SOUTH OAHU MARINE INVASIONS SHIPPING STUDY (SOMISS)

Final Report Prepared for the Hawaii Department of Land and Natural Resources
Division of Aquatic Resources

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EXECUTIVE SUMMARY

- The South Oahu Marine Invasion Study (SOMISS) was conducted February 1998 through December 1999. The goal of SOMISS was to broadly survey the maritime shipping industry in Hawaii by the collection of biological and operational data that would relate to the issue of marine NIS invasion. The operational aspect identified what type of vessels use Hawaii as a port, what unloading/loading operations are being conducted, what ballasting/deballasting operations are being conducted and from what regions the vessels are arriving. Biological data for organisms being transported by vessels encompassed three vectors: ballast water, ballast water sediments, and hull fouling.

- The ports of Honolulu Harbor and Barber's Point Harbor are the hubs of commercial maritime shipping activity in Hawaii, and would be the primary receiving areas for marine nonindigenous species (NIS) transported by this pathway.

- Hawaii is a net importer of bulk cargo and manufactured goods, and therefore receives less ballast water than regions that are net exporters of these items.

- The five most common commercial vessel types making port call to Hawaii for the period of 1997-1998 in order of dominance were: container vessels, foreign fishing boats, petroleum tankers, bulk cargo carriers, and overseas cargo barges. This is according to records kept by the Hawaii Department of Transportation, Harbors Division.

- The majority of commercial vessel traffic makes port call at Honolulu Harbor but only a small amount of ballast water was recorded as being discharged during the period of the study (February 1998-December 1999). This ballast water discharge was from container vessels arriving from the northwest Pacific region (average =125 m^3) and overseas cargo barges arriving from the northeast Pacific (average = 437 m^3).

- During the period of the SOMISS project ballast water was primarily being discharged at Barber's Point Harbor by petroleum tankers and bulk carriers conducting loading operations. The average ballast water discharge volume for petroleum tankers was 6427 m^3 and 1838 m^3 for bulk carriers. The common ballast water source regions were the east central Pacific, southwest pacific, northwest pacific, and open ocean for petroleum tankers, and the northeast pacific, northwest pacific, and open ocean for bulk carriers.

- The most common organisms present in ballast water samples were ciliated protozoans, diatoms, dinoflagellates, nematodes, platyhelminthes, molluscs, annelids, crustaceans, and chaetognathes.

- Ten ballast water samples taken for the purpose of bacterial examination were assayed for *Vibrio cholerae* 01 and 0139 serogroups. Fifty percent contained the 01 serogroup, while none of the samples contained the 0139 serogroup.

- Ballast water sediment samples were analyzed live and cultured for resting stage phytoplankton. This analysis recorded ciliated protozoans, dinoflagellates, diatoms, nematodes, and gastrotriches as occurring in more than 20% of the samples (n=13).

- A variety of marine NIS were discovered during hull fouling samples of eight vessels:
  Macroalgae (15 species)
  Sponges (1 species)
  Cnidaria (3 species)
  Annelids (5 species)
  Molluscs (9 species)
  Crustacea (5 species)
  Bryozoans (2 species)
  Tunicates (3 species)

- Of the 74 vessels boarded during the South Oahu Marine Invasion Shipping Study, only one was uninformed about the ballast water issue and management practices. The remainder followed guidelines based on regulations by the International Maritime Organization or U.S. Coast Guard.

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I. INTRODUCTION

Disturbance in the marine environment can be categorized in two ways: endogenous (natural) or exogenous (human-induced or anthropogenic). Examples of endogenous disturbance would be storms, predation, and disease. These natural perturbations, at intermediate levels, are considered beneficial in maintaining high diversity in marine environments like coral reefs (Connell 1978). Exogenous disturbances can be considered to be any anthropogenic disturbance that acts directly upon a marine habitat or alters the effect and/or response to endogenous disturbance. One type of disturbance, biological invasions of alien or nonindigenous species (NIS), can be included in both categories. The issue of marine biological invasions is complex and is covered in greater detail in Appendix A.

Biological invasions brought about by anthropogenic influences have occurred throughout the world through a variety of mechanisms including maritime shipping, live seafood and bait shipments, aquaculture, shipments of commercial and institutional aquarium species and the activities of education and research institutions. The primary pathway identified for marine NIS introductions has been maritime vessel traffic to ports around the world through ballast water discharge (Williams et al. 1988; Carlton & Geller 1993). Although this pathway is blamed for the majority of marine NIS introductions around the United States, the amount of ballast water being released varies among ports (Carlton et al. 1995; Smith et al. 1996). There are other pathways associated with maritime vessel activity that can be responsible for introductions.

Maritime vessel activity as a vector for marine NIS is a complex issue involving more than just ballast water. Ocean-going vessels can be thought of as biological islands for species that dwell in harbors and estuaries around the world. These vessels provide substrate for the settlement of species associated with fouling communities, protected recesses that can be occupied by both sessile and mobile fauna, and enclosed spaces that hold water in which everything from plankton to fish can become entrained. The pathways associated with ocean-going vessels are ballast water, ballast water sediments, and hull fouling.

II. THE SOUTH OAHU MARINE INVASIONS SHIPPING STUDY (SOMISS)

Hawaii is of special concern with respect to NIS introductions (marine and terrestrial) because tropical, insular systems may be more susceptible to invasion than continental systems (Vitousek et al., 1987). Information on the transport of marine NIS to Hawaii and around the tropical Pacific has been reported by Eldredge (1987, 1988, and 1994). Historical records of introductions and pathways have been reported by (Coles et al. 1999a). Recent surveys of harbor environments in Hawaii have detected marine NIS (Coles et al., 1997, Coles et al., 1999b, and Defelice & Godwin 1999). Two of these surveys (Coles et al., 1997 and Coles et al., 1999b) also included historical accounts of past marine NIS introductions with mention of some pathways. A survey of maritime shipping as a potential vector for introducing marine NIS to Hawaii would be a logical compliment to these studies. As mentioned previously, there have been many studies investigating maritime vessel activity as a vector for introducing marine NIS. However, no study of this kind has ever been conducted in the central Pacific other than a preliminary survey of Hawaii, which included the amounts of ballast water on board and source locations for six vessels (Carlton et al., 1995). A more complete survey of maritime activity in the main ports of Hawaii is needed to determine what potential exists for marine NIS introductions by this means.

The SOMISS project was therefore begun with the goal to broadly survey the maritime shipping industry in Hawaii by collection of biological and operational data that would relate to the issue of marine NIS invasion. The operational aspect identified what types of vessels use Hawaii as a port, what unloading/loading operations are being conducted, what ballasting/deballasting operations are being conducted and from what regions the vessels are arriving. Biological data for organisms being transported by vessels encompassed three vectors: ballast water, ballast water sediments, and hull fouling. The SOMISS project was supported by funds from the State of Hawaii Department of Land and Natural Resources, Division of Aquatic Resources and was conducted from February 1998 to December 1999.

III. VECTORS ASSOCIATED WITH MARITIME VESSELS

A. Ballast Water

From the early history of seafaring to the present, ocean-going vessels have needed ballast. All vessels before the middle of the 19th century used solid ballast in the form of sand, rocks, and other heavy materials. As ships became larger it became necessary to design ballast systems into vessels, in the form of dedicated tanks that could be filled with water. The need to use the aquatic environment for a transportation medium in the growing global economy has lead to the increases in vessel size and ballast water volume. This increased ballast water volume combined with faster ship speeds allows the uptake and survival of an increased number of organisms.

Why do vessels need ballast? Ballast is used to provide stability in the absence of, or in addition to, cargo weight. A ship displaces an amount of water that is equal to its own weight. The force of its weight (W) acts downward through its center of gravity (G) and is resisted by an equal buoyant force (W_B), which passes upward through the center of buoyancy (B) (see Figure 1). The point at which these vertical forces are acting is referred to as the metacenter (M). A vessel's initial stability is judged by the height of (M) above (G), so that the lower a vessel stays in the water the more stable it will be. Vessels that are light or empty of cargo will ride higher in the water and therefore be less stable. Ballast water provides this stability through decreasing the metacenter height and limiting the amount of loll side to side. Ships must be deep enough in the water to ensure safe operation during heavy weather. If the bow of a vessel is not submerged enough during heavy seas it will lead to the emergence of the forefoot (area under the bow) and heavy impact when the bow hits the water, which is referred to as slamming. Excessive slamming leads to structural stress and damage, but can be prevented by proper ballasting. The stern section must also remain submerged to a proper depth to allow for efficient propeller operations. Propellers that do not remain submerged at all times will experience periodic racing, or increases above the set revolutions per minute, which causes engine control problems and stress to the shafting and machinery. Ballast water can also create instability in a vessel because of a free surface effect caused by ballast tanks that are not completely full or slack. The free surface in slack tanks can throw off the center of gravity, or transverse stability, when the ship heels due to wind or wave action. Also, the slack ballast tank condition causes water to slosh around and slam into internal bulkheads, which is highly stressful to supporting structures. Ballasting operations can be complex and differ based on a variety of situations. Ballast water is taken aboard to achieve safe parameters related to differing conditions and operational needs. Ballasting is also used for adjustment of draft related to fuel consumption and port operation considerations.

Many situations exist where ballasting and deballasting operations are needed to adjust a vessel's draft when operating in port. Draft adjustment is required when making harbor approaches in channels of varying depth, passing under bridges, approaching under loading/unloading gantries, and adjusting to stresses on the hull during cargo operations. This final situation will be covered in more depth since it is the main reason vessels have to release ballast water, which in turn releases organisms that might be entrained in the ballast tanks.

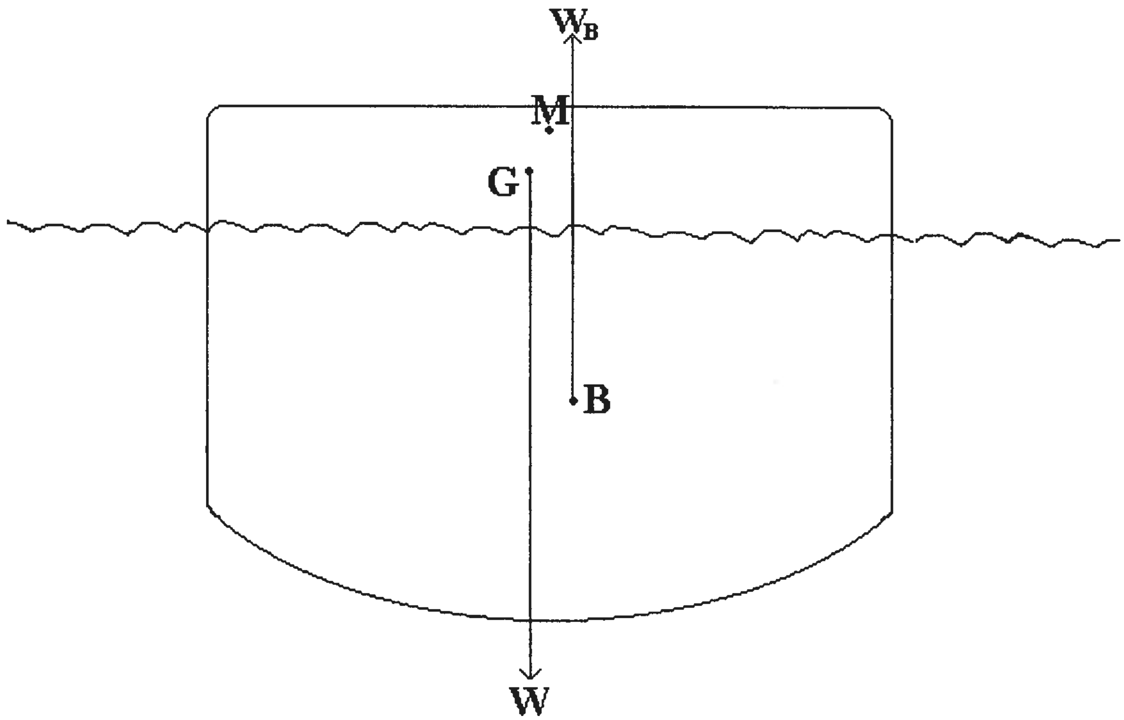


Figure 1. Weight and buoyancy forces acting on a vessel (based on National Research Council 1996)

A ship experiences stresses to the hull that are usually expressed in shear forces and bending moments during cargo loading and discharge operations. Proper ballasting counteracts these forces on the hull and prevents the situations of "hogging" and "sagging" caused by improper weight distribution during cargo loading. There are instances that occur due to less than ideal load/unload planning in which uneven weight distribution causes a rising at midships (hogging) and a flexing down at midships (sagging), both of which have negative impacts on structural integrity. When cargo is loaded, ballast water is released that either directly compensates for the weight or adjusts for the hull stresses, with the reverse operation during unloading. Once a vessel has completed cargo operations it will conduct further ballasting/deballasting operations that relate to drafts required for harbor egress, the sea conditions that will be encountered, and adjustment to bunkering (fueling) operations.

