are most likely only transient.

Monk seals are very rare in the Main Hawaiian Islands. None are believed to be resident within or adjacent to the study area. However, single monk seals have periodically hauled out on the Iroquois Point – Puuloa Beach area for at least the last five years (Smith pers. obs.). As noted, one individual was observed in the PHEC. Observations appear to support the idea that a single monk seal will visit the project area from time to time and probably remain in the vicinity for periods of up to a month. No monk seal sighting have been reported within Pearl Harbor itself.

4.7 The Impact of Alien Species on The Pearl Harbor Ecosystem

Biologists in recent years are becoming much more aware of the impact that alien species may have in host communities. Alien species may arrive in new geographical locations by natural colonization or mediated through the activities of man. Most successful introductions in marine environments occur through the movement of ships either on the hulls or in the ballast water of ships (Ruiz et al. 2000; Wonham et al. 2000, 2001; Eldredge and Carlton 2002). Once established, alien species may be competitively superior to native species for specific resources eventually resulting in the alien species displacing native forms and possibly leading to their demise (Coles et al. 1997).

Coles et al. (1997) provide an in-depth review and analysis of the establishment of alien species in Pearl Harbor. Of the 434 species and higher taxa reported by them, 96 (22%) were considered to be introduced or cryptogenic (of unknown origin). A common attribute with most Hawaiian aquatic introductions is that they appear to have a competitive advantage for space or food. The introduced species may also prey on natives in the shared habitat. In general, the impact of introductions is more evident in communities with fewer species such as in Hawaiian streams where much of the native fauna in the lower reaches of streams has been replaced by a handful of non indigenous species (Devick 1991). At the other extreme, in many marine settings where the communities are speciose, the impact of the recent introductions appears to be less evident.

The most obvious impact of alien aquatic species in Pearl Harbor is for those which require the occupation of substrate for part of their lifecycle. Once established, these sessile species may increasingly dominate space formerly occupied by native species. The alien intertidal barnacle, *Chthamalus proteus*, was first reported by Coles et al. (1997) in Pearl Harbor. This barnacle is one of the dominant life forms on hard substrate in the intertidal of Pearl Harbor as well as other harbors of Hawai'i and represents a serious threat to native species that occupy the same habitat (Coles et al. 1997). Similarly, the red mangrove (*Rhizophora mangle*) has become a dominant lifeform along the undeveloped shorelines of Pearl Harbor and elsewhere in Hawai'i where sheltered bodies of brackish water exist. The thickets and canopy of this species exclude all other intertidal vegetation.

The gorilla seaweed, *G. salicornia*, is an apparently alien species that in recent years has become very abundant in parts of Kaneohe Bay, Pearl Harbor and at numerous other sites statewide. It is believed to have been introduced in the early 1970s, and has become a dominant life form over large areas (hundreds of square meters) in many shallow portions areas of Pearl Harbor. Sites 10 (Beckoning Point), 13 (Debris Field 3), and 23 (Porites Reef, West Loch) in the present study had a large percent cover of this macroalga (Percent cover of *G. salicornia* as determined by the Quadrat Intercept Method; site 10 = 55%, site 13 = 71%, and site 23 = 81%). The second most common subtidal alga is also an alien Rhodophyta (*Acanthophora spicifera*); it is believed to have been introduced to Hawai'i in the early 1950s (Doty 1961).

The introduced eastern oyster, *Crassostrea virginica*, occupies large areas of the shallows in West Loch. *Crassostrea virginica* remains established in Pearl Harbor (Coles et al. 1997), with the present study noting this introduced mollusk at three sites. Kay (1979) give the history of this oyster in Hawai'i that began in 1866 with 12.5 hectares (ha) of *C. virginica* beds (estimated 35 million oysters) planted in Pearl Harbor.

The featherduster worm, *Sabellastarte spectabilis*, was recorded in the majority of benthic and macroinvertebrate transects in Pearl Harbor. This species is abundant on O'ahu's south shore reefs, and in Pearl Harbor and Kaneohe Bay at shallow depths, especially in dredged areas that receive silt-laden waters and may be an indicator of waters with high sediment content (Bailey-Brock 1976).

All of these successfully established alien species occupy space that might otherwise be utilized by native species. The biota of Pearl Harbor represents a mosaic of alien and native forms. Many of the most visually obvious aquatic and intertidal species in Pearl Harbor today are not native in their origin.