Ballast is taken aboard through piping systems that are connected to the ocean through the seachest. The seachest is a system of paired recesses that are below the water line and typically run along the keel (Figure 2).

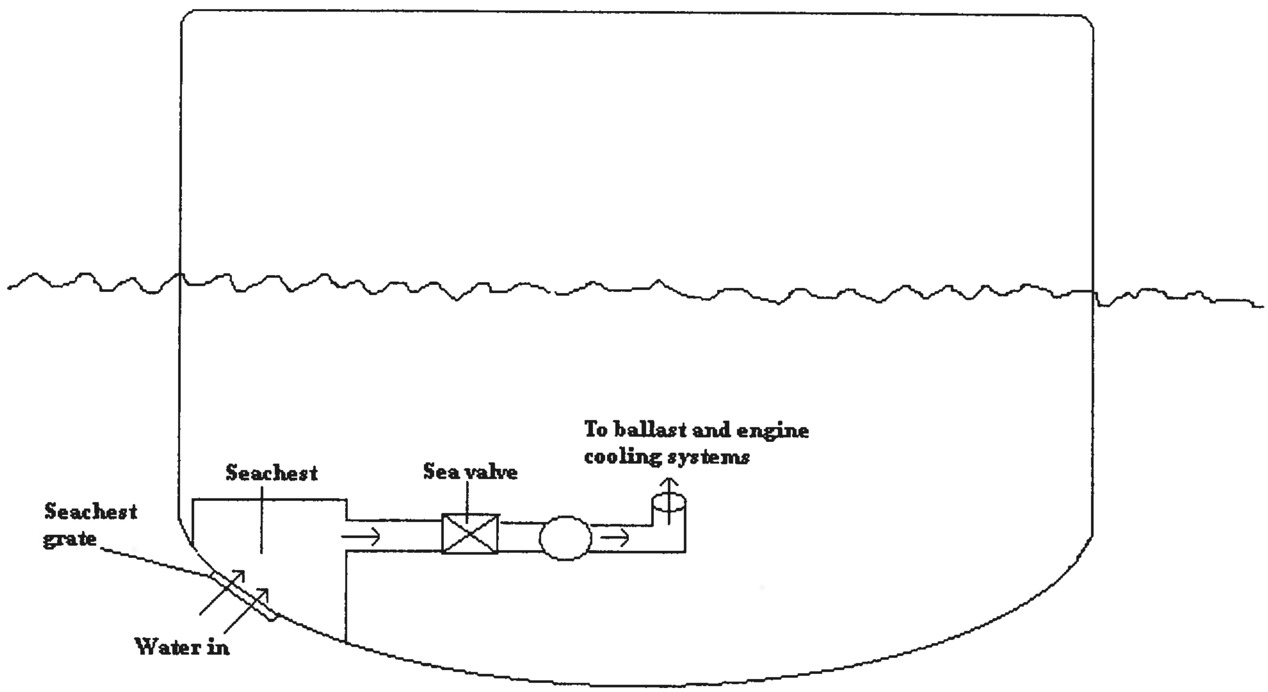


Figure 2. A seachest system located on one side of a vessel

The recess areas provide a "prime" for pumps that pull in water and distribute it through piping that serves the ballast system, the engine cooling apparatus, and the fire fighting hoses on deck. The seachest is covered with a grate with openings of 2-5 cm to prevent large objects from being pulled into the pumps. The same pumps are used for deballasting operations, with the water released through discharge valves located above the water line for some types of ballast tanks and below the water line for other types. Ballast water systems vary in design but are all based on ballast tanks arrayed in such a way as to provide the maximum stability.

There are many types of ballast tanks that carry differing volumes of water; the following ballast tanks are the most common and carry the majority of ballast water transported worldwide. Figures 3 through 6 show four common vessel types and the generic arrangement for ballast tanks that usually exists for each. Appendix B details the ballast tanks and total ballast water capacities that characterize these vessel types. All large commercial vessels have forepeak and afterpeak

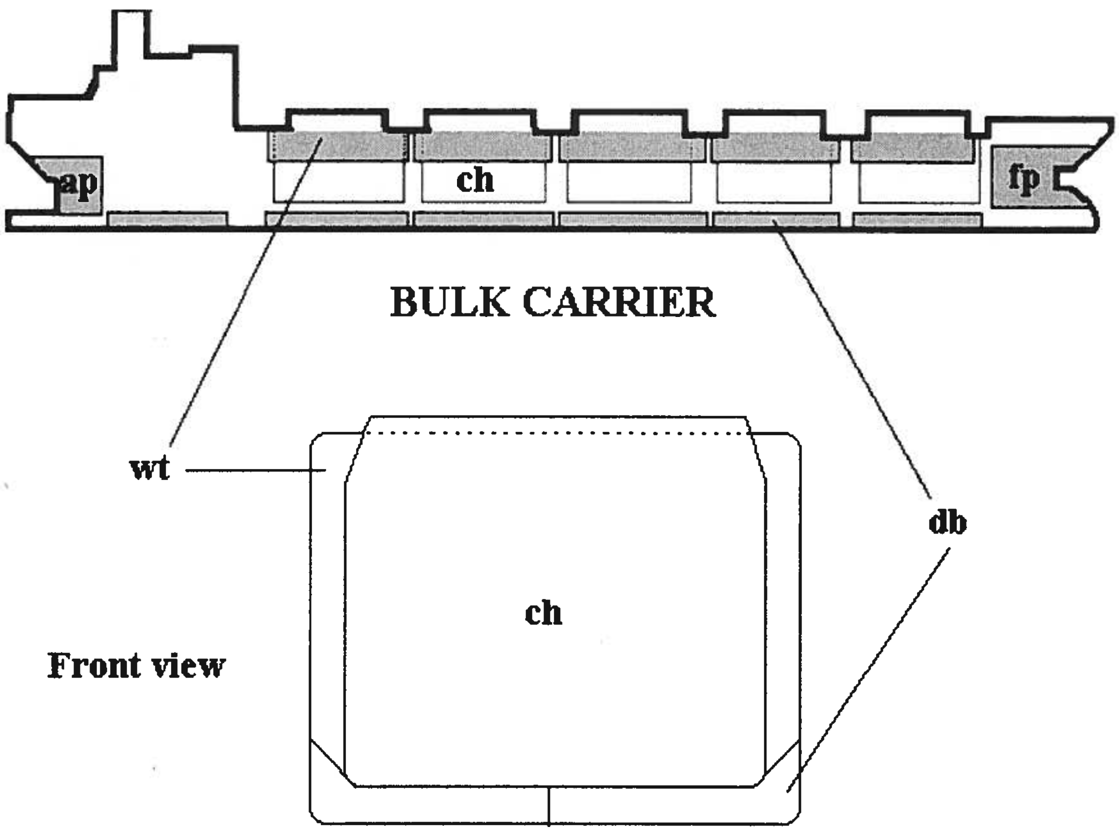


Figure 3. Diagram of a commercial bulk carrier (ch=cargo hold, wt=wing tank,db=double bottom tank, ap=afterpeak tank, fp=forepeak tank).

tanks to control trim at the bow and stern respectively, as well as a series of tanks that occupy varying arrangements between these two points. Liquid cargo tankers and domestic bulk carriers have a similar arrangement for ballast tanks, since cargo is carried along the centerline of both vessel types. These vessels have paired (i.e.; port and starboard) wing tanks that run between the stern and bow peak tanks. A wing tank begins at the upper deck and runs vertically down to just below the water line. In some cases, these types of vessels also have a series of double-bottom tanks that run along the keel below the termination of the wing tanks. Tankers and bulk carriers also have the ability to pump ballast water into cargo spaces to augment the existing ballast system during transits without cargo. Container vessels, in most cases, and roll-on roll-off vessel (car carriers)

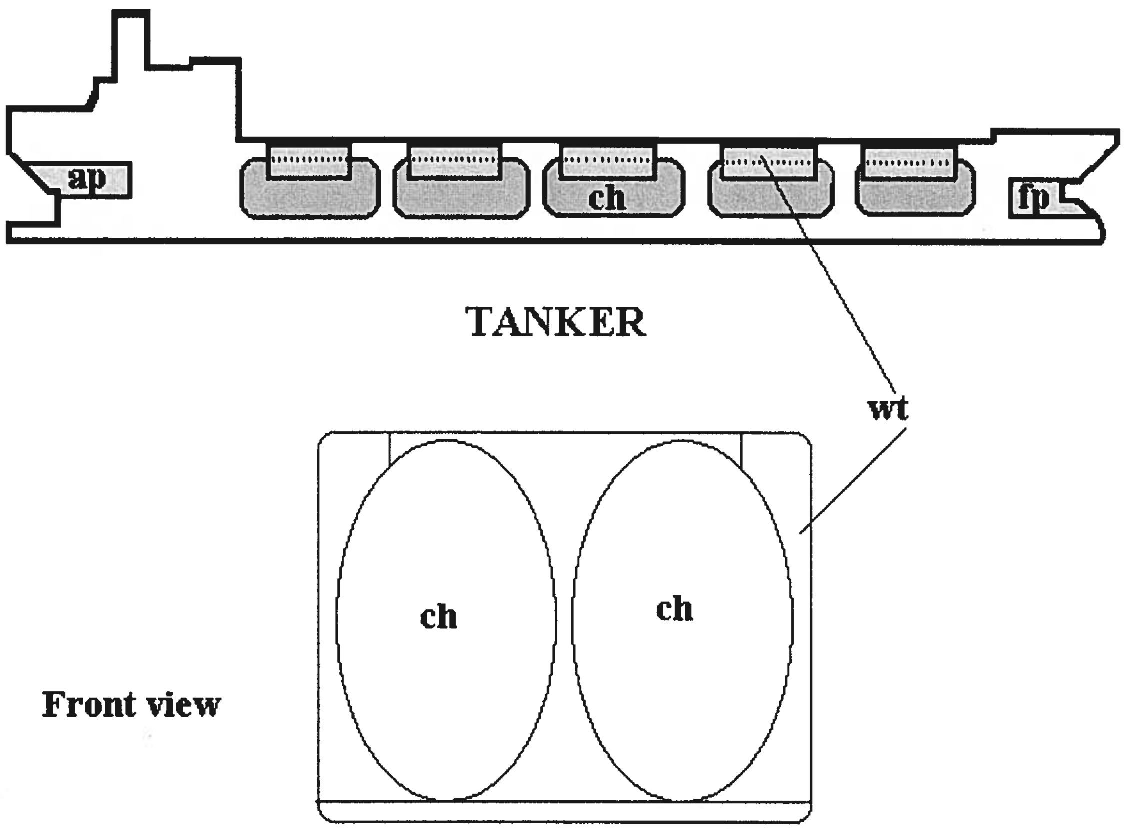


Figure 4. Diagram of liquid cargo tanker (ch=cargo hold, wt=wing tank ap=afterpeak tank, fp=forepeak tank)

only have afterpeak, forepeak, and double-bottom because of the design of cargo spaces. A fifth type of vessel is an open ocean cargo barge that is towed by tugboat. This class of barge generally has two sets of wing tanks and forepeak and afterpeak tanks (no diagram). All of the various tanks described for these different vessels have a 2-5cm diameter sounding pipe that begins on the upper decks and runs down to the tank so that water depth/volume can be physically measured with a sounding line in conjunction with gauges in the ballast control room. Physical access to the ballast water tanks is through deck covers that vary from 40cm to 1.5m in diameter and are secured by numerous bolts. The location of these deck covers is on the surface deck for wing tanks and far below deck for double-bottom and peak tanks. Access to deck covers on loaded container and

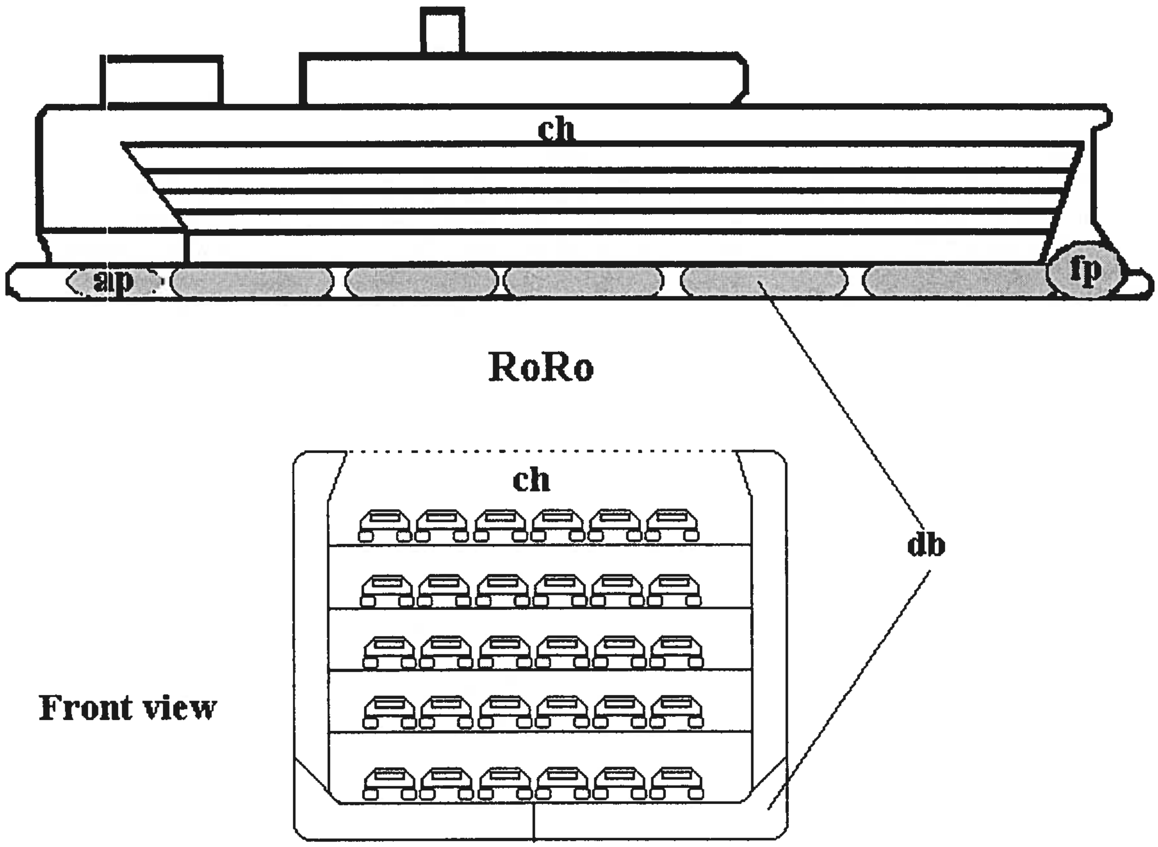


Figure 5. Diagram of a commercial roll-on roll-off (RoRo) vehicle carrier (ch=cargo hold, db=double bottom tank, ap=afterpeak tank, fp=forepeak tank).

roll-on roll-off (RoRo) vessels ranges from difficult to impossible due to the fact that the cargo is either physically on top of the plate or blocking the way. Wing tanks are generally accessible at all times through deck covers unless tanks are in a "pressed up" condition (i.e.; completely full), in which case ballast water must be released or pumped to another tank before opening hatches.

B. Ballast Sediments

Vessels generally ballast in coastal areas or ports that have a great deal of particulate matter suspended in the water column. This suspended matter is made up of organic and inorganic detritus and plankton. After ballast water is pumped into tanks particles begin to settle to the bottom and form a sediment layer. These layers can be up to 8cm thick (Godwin personal observation) and can

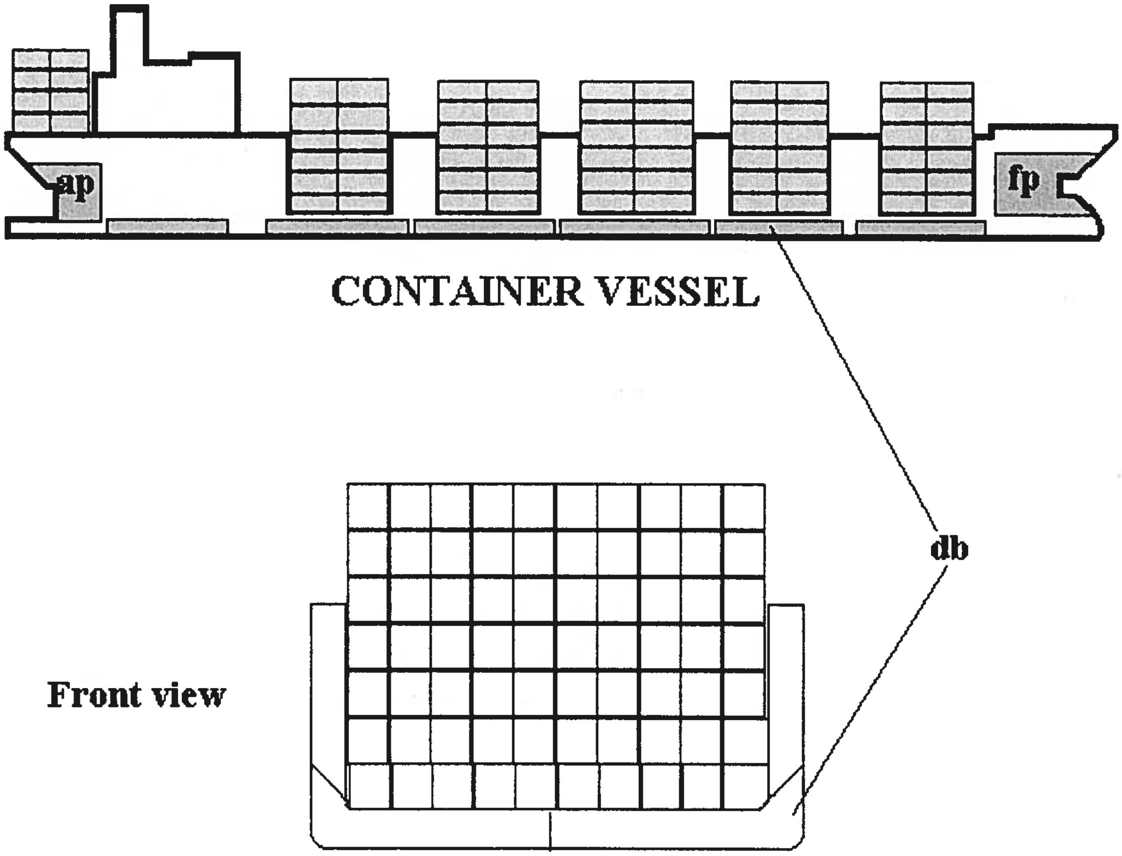


Figure 6. Diagram of a commercial containerized cargo carrier (ch=cargo hold, db=double bottom tank, ap=afterpeak tank, fp=forepeak tank).

provide a habitat for benthic fauna. A portion of the sediments can become re-suspended and discharged during ballasting and deballasting operations. Ballast tanks will always retain water and sediments in unpumpable sections of the tank until it is re-suspended by ballasting operations or movement of the vessel during transit. This material is removed from the tank periodically to prevent damage to pumps, and is undertaken by members of the crew during port visits and sea transits or by shipyard workers during service periods. In both cases the material can be either intentionally or unintentionally dumped overboard.

C. Ballast water and ballast water sediment research

There has been a great deal of research concerning ballast water as a major vector for marine NIS invasions and a few studies that examined ballast water sediments from this perspective. The following list highlights the major studies that have focused on ballast water and ballast water sediments as vectors for marine NIS (compiled by Cohen, 1998).

- **Medcof (1975)** – Plankton sampled from one Japanese vessel arriving at Australia in 1973
- **Williams et al.(1988)** – Plankton samples from 23 woodchip carriers arriving to Australia from Japan. Sediment samples from 9 woodchip carriers from Japan, also arriving to Australia.
- **Bio-Environmental Services (1981)** – Plankton samples from 46 vessels with ballast water form outside the northwest Atlantic, arriving to Montreal and the St. Lawrence River.
- **Carlton et al. (1982)** – Plankton sampled from a variety of vessels and routes arriving to ports in the North Atlantic.
- **Middleton (1982)** – Plankton identified form the ballast water of a domestic bulk carrier arriving to Australia.
- **Carlton & Geller (1993); Pierce et al. (1997)** – Plankton samples taken from 159 woodchip carriers arriving from Japan to Coos Bay, Oregon from 1986-1991.
- **Hallegraeff et al. (1990); Hallegraeff & Bolch (1992)** – Sediment sampled from the cargo holds of 31 Japanese woodchip carriers arriving to Tasmania from 1987-1993.
- **Locke et al. (1991, 1993); Subba Rao et al. (1994)** – Plankton samples from 86 ships arriving to the Great Lakes and the upper St. Lawrence River from overseas ports 1990-1991.
- **Kelly (1992, 1993)** – Plankton and sediment samples taken from 6 Japanese woodchip carriers in 1991 that arrived to the ports of Tacoma and Port Angeles in Washington state.
- **McCarthy & Khambaty (1994)** – Analysis of bacterial communities in the ballast water of 19 vessels arriving to Gulf of Mexico ports in the United States 1991-1992.
- **Smith et al. (1996)** – Plankton samples from 70 vessels as well as some analysis of sediments and fouling. Samples taken from vessels arriving to Chesapeake Bay 1993-1994.
- **Chu et al. (1997)** – Plankton samples from 5 vessels arriving to Hong Kong 1994-1995.
- **Macdonald (1995)** – Plankton sampled from 32 vessels and sediment from 24 others arriving to Scottish ports 1994-1995.
- **Wonham et al. (1996)** – Analysis of survival of ballast water organisms and the efficacy of ballast exchange on a vessel between the Mediterranean and the Chesapeake Bay 1995.
- **Hay et al. (1997)** – Plankton samples from 50 vessels arriving to ports in New Zealand 1995-1997.
- **Ruiz et al. (1997)** – Ballast samples taken from 16 oil tankers arriving to Valdez, Alaska 1996.
- **Galil & Hulsmann (1997)** – Sampling and culture of ballast water and sediments from 17 vessels in Israel 1996.
- **Gollasch et al. (in press)** – Analysis of ballast water organisms from 189 vessels. Sediments and surface fouling from some vessels. All samples taken from vessels at German ports 1992-1995.

Studies currently in progress (1998-present) – Currently studies are under way in Chesapeake Bay, Long Island Sound, North Carolina (Morehead City), California (Long Beach), Gulf of St. Lawrence, British Columbia, Sweden, and Wales.

D. Organisms associated with ballast water and ballast water sediments

Organisms that are associated with marine plankton communities can be pulled into the ballast tanks of vessels during ballasting operations. These organisms are characterized as holoplankton, meroplankton, and tychoplankton. The holoplankton are the species that live entirely in the water column their entire life. Holoplankton are further divided into the phytoplankton, which includes unicellular algae and various bacteria, and the zooplankton. This latter grouping includes small crustaceans, gelatinous species and a variety of other organisms. Meroplankton are the larval forms of marine species that use the water column to feed and disperse before becoming adult organisms. The larvae and eggs of crabs, barnacles, snails, clams, starfish, worms, fish and many other species are present in meroplankton and represent a large part of the biomass of plankton communities. Tychoplankton are species that normally live in bottom communities and become suspended in the water column temporarily. Additionally, adult organisms of animals such as fish and crabs can become entrained in ballast tanks by being in close proximity to seachest intakes or as attached organisms on debris.

Bacteria that have the potential for causing human health problems can also be found in ballast water. In the early 1990s shellfish beds in the southeastern United Sates along the Gulf of Mexico had to be closed because of the presence of cholera bacteria (*Vibrio cholerae)*. This occurrence of *Vibrio cholerae* was traced back to ballast water discharges from vessels arriving from South America. The strain present in the Gulf of Mexico was the same that triggered an epidemic in South America that caused 10,000 deaths. The vibrios are waterborne bacteria that cause cholera when humans ingest contaminated water or raw or poorly cooked seafood taken from contaminated areas. There are 139 serogroups of *Vibrio cholerae* but only two (01 and 0139) cause cholera of epidemic proportions. The association of cholera bacteria with ballast water Began to be realized more widely following the study of McCarthy & Khambaty (1994) in the Gulf of Mexico. Further research by Rawlings (1998 Unpublished data) has detected both 01 and 0139 serogroups in ballast water being discharged in the United States Mid-Atlantic ports of Baltimore and Norfolk in the Chesapeake Bay.

Ballast water sediments can harbor communities of adult organisms that result from the settlement of larvae and eggs from the meroplankton. These organisms can mature and become a source for new larvae that become suspended within the water column of the ballast tank. Another common component of the sediment is the resting stages of phytoplankton species such as dinoflagellates and diatoms. All of the above studies have recorded a variety of organisms in ballast, of which the meroplankton component would be considered as the vector responsible for the majority of the marine NIS introductions listed in Tables 3 and 4 of Appendix A, as well as others worldwide. The larvae of some of these organisms naturally remain in the water column for extended periods that are long enough to allow transport in ballast water. Only a few of the studies listed have dealt with ballast sediments. The most notable are the studies by Hallegraeff et al. (1990) and Hallegraeff & Bolch (1992) that demonstrated the presence of viable resting stages of phytoplankton species in ballast sediments. These studies connected the introduction of the toxic dinoflagellates that cause paralytic shellfish poisoning - *Gymnodinium catenatum* and *Alexandrium catenella* - in southern Australia to ballast water sediment. These sediments can also harbor bacterial communities that can flourish by deriving nutrients from the abundant organic matter settling out to the bottom of the ballast tank.