The situation with impacts created by alien fishes is more difficult to quantify. Several alien fishes encountered in this and previous studies in Pearl Harbor include guppies and mollies (Poecilidae), silvery tilapia (*Tilapia melanotheron*), blacktail snapper (*Lutjanus fulvus*), small mullet (*Valamugil engeli*), striped goatfish (*Upeneus vittatus*) and goldspot herring (*Herklotsichthys quadrimaculatus*). In his discussion of the impacts of alien fishes, Maciolek (1984, page 148) notes:

> Impacts of immigrant species may be beneficial, negligible, adverse, or a combination of these for a given species under some circumstances. Beneficial and negligible effects generally relate to the purpose for a species introduction, such as for food, forage, recreation, or biological control. Adverse effects center on changes in natural ecosystems induced by exotics, particularly on native species that may be direct (competition and predation) or indirect (e.g., introduction and

transmission of disease or parasites). Benefits are generally self-evident, as are some adverse impacts, but even these are difficult to quantify.

There has been federal recognition of the impact that aquatic alien species may have on native ecosystems. Adoption of the International Maritime Organization Assembly Resolution A.868(20) (IMO 1997) that provides guidelines for the control and management of ships' ballast water should help to reduce or eliminate future introductions. In addition, the Navy has implemented procedures which significantly reduce the likelihood that alien species will be introduced into Pearl Harbor.

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5.0 SUMMARY AND CONCLUSIONS

The following answers to the seven questions posed in the Introduction (refer to Section 1.1) summarize the findings and offer general conclusions.

1. Have there been any changes in the fish and benthic communities since the Evans (1974) investigation?

The duration of the present study was shorter and only non-destructive data collection methods were utilized. Nevertheless, the authors believe the following conclusions are supported by the data:

- The standing crop of fishes at some study sites has increased, for example, Hospital Point and Mokunui Islet.
- In areas such as Beckoning Point, where the alien gorilla seaweed *Gracillaria salicornia* has taken over more than 98% of the seafloor, habitat complexity has been significantly reduced and the standing crop of fishes has declined.
- Individuals of a number of ecologically, recreationally and commercially important fish species are significantly more common and larger within Pearl Harbor than at other locations in the Main Hawaiian Islands. These species include giant trevally (*Caranx ignobilis*), golden trevally (*Gnathanodon speciosus*), whitesaddle goatfish (*Parupeneus porphyreus*) and spectacled parrotfish (*Scarus perspicillatus*).
- No stony corals were recorded at any of the Evans study sites in 1974. In Coles (1999) five stony coral species were recorded, while Smith (2002) recorded eight and the present study recorded 11 species. The return of stony corals to Pearl Harbor is believed to be a strong indicator or improving environmental conditions. It should be noted, however, that some specific coral colonies recorded in 2002 were being overgrown and killed by the alien gorilla seaweed *Gracillaria salicornia* in 2005.
- In addition to stony corals, other formerly abundant species appear to be making a comeback as well. The striped mantis shrimp (*Lysiosquilla maculates*), for example, was well represented at four separate transect sites.

2. How do fish communities and fish stocks in Pearl Harbor compare to other locations around O'ahu and in the Main Hawaiian Islands?

- The data strongly show, for the species compared, fishes in Pearl Harbor are not only more abundant, they are also significantly larger. For example, the highly esteemed spectacled parrot fish surveyed off Lana'i averaged 71 g per fish and 1.8 specimens sighted per transect (290 transects). In Pearl Harbor a mean of 14 individuals were recorded per transect with a mean weight of 243 g.
- The control of Pearl Harbor by the U.S. Navy for a century has limited civilian use of the aquatic resources in Pearl Harbor. This has made much of Pearl Harbor a de facto aquatic preserve which as allowed resources to exist with little or no fishing pressure exerted upon them. The result is that some fishery resources are relatively abundant with individuals of some highly-sought commercially important species attaining much greater mean sizes in Pearl Harbor than found elsewhere outside of Pearl Harbor.
- The highest fish densities within Pearl Harbor were found associated with artificial structures, such as sunken barges and piers. These debris items were providing important habitat to diverse fish populations.

3. What is the status of stony corals in Pearl Harbor and the Pearl Harbor Entrance Channel? How does this compare with the findings of Evans (1974) and Smith (2000, 2002)?