E. Hull Fouling

Ballast water is the pathway that has been the major focus of investigation as a marine invasion vector, and the biofouling that occurs on the surfaces of vessel hulls has been given less attention. Historically, wooden sailing ships provided an ideal surface to which marine fouling organisms could attach. Common fouling organisms on these vessels were the wood-boring shipworms (*Teredo*). The cosmopolitan range of this organism is thought to have resulted from worldwide spread by wooden vessels, especially as trade routes opened up between the Atlantic and the Pacific. Hull fouling has been dramatically reduced with the advent of steel hulls with anti-fouling coatings. The steps taken by modern commercial and military vessels to eliminate hull fouling are not completely effective though, and organisms are still being transported by this means. Research surveys documenting modern day hull fouling organisms have been conducted periodically since the 1920's, as follows :

- **Visscher (1928)** - survey of 250 commercial and military vessels during shipyard service on the Atlantic coast of North America.

- **Ohshima et al., (1940 and 1943)** - study of the fouling organisms on vessel hulls in Japan and their transport to other locations.
- **Edmondson (1944)** - a record of hull fouling species occurring in Pearl Harbor, Hawaii.
- **Woods Hole Oceanographic Institution (1952)** - study of hull fouling and its prevention for the U.S. Navy.
- **Allen (1953)** - analysis of introduced fouling organisms in Australia associated with hull fouling transport.
- **Skerman (1960)** - survey of 89 vessels in drydock arriving to New Zealand from regional and overseas destinations.
- **Huang et al., (1979)** - study of fouling organisms on vessel hulls in China and their transport to other locations.
- **Evans (1981)** - introduction of marine algae by hull fouling.
- **Callow (1986)** - survey of marine algae transported by hull fouling.
- **Bagaveeva (1988)** - study of polychaete worms in the hull fouling community of vessels arriving to Russian ports on the Sea of Japan.
- **Yan and Huang (1993)** - hull fouling sampled from five vessels arriving to Daya Bay, China
- **Ranier (1995)** - hull fouling samples from 8 vessels arriving to Tasmania.

F. Organisms associated with hull fouling

The organisms that generally foul vessel hulls are the typical species found in natural marine intertidal and subtidal fouling communities. The surveys listed above have reported typical invertebrate phyla associated with marine fouling communities such as arthropoda (barnacles, amphipods, and crabs), mollusca, porifera, bryozoa, coelenterata (hydroids and anemones), protozoa, annelida, and chordata (sea squirts and fish), as well as macroalgae. Fouling organisms tend to concentrate in sheltered areas of the hull such as seachest intakes and rudder posts, and develop in areas where anti-fouling coatings have been compromised. Anti-fouling coatings wear off along the bilge keel and weld seams, which makes the surfaces susceptible to settlement of fouling organisms. Two recent marine NIS introductions to Hawaii are directly attributed to hull fouling. The crab *Nanosesarma minutum* and the sponge *Mycale armata* both were likely introduced from the fouling community on the hull of a floating drydock towed to Hawaii in 1992 from the Philippines (Coles et al. 1997).

IV. ALTERNATIVES FOR CONTROLLING MARINE NIS INTRODUCTIONS FROM MARITIME VESSEL ACTIVITY

The potential for introduction of marine NIS by maritime vessel activity can be minimized by a variety of management and treatment options. The list in Table 1 is a compilation of strategies and treatment options to lessen the likelihood of the transport of bacteria, plankton, macroinvertebrates, and macroalgae through ballast water, ballast water sediment, and hull fouling. The following section covers the points listed in Table 1 in greater detail. The information is derived from multiple sources (Oemecke and van Leeuwen 1998a, 1998b, National Research Council 1996, and Carlton et al., 1995)

A. Ballast water

The concept of ballast water management focuses on the choice of location in which to conduct ballasting operations and what to do if water is from an inappropriate source. The use of the "Global Hot Spot" concept was set forth by the International Maritime Organization's Marine Environment Protection Committee Resolution 50(31) in 1991. Its purpose is as an advisory network to inform the international shipping community of regions where taking up ballast water and transporting it to other areas is not advised. Locations of outbreaks of infectious diseases or of waterborne organisms that have been identified as threats to human or environmental health would qualify as hotspots. This would include blooms of phytoplankton, such as dinoflagellates, which have caused human illnesses such as paralytic shellfish poisoning.

Performing ballast operations in areas of high sediment load and sewage discharge leads to the potential transport of organisms that can cause human health or ecological impacts. Sediments can contain the resting stages of dinoflagellate species that cause toxic algae blooms, which are readily transported in ballast water tanks (Hallegraeff and Bolch 1992), and sewage discharge contains bacteria with human health risks. Also, the input of excessive nutrients by sediment loads and sewage inputs can lead to localized blooms of various types of organisms, which creates a larger pool of organisms to potentially be drawn into ballast water tanks. The acknowledgment of these types of situations and practicing preventative measures is at the discretion of the individual vessel and are usually not reported at an international level.

Table 1. Methods to minimize transport of organisms associated with maritime vessels

<u>Ballast water</u>

A) Management

1. Do not ballast in "Global Hot Spots"

- Areas experiencing toxic algae blooms
- Areas with the occurrence of waterborne disease outbreaks

2. Do not ballast in areas of high sediment load

3. Do not ballast in areas in close proximity to sewage discharge.

4. Do not ballast at night

5. Exchange ballast water en route in open ocean water greater than or equal to 2000 meters in depth

B) Preventing intake of organisms into ballast tanks

1. Filtration

2. Ultra Violet treatment

3. Sonic treatment

4. Ozonation

5. Various combinations of each

C) Extermination of organisms in ballast tanks

1. Direct treatment with chemical biocides

2. Thermal treatment

3. Electrical treatment

<u>Ballast water sediments</u>

A) Management

1. Do not ballast in areas of high sediment load

2. Do not ballast in shallow locations where sediment will be pulled in from the bottom

B) Maintenance

1. Direct biocidal treatment of sediments

2. Cleaning tanks more frequently with proper disposal of sediments

<u>Hull fouling</u>

A) Maintenance

1. Regular under water video inspections

2. More frequent shipyard cleanings of hull

3. Time release biocides in seachest

If a vessel ballasts at night there is a potential for a greater abundance of organisms to be present. Certain benthic and epibenthic marine organisms rise up into the water column in the evening for the purpose of feeding and/or mating. Small crustaceans such as isopods, amphipods, cumaceans, tanaids, and mysids, as well as marine worms can be almost absent during the day and occur commonly at night. This phenomenon is called vertical migration, and it provides a much more diverse assemblage of organisms that can be pumped into a ballast system.

If a vessel has ballasted in a location that is problematic for any reason it can pump out that water and replace it with water that is not suspect. In the majority of cases, vessels will choose to exchange ballast in the open ocean far away from coastal areas. In comparison to coastal regions and harbors the open ocean is depauperate of planktonic organisms and the organisms that dwell there cannot survive in environments that exist closer to shore and in harbors. Vessels exchange ballast mostly by either of two methods-empty/refill or flow-through. The empty/refill method involves pumping out all the water of a ballast tank and completely refilling it to the previous level. This method can be dangerous while the vessel is underway because of the potential structural stresses associated with changing the trim characteristics. The flow-through method involves turning on the ballast water pumps and allowing a tank to overflow from the ballast tank vents for a time that equals two to three volumes of the ballast water tank. This method also has its problems because the vents overflow on the ship's deck, which creates a hazardous situation for crew. Tankers and bulk carriers can potentially contaminate cargo with saltwater that is flowing across the deck near cargo holds during the overflow procedure. Ballast water exchange is the only method internationally recognized by the maritime shipping industry for dealing with marine NIS transported in ballast water. Ballast water management guidelines proposed for vessels entering United States ports suggest open ocean exchange in water depths of 2000 meters or greater. This safely puts the vessel in water considered non-coastal.

Another approach is to prevent live organisms entering the ballast system. This involves physical or chemical methods that eliminate or kill organisms at the intake stage of ballasting operations. The only chemical method is ozonation. Ozone is a powerful oxidizer and biocide that is used for water sterilization. Before water reaches the ballast tank it passes through an ozone "contact zone" that essentially oxidizes all organisms in the water. Ozone has drawbacks because bromide reduction diminishes its effectiveness in salt water (Oemcke and van Leeuwen 1998a). Also, it is a greenhouse gas that has to be controlled within a closed system and then eliminated. Plankton vary in size from 2-3 mm to less than 20 μm but could be removed with an appropriate filtration system. Filtration of items in this size range requires filters that become clogged quickly and decrease water flow. However, filtration systems specifically designed for ballast systems have been tested in the Great Lakes of North America and have provided filtration without too great a loss of flow rate (USA Ballast Book 1998). Sonic treatment and ultra-violet radiation require a similar procedure as ozonation, in that the water comes into a "contact zone" influenced by the treatment before entry into a ballast tank. The sound waves and ultra-violet radiation kill the organisms by disrupting their tissues. The level of effectiveness of these procedures in high flow ballast water is debated and they may only be useful in conjunction with other methods such as filtration (R. Woolsey, Personal Communication). The setup and retrofitting of all these methods is costly but their inclusion into new vessel design could be a possibility.

Alternatively, organisms can be exterminated within the ballast tanks themselves. Addition of chemical biocides, such as chlorine, directly to ballast tanks can eliminate live organisms, but there can be many drawbacks. The amount of chemical needed to achieve a concentration that has biocidal properties would be immense because of the large volume of ballast systems. The chemicals would also have to be stored on the vessel, which has potential safety concerns, or they would have to be readily available in ports of call, some of which may be remote and not have the infrastructure to safely handle such items. Ballast tank coatings that slowly release biocidal agents are another option but would only be effective if water is retained for long periods or only used in small volume ballast water tanks. Discharge of these biocides would be prohibited in most regions, so the use of a neutralizing agent would be necessary to make the operation environmentally compliant. These problems have made currently available biocides uneconomical and inappropriate. Further research with different chemical types and administration methods is needed before this will be a viable option. Non-chemical methods for on-board treatment of ballast water are also available The use of heat to kill organisms in ballast tanks has been studied in New Zealand (The Royal Society of New Zealand, 1995). The main engine of a large vessel produces large quantities of heat and is cooled by a heat transfer system using ocean water. This water is continually pumped through the heat exchange system while the vessel is underway. The idea is to redirect this heated water through the ballast system in a flow-through operation. Obviously this can only be done when the vessel is underway since the engines are not being run while the ship is pierside. If this method can raise water temperature in the ballast system to the lethal zones for both vegetative and encysted stages of phytoplankton, zooplankton, and macrofauna it could be successful. Further study is required to determine whether enough heat can be produced to treat large volume ballast systems. The use of electrical current to treat ballast water on-board a vessel may be a possibility. Electrical current is used to sterilize water in poultry plants and has been proposed as a measure to use in ballast tanks. The efficiency of this method is presently being tested in the Gulf of Mexico (Mississippi/Alabama Sea Grant, personal communication).

B. Ballast water sediment

The measures taken to minimize the transport of organisms by ballast water sediments are similar to the steps taken for ballast water. If an area has a potential for uptake of abnormally high levels of sediment, it should be avoided as a ballasting site. Addition of large quantities of sediment to a ballast system is generally avoided because the potential damage to pumps and to minimize the number of times tanks have to be cleaned between shipyard service periods. Guidelines exist for disposal of this sediment (IMO, 1998) and state that it should be disposed of in land-based facilities or in open ocean environments.

C. Hull fouling

Of all the vectors associated with maritime vessels, hull fouling is the most problematic to control and monitor. Modern anti-fouling coatings prevent a great deal of fouling and maintenance of these coatings is the best preventative measure for transport of organisms by this means. Increasing the frequency of shipyard service to hulls is the optimal way to maintain the integrity of hull coatings, but would be prohibitively costly to the vessel owners, and hence an unrealistic option. Hull fouling occurs in areas where the anti-fouling coating has been compromised due to physical damage, but it occurs more frequently in sheltered areas such as the seachest. Fouling that occurs in accessible regions of the hull can be spot cleaned by commercial divers, but the seachest can only be accessed during drydock service in a shipyard. This seachest fouling can spread and clog or restrict flow through the piping that supplies water for engine cooling, fire fighting, as well as the ballast water system. As a control measure, the United States Navy has tried the placement of slow-release biocide devices in the seachests of some vessels (Godwin, personal observation).