- As noted in the response to question 1, 11 species of stony corals have been recorded within Pearl Harbor. The number of species and locations at which they occur has steadily increased since 1999. The greatest threat to stony corals in Pearl Harbor is judged to be the spread of the alien gorilla seaweed *Gracillaria salicornia.*

- The PHEC provides relatively poor habitat for stony corals, due to the quality of the substrate. Coral cover on the seafloor is very sparse, less than 1%. The only mature coral colonies on the PHEC seafloor are located on metallic or concrete debris or limestone blocks which have broken off the channel walls, In contrast to the seafloor of the PHEC, the walls and adjacent fossilized reef platforms support modest to substantial coral development. The best developed reefs occur on the western side of the channel between Buoys 1 and 3; during this study the percentage of seafloor covered by stony corals was quantitatively estimated to be as high as 15%.

4. What changes have occurred in the Turtle/Tripod Reef coral community between 2002 and 2005?

- Permanent transects were established in 2002. In 2002, the percentage of the seafloor covered by stony coral was quantitatively determined to be 100%, within the transect corridor.
- Coral cover on the western side of the PHEC was significantly lower in 2005 than when the same sites were assessed in 2002, prior to construction. Coral cover was estimated to be 15.0% and 11.4% based on the PCQM and QIM, respectively.
- Although this is a dramatic change, the authors believe coral at this site is recovering due to the large numbers of young coral colonies and the absence of disease, bleaching, algal overgrowth and other indicators of stress.
- Species composition of stony corals, other macro invertebrates and fishes appears to be the same as in 2002, although quantitative surveys of these other organisms were not done in 2002.

5. How did the construction of the Fort Kamehameha Outfall Replacement affect stony coral distribution in the trenched portion of the outfall corridor, located within the PHEC?

- Extensive quantitative coral surveys were completed in the outfall corridor during 2000, prior to construction in 2003. During the 2005 surveys, a portion of the 2000 survey area was reassessed using the same techniques and personnel. The seafloor appeared to be the same; it consisted of coarse sand and unstable rubble.
- In 2000, coral diversity was low, the percent coral cover was 0.13% and the mean area within which each coral colony occurred was 8.7 m^2. In 2005 five of the six species recorded in 2000 were present, the percent coral cover was 0.02% and the mean area surrounding each colony was 9.9 m^2.
- Based upon the area within which each coral colony occurred, the authors concluded that the amount of suitably sized rubble for coral larval settlement was not changed as a result of the construction project. As expected, individual colony size was smaller in 2005, since the oldest colony was only two years old. Of course, the younger, smaller colonies resulted in a reduced percent coral cover.
- Construction of the outfall did not produce significant long term impacts to the corals community within the trenched portion of the outfall corridor in the PHEC. Coral development was extremely sparse in 2000, and remained extremely sparse in 2005.

6. Are corals recruiting to the pile supported portions of Fort Kamehameha Outfall and what other macrobenthic species are present on the outfall pipe and pile supports?

- Most of the biotic cover on both the piles and the pipe was turf algae; however stony corals, encrusting sponges, crustose coralline algae and sessile bivalves were also recorded.
- The size of stony corals on the pipe and piles was statistically identical.
- At least three species from two genera (*Porites* and *Montipora*) were present. The largest specimen measured was 3.7 cm in diameter. Based upon generally accepted growth rates for these genera in Hawai'i, the largest specimen presumably settled on the outfall shortly after it was completed (two years prior to the survey).

7. What marine threatened and endangered species occur within Pearl Harbor, the PHEC and along the pile supported portion of the outfall, seaward of the PHEC?

   - The only protected marine species sighted within Pearl Harbor during this study was the threatened green sea turtle.
   - Historically, there have been single sightings of the endangered humpback whale and the endangered hawksbill sea turtle. There are no recorded sightings of the endangered monk seal within Pearl Harbor.
   - With the possible exception of the lower reaches of West Loch, it is unlikely that there are any resident green sea turtles within Pearl Harbor. Green sea turtles do, however, enter and transit through Pearl Harbor occasionally.
   - The PHEC supports a resident population of green sea turtles, estimated to range in number from 32 to 41 individuals. Preferred resting habitat and preferred forage were both abundant in the PHEC.
   - The pile supported portion of the outfall appeared to attract green sea turtles. Specimens were sighted there on every dive.
   - Single adult monk seals have periodically hauled out on the Iroquois Point – Puuloa Beach during the last five years. A single sighting was recorded underwater in the PHEC (August 2005). The individual bore a tag (H 58) and was estimated to be 2.5 m long.
   - No monk seals are believed to be resident within Pearl Harbor, the PHEC or the adjacent areas.