Efforts to identify vessels with high potential for hull fouling introductions could be taken by port authorities. Vessels that have a high incidence of hull fouling are barges, floating drydocks and vessels from decommission yards. Towed cargo barges are used by many companies to cheaply carry small quantities of bulk and general cargo. Floating drydocks are generally surplus military platforms that have been purchased by private shipyards to supplement land-based drydock facilities. Vessels from military decommission yards are purchased to be used as war monuments, scrap metal, and as hardware for the navies of developing nations. The cargo barges tend to spend more time in port and move at slow speeds when being towed, which creates a situation more conducive to settlement and establishment of fouling organisms. Cargo barges are maintained in the same way as other commercial vessels, in respect to hull maintenance. This is not the case for vessels from decommission yards, which have been idle for many years and poorly maintained. These vessels and cargo barges are the extreme cases for hull fouling and should be targeted by port authorities as high risk vessels for marine NIS introductions. Requiring hull maintenance records for the vessels and denying port entry to those vessels deemed high risk based on these records would be one approach. Another method could be to provide quarantine areas in water greater than 2000 meters in which remote video inspections could be done on the hull of vessels unable to produce recent maintenance records. All ports need to create policies concerning hull fouling introductions that will educate the maritime shipping industry and provide vessel owners clear guidelines to follow. The port could create an infrastructure that assists in development of hull monitoring programs with commercial divers and remotely operated video inspection equipment. Awareness of this issue by the industry and port officials is the best method for prevention.

V. LEGISLATION CONCERNING MARINE NIS NATIONALLY AND IN HAWAII

The state of Hawaii is heavily impacted by NIS in the terrestrial environment. Hawaii has a unique indigenous terrestrial biota, as a result of its remote location, topography and climate. Many of its species are already lost because of predation or competition with NIS and because of habitat disturbance, and at least one half of the species in the wild in Hawaii are NIS (Office of Technology Assessment 1993). The battle to control NIS in Hawaii has primarily focused on terrestrial plants and animals; there is little regulation dealing with marine NIS. Hawaii has a history of concern about NIS. Policy PI-8 was adopted by the Territory of Hawaii in 1955 and required that organisms be introduced into Hawaii only with the permission of the Territorial Board of Agriculture and the U.S. Fish and Wildlife Service. This policy created a list of allowable organisms and created subcommittees consisting of academic, federal and state representatives that specifically handled land vertebrates, invertebrates, insects, plants, and aquatic biota. After statehood, Policy PI-8 became State Law Chapter 150A and basically did not change, except for amendments to the species lists. In 1991, Chapter 150A was modified and approved by Act 104 and was implemented by Hawaii Administration Rules, Chapter 4-71, which delegates authority to the State of Hawaii Department of Agriculture (DOA). The DOA authority applies to introductions of NIS in all environments and it includes inspections of containers entering the state and destruction of organisms. In the area of marine species, efforts are directed at requests to import organisms for the aquarium trade, aquaculture and other planned uses, and confiscation and destruction of organisms imported without permits. House Bill 1965, relating to harmful aquatic life, was put forth in the State Senate in 1998, which would have made marine NIS the responsibility of the State of Hawaii Department of Land and Natural Resources, and would have established an alien aquatic organism task force; the bill did not pass.

Federal responsibilities for marine NIS in Hawaii lie with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service. These responsibilities are defined by the Lacey Act, which only applies if dealing with interstate commerce or international imports. The Injurious Species Act and the Endangered Species Act could also provide authority dealing with marine NIS issues in Hawaii. In 1990, the Nonindigenous Aquatic Nuisance Prevention and Control Act, PL. 101-646 was created, which legislated ballast water activities in the Great Lakes region. This was amended in 1996 as the National Invasive Species Act, PL. 104-332, which expanded legislation concerning ballast water to cover all ports in the United States. In 1999, Presidential Executive Order 13112 concerning NIS introduction was signed and is designed to assess and reduce invasive exotic species impacts. Presently, under the authority of the National Invasive Species Act, the Unites States Coast Guard has imposed voluntary guidelines for ballast water management practices, as well as implemented mandatory ballast water reporting procedures beginning July 1, 1999 for all vessels entering ports in the United States.

VI. METHODOLOGY

A. Operational component

The initial stage of the SOMISS project sought to characterize the commercial maritime vessel activity in Hawaii. This was done through meetings with State of Hawaii Department of Transportation, Harbors Division, which controls the harbors, and the private sector representatives of companies that act as shipping agents for vessels using port facilities. Within the Harbors Division there is an overall head and a harbor master for each major commercial port. A group of major companies act as shipping agents for all arriving vessels. These agents act as liaison between vessels and the port authority, and private sector groups that provide essential services to vessels, such as fuel, food, and maintenance. The involvement and cooperation of the port authority and the private sector were essential for conducting the SOMISS project.

The first contact was made with the Harbors Division to obtain permission to conduct the SOMISS project and to secure points of contact essential to accomplishing the study, such as state harbor masters and shipping agents from all the companies represented in the port community. Once this information was obtained, a series of meetings took place with these points of contact to obtain the preliminary information required to begin characterizing the dynamics of port operations.

Data sought from this process

A far more accurate understanding of the marine NIS vectors associated with the maritime shipping industry in Hawaii was possible once port-specific and vessel-specific information was obtained. These data included aspects such as:

1. Characterization of the net import/export profile of the port system.
- The import/export profile of a port system is an indicator of how much ballast water is being transported into a port. A net export situation would mean cargo going out and greater ballast water quantities coming in and vice versa.
2. What types of cargo operations exist, in what port locations are they conducted and to what level are they conducted?
- Certain cargo operations require more deballasting/ballasting operations, such as the loading of bulk commodities (i.e.; coal, grain, sand). More focus has to be placed on port areas that conduct such cargo operations
3. What types of vessels make port calls and from what regions do they originate?

- The potential for ballast water, ballast water sediments, and hull fouling acting as pathways for marine NIS introductions varies among vessel types. The last port of call and/or last region of operation determine the source of the organisms associated with a vessel.

4. Daily vessel arrival schedules for the period during the study (March 1998-December 1999) and previous years.

- Tracking the arrival of vessels was needed to identify vessels to be boarded. Data from previous years (1997 through 1998) provided insight into seasonal or regional trends for vessel arrivals. Arrivals were categorized by last port of call region based on the United Nations Food and Agricultural Organization classification system (Appendix C)

5. Vessel-specific information obtained from on – board interviews.

- Information obtained from officers and crew provided specific information about ballast water and cargo operations that was used to create a profile of all commercial vessels that make port calls in Hawaii.

B. Biological Component

The operational component provides information about commercial vessel activity in Hawaii, which allowed vessels to be targeted for biological sampling. The procedures for collecting data pertaining to ballast water, ballast water sediments, and hull fouling are now described:

Ballast water

In Section II.D the organisms usually associated with ballast are briefly described. The goal of the ballast water sampling program was to characterize the plankton communities present in vessels arriving in Hawaii and to test for the presence of *Vibrio cholerae* bacteria in a selected cross-section of those vessels.

Sampling:

The difficulties in sampling ballast water were mentioned in section II.A, which also gives detailed information about the types of access to ballast tanks: deck hatches and sounding pipes. Each access type required a different sampling strategy. Physical parameters of the water in the ballast tank were measured before any samples of organisms were taken. Samples from the bottom and top of the water column were taken with a Niskin bottle and physical parameters were measured. Salinity was measured with an optical refractometer and the temperature was taken with a hand held field thermometer.

A plankton net with 80 µm mesh and a 30 cm opening was used to sample organisms from the ballast tank when access could be gained through a deck hatch. The depth of the tank was measured and the plankton net was lowered to the bottom and pulled vertically through the water column. One ballast tank per vessel was sampled with the plankton tow method and two tows were performed, unless samples for bacteria were being taken (see below). Once samples were taken they were stored in an aerated cooler for transport to the laboratory.

In the case of container ships and roll-on roll-off vessels, the deck hatch accesses were normally blocked by cargo. In these instances, a 11/2 horsepower electric pump with a 25 millimeter suction hose was used to sample ballast water through the sounding pipe. Tanks had to be greater than half full for the pump to successfully pull water up through the sounding pipe. When pumping was successful a total volume of 95 liters was filtered through 80 µm and 25 µm sieves and stored in an aerated cooler for transport to the laboratory.

Certain vessels were targeted to test for the presence of *Vibrio cholerae* bacteria. These vessels were targeted because they came from regions likely to have *Vibrio cholerae* in their coastal waters (e.g. China and Indonesia). Two extra plankton tows and two 1 liter water samples (whole water samples) were taken for testing.

Analysis:

Plankton tow samples were immediately analyzed live on return to the laboratory. Samples were filtered through an 80 µm sieve and washed into bowls with water from the ballast sample. Each sample was examined with a 10-40x dissecting microscope for a qualitative assessment of the condition of organisms, the diversity of species present, and the abundance of certain taxonomic groups. Each morphologically distinct taxonomic group was noted on a standardized data sheet (Appendix D), and its abundance estimated, as follows. A species or morphotype was considered rare (1-10 /sample), common (10-100/sample), or abundant (>100/sample). Whether organisms were live or dead was recorded during the enumeration process and once the process was complete the whole sample was fixed in 10 % formalin. After two weeks in 10 % formalin the samples were transferred into 75 % ethanol for long term storage. Quantitative counts were then performed on the preserved samples by standard procedures involving sample splitting with a Folsom plankton splitter. These numbers were combined with the calculated tow volume and volume of water in the ballast tank to acquire a species density.

Plankton tow samples taken for the purpose of assaying for *Vibrio cholerae* were also sieved through an 80 μm sieve and put directly in 2 % formalin for later bacterial assay. The two 1 liter whole water samples were filtered separately through a 0.1 μm sieve with vacuum filtration and the entire filter was put in 2 % formalin. Both plankton and whole water samples were analyzed for *Vibrio cholerae* 01 and 0139 at the Smithsonian Environmental Research Center, Edgewater, Maryland. Plankton tows permitted detection of *Vibrio cholerae* cells associated with the surfaces of planktonic organisms, and the two 1 liter whole water samples determined the abundance in the water column. The analysis was done with the use of a direct fluorescent monoclonal antibody (DFA) staining technique used to detect the 01 and 0139 serogroups in water (Chowdhury et al., 1995).

Ballast sediments

Ballast sediments were assayed for infaunal invertebrate communities, but the main focus was detecting resting stage phytoplankton such as diatoms and dinoflagellates. Coarse differential sieving of the sediments was used to separate the infaunal invertebrates, and fine mesh sieves were used to retain phytoplankton.

Sampling:

Samples of the sediments that collect at the bottom of ballast tanks can be difficult to obtain. Ladders that descend from the deck hatch down the tank wall are used to access the bottom of ballast tanks. Ballast tanks are dangerous environments with potentially high levels of carbon monoxide and must be tested by a member of the crew to determine if entry is possible. If the environment within the tank is unsafe it must be vented for 24 hours and tested again. In most cases, vessel officers do not allow anyone other than crew into the ballast tanks because of liability issues. If permission is granted to enter a tank or if a crew member volunteers, a minimum of 500 ml of sediment is taken for analysis. While inside the tank a visual inspection for signs of macrofauna such as gastropods and crustacea is also performed. All samples were returned to the lab and refrigerated until the analysis.

Analysis:

Sediment samples were washed through a progression of 100 µm, 80 µm, 45 µm, and 25 µm sieves with filtered and autoclaved sea water, and all matter retained was then rinsed into separate finger bowls. The 100 µm, 80 µm, and 45 µm samples were analyzed for infaunal invertebrates under a dissecting microscope, and ten random samples taken with a pipette from the 25µm sample were analyzed under a compound microscope. The purpose of the 100 µm, 80 µm and 45 µm samples was to look for invertebrates, and an attempt was made with the 25 µm to detect resting stages of dinoflagellates and other phytoplankton. Once this analysis was finished the 25 µm sample and any sediment that passed through the 25 µm sieve was split into equal aliquots and put into 10-20, 20 ml culture tubes. The sediment was cultured in Guillard's f/2 media with silicate in an attempt to excyst any resting stage phytoplankton. Cultures were held at a temperature of 25 °C, which combined with 39 ppt sea water, mimicked local harbor conditions as closely as possible. The sediment cultures were kept on a phytoplankton growth table and agitated once a week. If signs of phytoplankton growth appeared, a 1 ml sample was removed under a transfer hood and examined with a compound microscope. If phytoplankton was present, an additional 5 ml was taken and was transferred to additional culture tubes in an attempt to grow a pure culture. This process was repeated weekly until the end of the three month culture period. At the end of three months, samples were analyzed one last time and then disposed of in 20 % bleach solution. All organisms were recorded on a standardized data sheet (Appendix D).

Hull fouling

Surveys for adult invertebrates that were part of the hull fouling communities were done to determine to what extent marine NIS species are being transported in this fashion. The focus was to perform a qualitative analysis that created a list of species recorded.

Sampling:

Sampling organisms from the hull of a ship is easiest and most efficient while the vessel is drydocked. At present, Hawaii has no shipyard facilities capable of handling large commercial vessels, so hull surveys were done with SCUBA. Because of liability issues, no company would give permission for hull fouling surveys on large commercial vessels but permission was granted to survey the hulls of towed vessels such as barges and drydocks. Two divers, swimming from bow to stern on the port and starboard side, conducted the hull fouling surveys. The surveys involved qualitative sampling of each type of organism seen during the dive with the use of scrapers and chisels.

Analysis:

All samples were analyzed live upon return to the laboratory to determine if organisms were live or dead, and each taxonomic group was recorded on a standardized data sheet (Appendix D). Hard-shelled organisms were preserved in 75 % ethanol, tunicates and cnidarians were relaxed and fixed in 10 % formalin then preserved in 75 % ethanol, and macroalgae were preserved in 2 % formalin. Organisms were then identified at a later date.

C. **Summary of typical field data gathering scenario:**

1) Vessel tracking: Weekly schedules for arriving vessels were consulted and vessels of different classes and origins were chosen. The shipping agent handling a particular vessel was contacted for up-to-date arrival schedules and permission to board the vessel upon arrival was obtained.
2) Vessel particulars and ballast water information: Vessels were boarded and the Chief Officer was interviewed to collect information concerning the ballast water capacity, volume of ballast water on board, source region(s) for ballast water, what ballast water operations were to be conducted in port, ballast water operations before entry into port, last port of call, next port of call, and access to ballast water tanks. All of this information was recorded on a standardized data sheet (Appendix D). If there was ballast water on board and ballast water tanks were accessible, the tanks were opened and sampled. If there were empty ballast tanks, a request was made to enter a tank to collect sediment samples.
3) Physical parameters of ballast water: Once ballast water tanks were opened the water depth was recorded, water samples from the surface and bottom were taken, and temperature and salinity were measured
4) Biological samples of ballast water: Plankton samples were collected by pulling a plankton net vertically through the water column.
5) Additional observations and samples: After ballast water samples were collected, the surface waters were examined for large mobile organisms (e.g., fish) and the tank sides were examined for fouling organisms. If any of these were present, an attempt was made to collect them. If

permission was granted, sediment samples were collected from empty ballast tanks. If the sampling event involved a towed barge or drydock, hull fouling surveys were conducted the following day.

6) Physical parameters of port water: Once the vessel boarding procedure is complete the physical parameters for the port water were measured. Temperature and salinity were measured at the surface and 10 meters depth in the same manner for previous shipboard samples.
7) Data entry: Once qualitative and quantitative analysis of biological samples was complete, these data, as well as the corresponding boarding data were entered into a standardized spreadsheet.

VII. RESULTS

A. Operational component

Contact was made with representatives of the State of Hawaii Department of Transportation, Harbors Division, and shipping agents from the companies handling the majority of maritime vessel traffic. These were iterative meetings scheduled throughout the period from March 1998 to August 1998. Each meeting covered standard questions and individuals were allowed to expand and add information during the whole process. The representatives from the Harbors Division were asked general questions about the port system, vessel traffic patterns and cargo operations, and were requested to outline locations where all operations take place in the port system of the state. Shipping agency representatives provided specific data about the vessels handled by their organization, and worked out strategies for vessel tracking and boarding.

Port Characteristics

Hawaii is an important transportation hub and serves as a crossroads for maritime vessel traffic operating in the Pacific Basin. The Hawaii port system consists of seven deep-draft and two medium-draft harbors located on five islands throughout the state. Oahu maintains two deep draft commercial harbors, (Honolulu Harbor, Barber's Point Harbor), and a medium draft harbor (Kewalo Basin). Honolulu Harbor is the primary port of the state of Hawaii, Kewalo Basin is located east of Honolulu Harbor and handles sightseeing, charter and commercial fishing, and small cruise vessels, and Barber's Point Harbor located 19 nautical miles west along the southwest shore handles bulk cargo. The remaining deep draft harbors in Hawaii are: Hilo Harbor and Kawaihae Harbor on the island of Hawaii, Kahului on Maui, and Port Allen and Nawiliwili Harbor on Kauai. The second medium draft harbor is located at Kaunakakai on the island of Molokai. Additional facilities include the United States military base at Pearl Harbor, 6 nautical miles west of Honolulu Harbor, which is closed to commercial vessel traffic, and a system of offshore mooring berths at the west end of Mamala Bay that are the site of considerable bunkering and repair operations conducted by local companies.

Oahu is the hub of the commercial harbor system in the state of Hawaii. All overseas waterborne traffic, with only a few exceptions, enters and departs Honolulu Harbor and Barber's Point Harbor. Cargo destined for the all other main island ports arrives at Honolulu Harbor first and is then shipped to the receiving destinations. Hawaii is a net importer of consumer goods and other commodities, and 98 percent of this enters through Honolulu Harbor and Barber's Point Harbor (Harbors Division, personal communication, 1998).

Cargo Operations

Hawaii is considered the "Crossroads of the Pacific" and receives a variety of cargo for import and trans-shipment to other destinations. Cargo ships unload and load commodities such as basic consumer food items, household goods, automobiles and industrial equipment, and bulk cargo.

The majority of consumer goods shipped to Hawaii arrive as containerized cargo. Honolulu Harbor is among the 10 largest container handling ports in the U.S (Port Hawaii Handbook 1993), and most of the overseas containerized cargo is handled at facilities on Sand Island and Pier One. Tugboats move containerized goods to other ports in the state, and to overseas destinations aboard ocean-going barges. These barges sustain a steady flow of goods to the other main islands of Hawaii and provide service to regional destinations in the Marshall and Mariana Islands. Honolulu Harbor is also a trans-shipment hub for containerized cargo between the principle ports of Asia, Australia, New Zealand, various Pacific islands and the mainland United States, and Mexico.

Hawaii is reliant on bulk cargo shipments to supply coal, petroleum products, and provide clinker (concrete aggregate). Bulk cargo shipments such as coal and clinker mostly arrive to Barber's Point Harbor and a small amount of refined petroleum products arrive to Honolulu Harbor. Unrefined petroleum products off-loaded at a single-point mooring facility located roughly 1 nautical mile offshore from Barber's Point Harbor and processed. The single-point mooring is needed because Hawaii has no shore facilities to handle cargo discharge from large crude oil tankers. Hawaii is a net importer of bulk commodities but does have an export trade in scrap metal to Asia and refined petroleum products to Asia and the Central and South Pacific. Interisland transport of coal, petroleum products, clinker, and sand is also based at Barber's Point Harbor.

There are other commodities (automobiles, industrial equipment, boats, construction materials, general cargo) handled by the port system. These items all arrive to Honolulu Harbor or Barber's Point Harbor and are shipped to final destinations locally or regionally. Finally, the cruise ship industry and its cargo of visitors constitute a small fraction in overall vessel arrivals but represent an important source of income to the state. Also, cruise ships are the only overseas vessels that do not make exclusive port call in Honolulu Harbor. Cruise ships arrive from destinations all over the Pacific and usually make port call at all the deep draft harbors in the commercial port system.

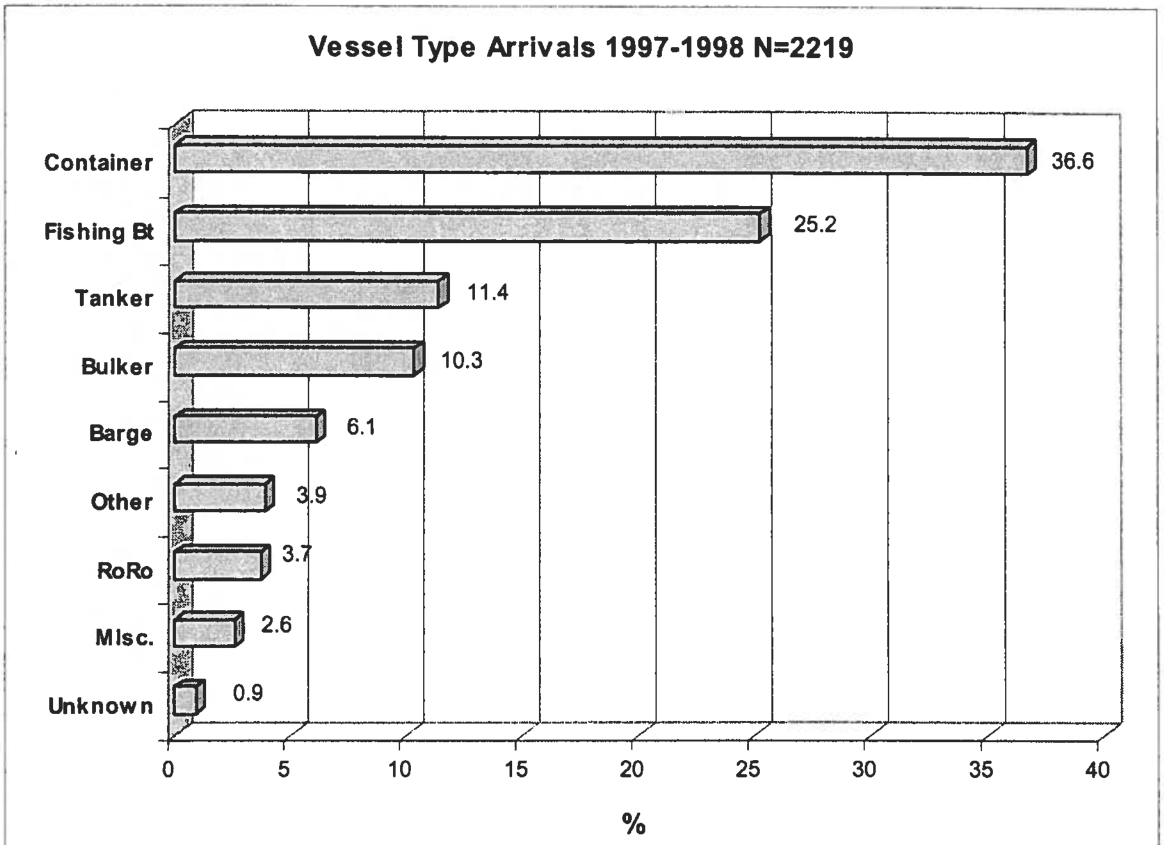
Type of Vessels, Arrival Patterns and Operations

The type of vessels arriving to a port dictates the cargo operations that predominate. Hawaii has a port system that is geared to handle a variety of import and export operations. Since the state is a net importer of goods, the majority of vessels are arriving loaded with cargo to discharge, and a smaller percentage are arriving to load cargo. A large component of vessels arriving to Hawaii use the Mamala Bay anchorage for bunkering (re-fueling) and temporary mooring, and do not come into port.

Honolulu Harbor and Barber's Point Harbor are the hubs of activity for the commercial port system of Hawaii. A profile of the dynamics of the port system was created and was based on vessel arrival data for these two ports. Data for overseas traffic for 1997 and 1998 was obtained from archived records provided by the State of Hawaii Department of Transportation, Harbors Division.

Figure 7 shows the breakdown of vessel types arriving to Honolulu Harbor and Barber's Point Harbor for 1997 and 1998. Based on the percentage of overall arrivals, the primary vessels were container, tanker, RoRo, bulker, barge, and fishing boats. The category "other" includes general cargo, refrigeration, and dredge vessels and "miscellaneous" comprises tugs, cruise ships, yachts, and government vessels (e.g.; Coast Guard, NOAA, and DoD). Unknown vessels included those that could not be identified from the data. The regions of origin for vessel traffic are also shown in Figure 7, and are based on the United Nations Food and Agricultural Organization (FAO) classification of the waters of the world (Appendix C). If a vessel was recorded as arriving from the open ocean, the region is recorded as OO.

The predominance of certain types of traffic led to focus being placed on these particular vessels, and the FAO regions from which they originated. Focus was placed on container, RoRo, tanker, bulk, and barge vessels, and is illustrated in Figures 8 through 10. Fishing boats were omitted from all results other than overall arrival patterns because of reasons explained later in the report. Tankers, container vessels, bulk carriers, RoRos, and barges were designated the primary vessels for the remainder of the SOMISS project.