Based upon this investigation, the marine biological communities in Pearl Harbor, the PHEC and the immediately adjacent areas are judged to be generally healthy. The numbers of fin fish and size of fin fish is larger than at other sites investigated in the Main Hawaiian Islands. Stony corals and other key invertebrates which were absent or undetected during the extensive surveys in 1974 are returning, and indicative of improving environmental conditions. Sunken derelict items, hull fragments and piers are providing important habitat for fish, corals and green sea turtles both in Pearl Harbor and in the PHEC. These items should not be removed unless they create a navigational hazard. Corals sustained some impacts in the PHEC during construction of the Fort Kamehameha Outfall Extension (2001-2003); however, they were recovering at the time this survey was conducted and are expected to return to their pre-construction densities and size in the future.

The most significant threat to organisms investigated during this study is judged to be the alien gorilla seaweed *Gracilaria salicornia.* This species is a serious problem at many locations throughout the Hawaiian Islands, in addition to Pearl Harbor. As documented in this report it has over grown and killed coral colonies within Pearl Harbor and degraded formerly productive fish habitat, such as Beckoning Point. Control of *Gracilaria salicornia* should be considered the most important priority for sustaining and protecting the fishery and benthic invertebrate resources of Pearl Harbor.

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APPENDIX 1

QUANTITATIVE VISUAL CENSUSES OF FISH

Appendix 1. Abundance of fishes observed in 32 visual census transects conducted among 17 locations in Pearl Harbor and the Pearl Harbor Entrance in 2005. The transects were each 25 m long, 4 m wide, and the height of transects reached from the seafloor to the water's surface. Twenty-five transects were done at 11 locations in Pearl Harbor (sites 7 through 17), and seven transects at six locations within the Pearl Harbor Entrance Channel (sites 1 through 6).

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
MURAENIDAE																																
Gymnothorax flavimarginatus				1																												
Gymnothorax meleagris			1																													
Echidna nebulosa						1																										
SYNODONTIDAE																																
Saurida gracilis																			1		1											
ATHERINIDAE																																
Pranesus insularum																						2000										
HOLOCENTRIDAE																																
Adioryx lacteoguttatus																						14										
Myripristis amaenus																						61										
PRIACANTHIDAE																																
Priacanthus cruentatus																						1										
SYNGATHIDAE																																
Hippocampus kuda																													1			1
SERRANIDAE																																
Cephalopholis argus			1																													
APOGONIDAE																																
Apogon kallopterus			31					5			1																					
Foa brachygramma					4		5		3				22													12	10					
CARANGIDAE																																
Gnathanodon speciosus																									1		1					
Caranx ignobilis														1																		
Scomberoides laysan																			40													
Decapterus macarellus												9							88													
Caranx melampygus				2																												
LUTJANIDAE																																
Lutjanus fulvus										46	1	3							190		124	48	73	44				8	29			
SPARIDAE																																
Monotaxis grandoculis			2																													
MULLIDAE																																
Mulloides flavolineatus												2										6	1									
Mulloides vanicolensis																						23	6									
Parupeneus cyclostomus		1		3																												
Parupeneus porphyreus												1							2		6	2	2	1							1	
Parupeneus multifasciatus	1		5	3	2																2	1										
Parupeneus bifasciatus		1																														
CHAETODONTIDAE																																
Forcipiger flavissimus				2																												
Chaetodon auriga								3		1	2	2	2						10		15	1	2	2								1
Chaetodon unimaculatus			1																													
Chaetodon lunula			2					2												2	1	1	1									
Chaetodon lunulatus																					2											
Chaetodon quadrimaculatus		2	1																													
Chaetodon multicinctus	2		2																													
Chaetodon miliaris		5	9																													
Chaetodon ephippium			2							2									2		8	1										
POMACENTRIDAE																																
Dascyllus albisella	4		15		18	8		48		22	53		6						51				3	9								20
Abudefduf abdominalis								32		51		21							66		105	44	28	34			2		34			
Abudefduf sordidus												2									1	1	2	4								
Plectroglyphidodon johnstonianus			4																													
Plectroglyphidodon imparipennis		6																														
Chromis vanderbilti	14	125																														
Stegastes fasciolatus			4																													
CIRRHITIDAE																																
Paracirrhites arcatus	4	6																														
Paracirrhites forsteri			1																													
SPHYRAENIDAE																																
Sphyraena barracuda															1									1				8				

Appendix 1 (continued). Abundance of fishes observed in 32 visual census transects conducted among 17 locations in Pearl Harbor and the Pearl Harbor Entrance in 2005. The transects were each 25 m long, 4 m wide, and the height of transects reached from the seafloor to the water's surface. Twenty-five transects were done at 11 locations in Pearl Harbor (sites 7 through 17), and seven transects at six locations within the Pearl Harbor Entrance Channel (sites 1 through 6).