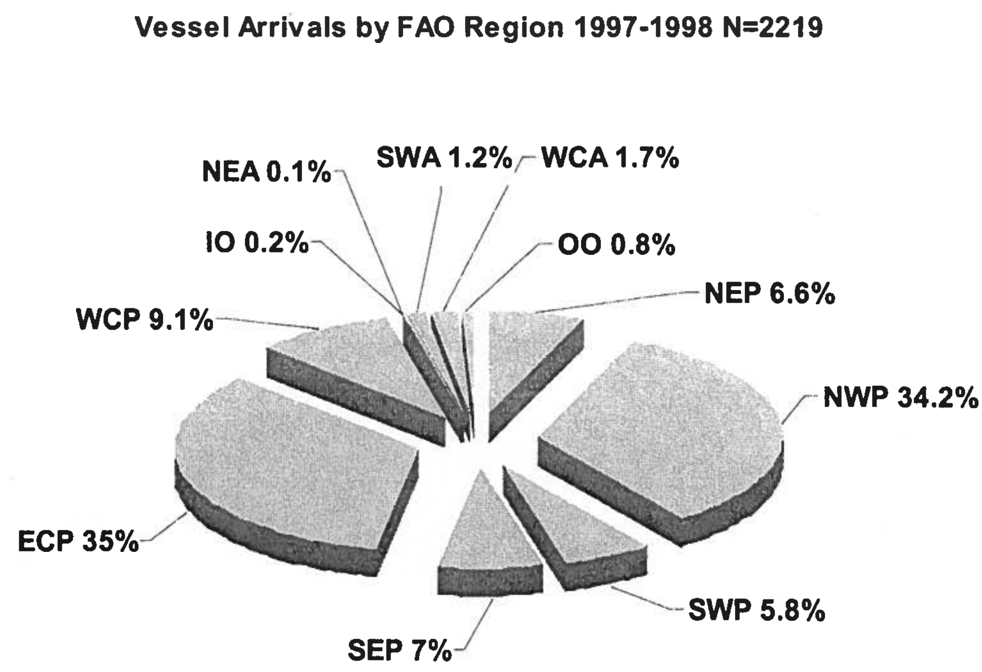


Figure 7. Vessel Arrivals for Oahu 1997-1998.

Figures 8 through 10 show all the FAO regions from which primary vessels originated during the 1997 through 1998 period. The FAO regions of origin that were most common for each vessel type were as follows:

- Tankers : NEP-17.86%, SWP-19.05%, NWP-23.81%, WCP-23.81%
The majority of tanker traffic was represented by offshore arrivals from Alaska (NEP) and Indonesia (WCP) that were discharging petroleum products at the offshore mooring. The remainder were conducting loading and discharge operations at Honolulu Harbor and Barber's Point Harbor, and originated from Japan (NWP), Tahiti (SWP), and American Samoa (SWP).

- Container: ECP-80.81%
Bi-weekly container vessel arrivals from California represented the bulk of this percentage and created and uneven distribution that masked the less frequent arrivals from Japan (NWP-6.64%), New Zealand, and Australia (SWP-7.01%).

- Bulk carriers : SEP-35.81%, NWP-37.89%, WCP-10.04%
Bulk carriers mooring at the Mamala Bay anchorage for bunkering were the principle component of the SEP and NWP. A small percentage of arrivals from the NWP region were loading cargo at Barber's Point Harbor. The vessels arriving from the WCP region were conducting cargo discharge operations at Barber's Point Harbor.

- RoRo: NWP-97.56%
The only regular port arrivals of this type were from Japan (NWP).

- Barge: NEP-54.07%, WCP-31.11%, ECP-14.81%
The majority of overseas barge traffic arrived from the west coast of the mainland United States (NEP and ECP). The WCP component originated from the Marshall Islands and Johnston Atoll.

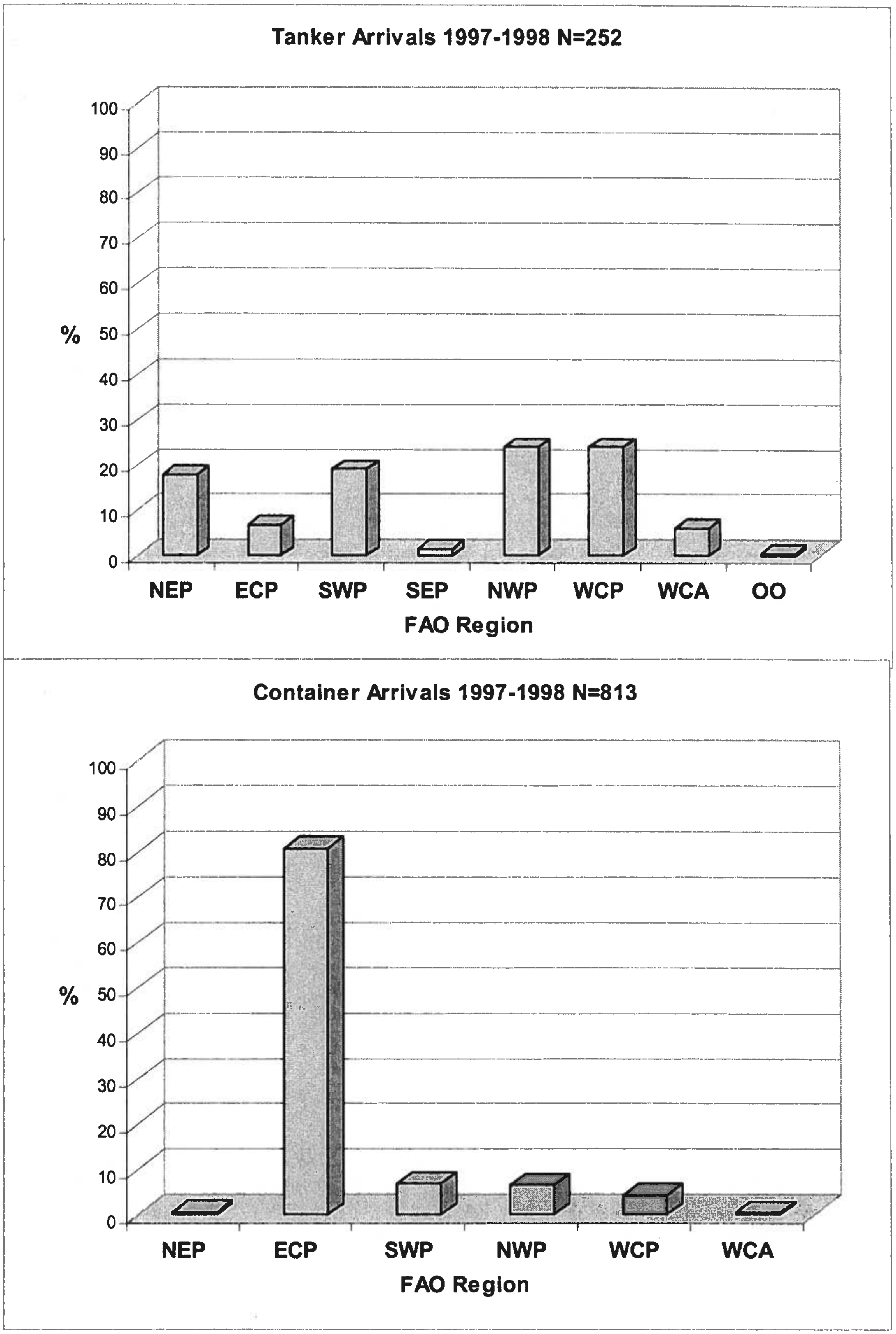


Figure 8. Tanker and Container vessel arrivals to Oahu 1997-1998.

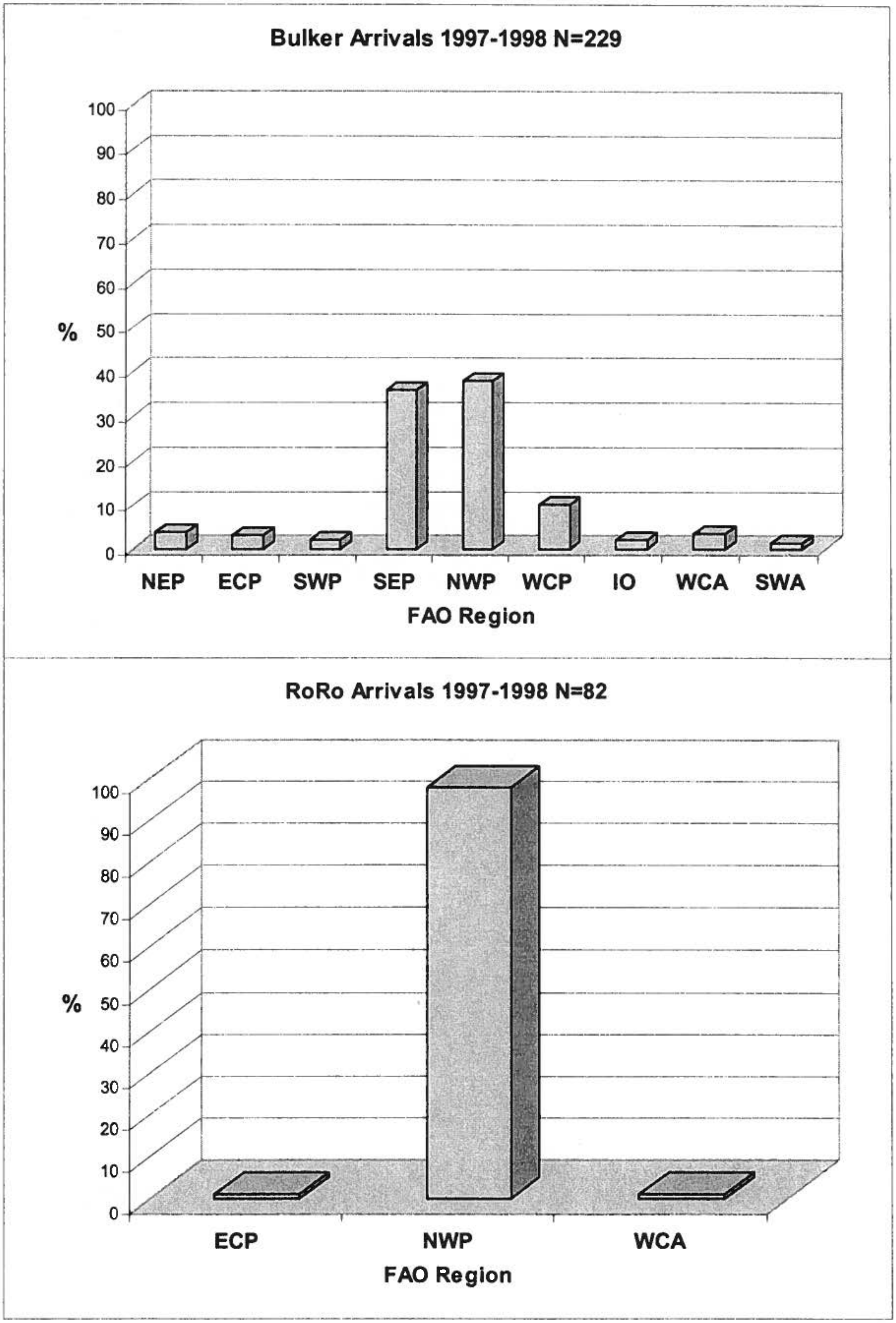


Figure 9. Bulk carrier and Roll-on Roll-off arrivals to Oahu 1997-1998.