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
LABRIDAE																																
Labroides phthirophagus			1		2																											
Bodianus bilunulatus		1	1	3																												
Oxycheilinus unifasciatus										2									1		1											
Cheilinus bimaculatus	5				3	1																										
Pseudocheilinus octotaenia			1																													
Thalassoma duperrey		25	8	1	5	14		14																1								
Thalassoma purpureum		1																														
Gomphosus varius		4	4																				1									
Coris venusta	2																															
Coris gaimard		1	2																													
Pseudojuloides cerasinus			1	8																												
Stethojulis balteata	5					26																										
Halichoeres ornatissimus		1																														
SCARIDAE																																
Calotomus carolinus								1																								
Scarus perspicillatus		7	4					2		21		29							19	2	13	21	10	2			19		106		67	
Chlorurus sordidus		13	11							50		19																				
Scarus psittacus		14				23		23		8	12	94	103			64				138		36						1			4	
Scarus rubroviolaceus			1	1																	2											
GOBIIDAE																																
Bathygobius fuscus					3											1															3	
Gnatholepis anjerensis				3		1																										
Psilogobius mainlandi																				4												
Asterropteryx semipunctatus							12	72	12		19	18	35	6	4	3	4						23			9	4	8	16		18	35
PARAPERCIDAE																																
Parapercis schaunslandi				8																												
ACANTHURIDAE																																
Acanthurus triostegus						1		14		1		3							1												1	
Acanthurus nigrofuscus	57	47	18	11																												
Acanthurus nigroris		3		5																												
Acanthurus blochi		25	41	63				18		87			33		2				15	152	390	82	73	43					86			14
Acanthurus olivaceus	1			4															391													
Acanthurus dussumieri		1		48				46		27		37							35	8		1	4									
Acanthurus xanthopterus																										38	1	93	109		29	
Ctenochaetus strigosus		5	23																				10	3								
Zebrasoma flavescens			1							16	1								4	8	6	1		2				2	2			
Zebrasoma veliferum		6								2		11																				
Naso hexacanthus		7																														
Naso lituratus		3	1																													
Naso unicornis												2																				
Naso brevirostris													18						1		13		29									5
ZANCLIDAE																																
Zanclus cornutus				1															4			1	2	2								
BALISTIDAE																																
Rhinecanthus rectangulus		1				1																										
Sufflamen bursa	2	5	2	1																												
MONACANTHIDAE																																
Cantherhines dumerili				2	1																											
Cantherhines sandwichiensis	1	1																														
TETRAODONTIDAE																																
Arothron hispidis							1	1	1		1		3	1					2			1							1		1	1
Canthigaster coronata				1																												
Canthigaster jactator	7	3	5		3	3																										
DIODONTIDAE																																
Diodon hystrix											1								1													
Number of Species	**13**	**28**	**33**	**20**	**8**	**10**	**3**	**14**	**3**	**14**	**9**	**15**	**8**	**3**	**3**	**3**	**1**	**0**	**20**	**7**	**16**	**21**	**17**	**13**	**1**	**3**	**6**	**6**	**9**	**0**	**8**	**7**
Number of Individuals	**106**	**320**	**208**	**170**	**40**	**79**	**18**	**281**	**16**	**336**	**91**	**253**	**222**	**8**	**7**	**68**	**4**	**0**	**924**	**314**	**690**	**2347**	**270**	**148**	**1**	**59**	**37**	**120**	**384**	**0**	**124**	**77**
Biomass (g/m2)	**14.1**	**214.9**	**414.3**	**1260.6**	**2.3**	**7.3**	**3.5**	**184.4**	**1.5**	**547.4**	**66.2**	**644.9**	**187.2**	**54.9**	**3.1**	**1.7**	**0.01**	**0.0**	**1549.9**	**487.4**	**1343.1**	**490.5**	**611.7**	**162.4**	**18.1**	**172.5**	**25.7**	**560.0**	**744.0**	**0.0**	**17.6**	**35.12**