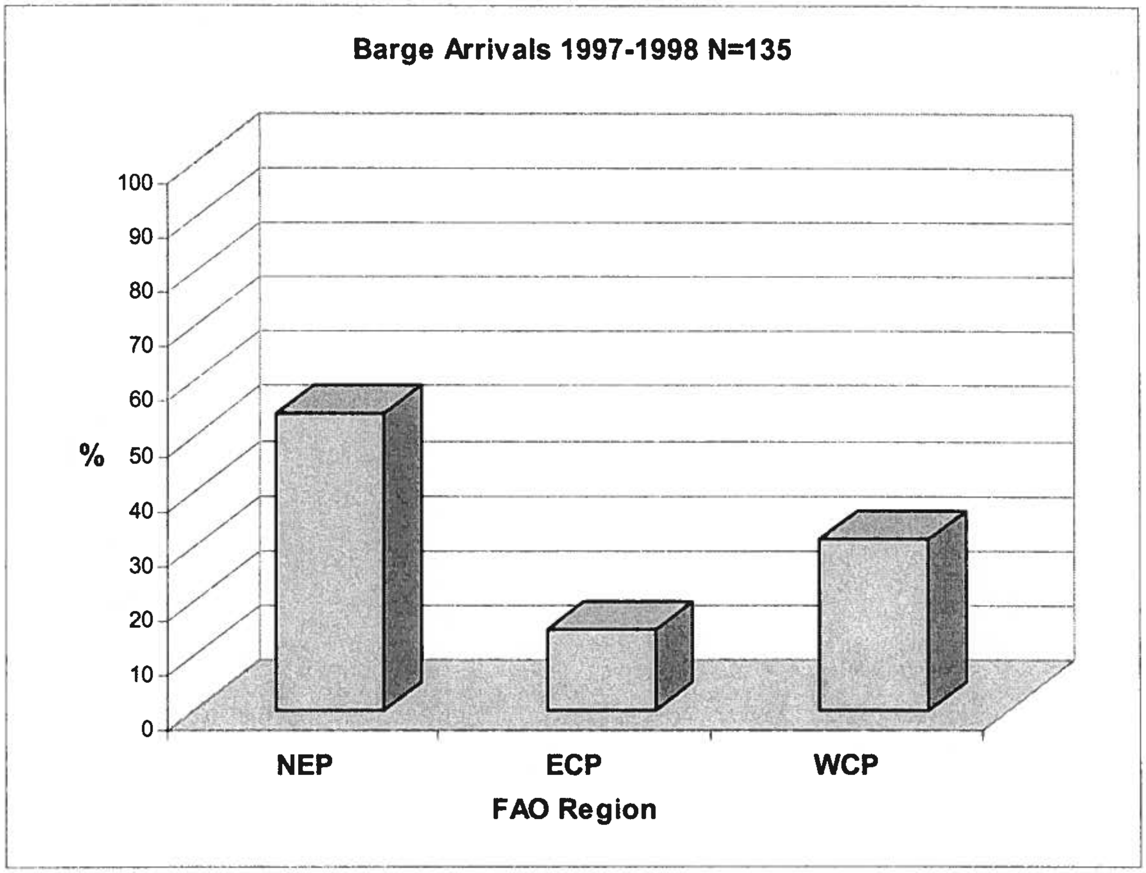
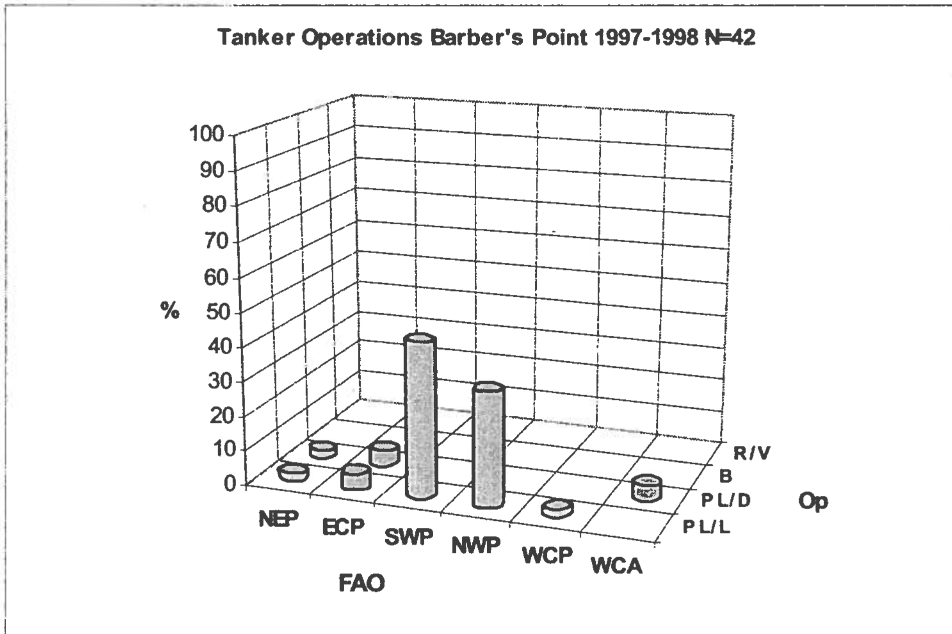


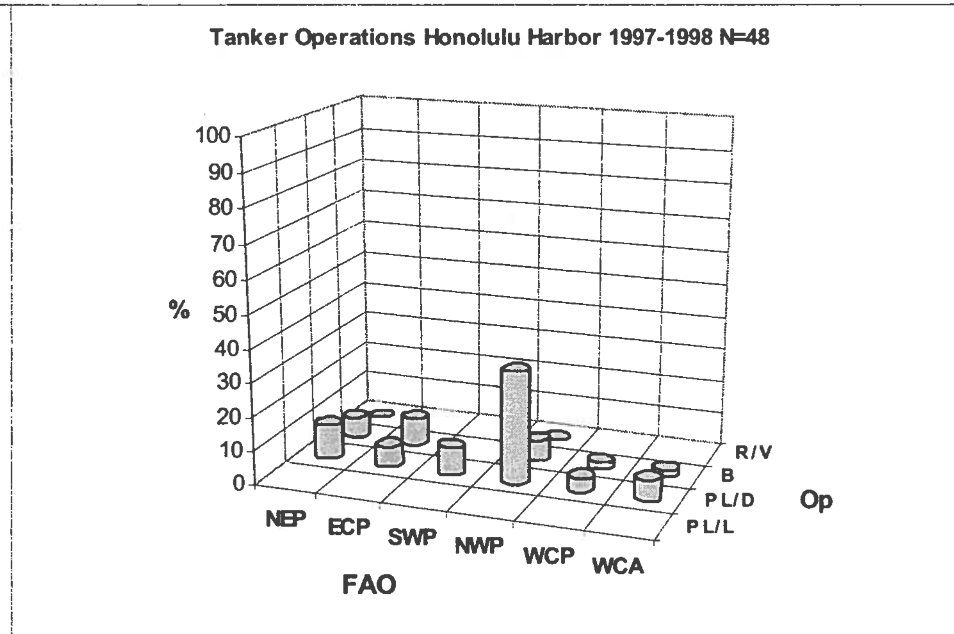
Figure 10. Overseas barge arrivals to Oahu 1997-1998.

Operations conducted by the primary vessels took place at Honolulu Harbor, Barber's Point Harbor, and the Mamala Bay anchorage. Operations were categorized as follows:

C/D C/L – Discharge and load containerized freight
F/D – Discharge freight
F/L – Load freight
PL/D – Discharge petroleum products
PL/L – Load petroleum products
B – Bunkering
R/V – docked or moored for repairs or other reasons (e.g.; medical, shore leave)

The two-year period of 1997 through 1998 showed discharge and discharge/load operations by 47 % of arriving vessels. Vessels exclusively loading cargo made up 2.3 % of the total. The second most common operation was bunkering at Honolulu Harbor (21 %), and the Mamala Bay anchorage (9 %). The majority of bunkering at Honolulu Harbor was by small overseas fishing boats, whereas the bunkering operations at the anchorage were large bulk carriers. Figures 11 through 14 show the breakdown of operations by vessel type, port location, FAO region of origin, and the operation (by percentage).





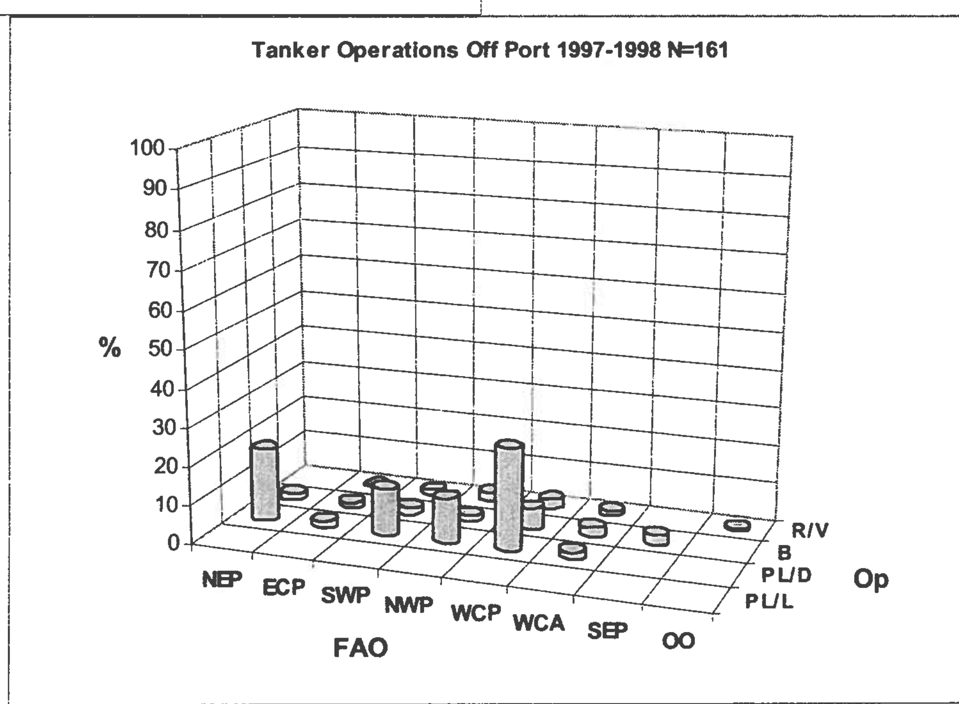


Figure 11. Tanker operations for Oahu 1997-1998

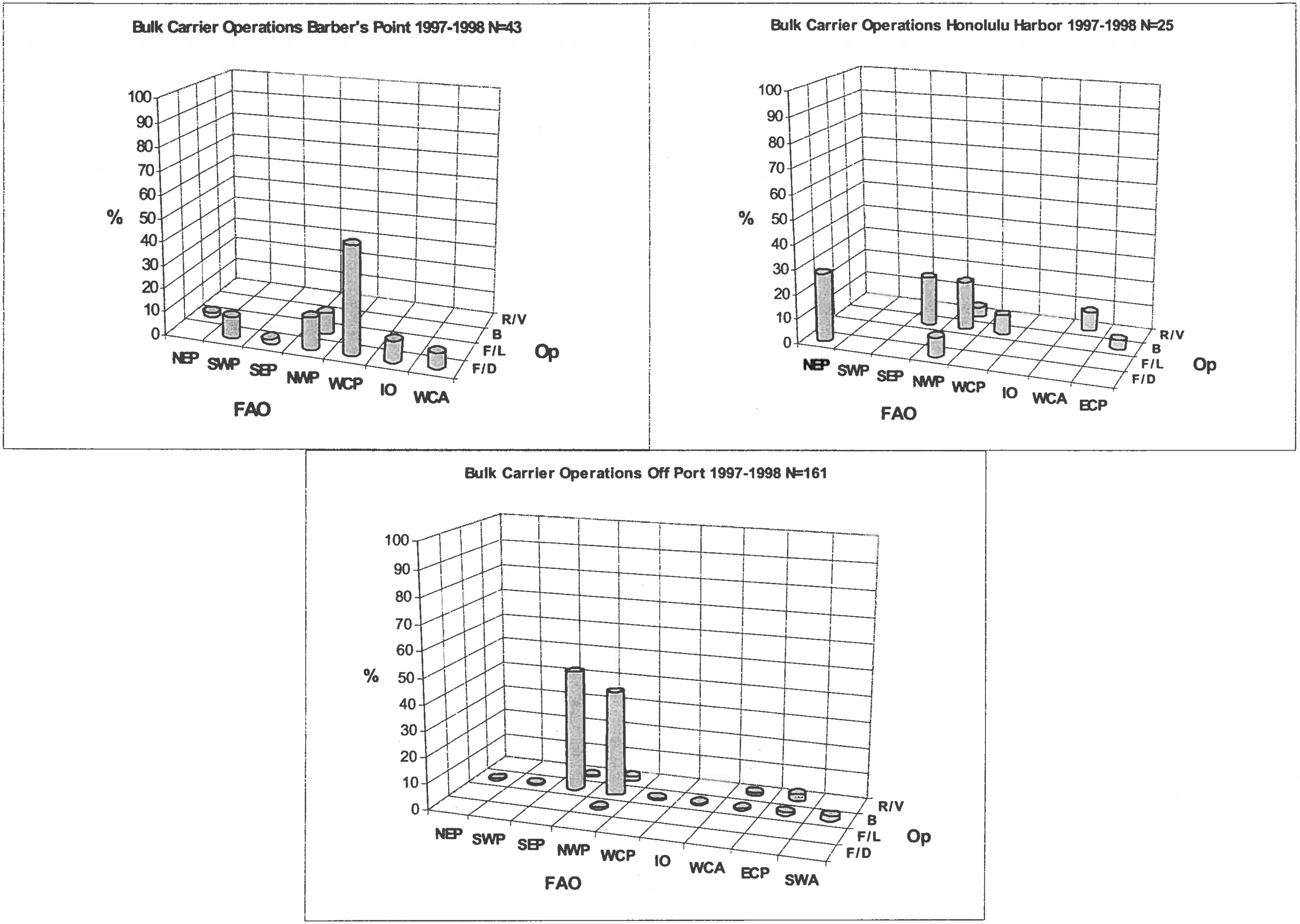


Figure 12. Bulk carrier operations for Oahu 1997-1998

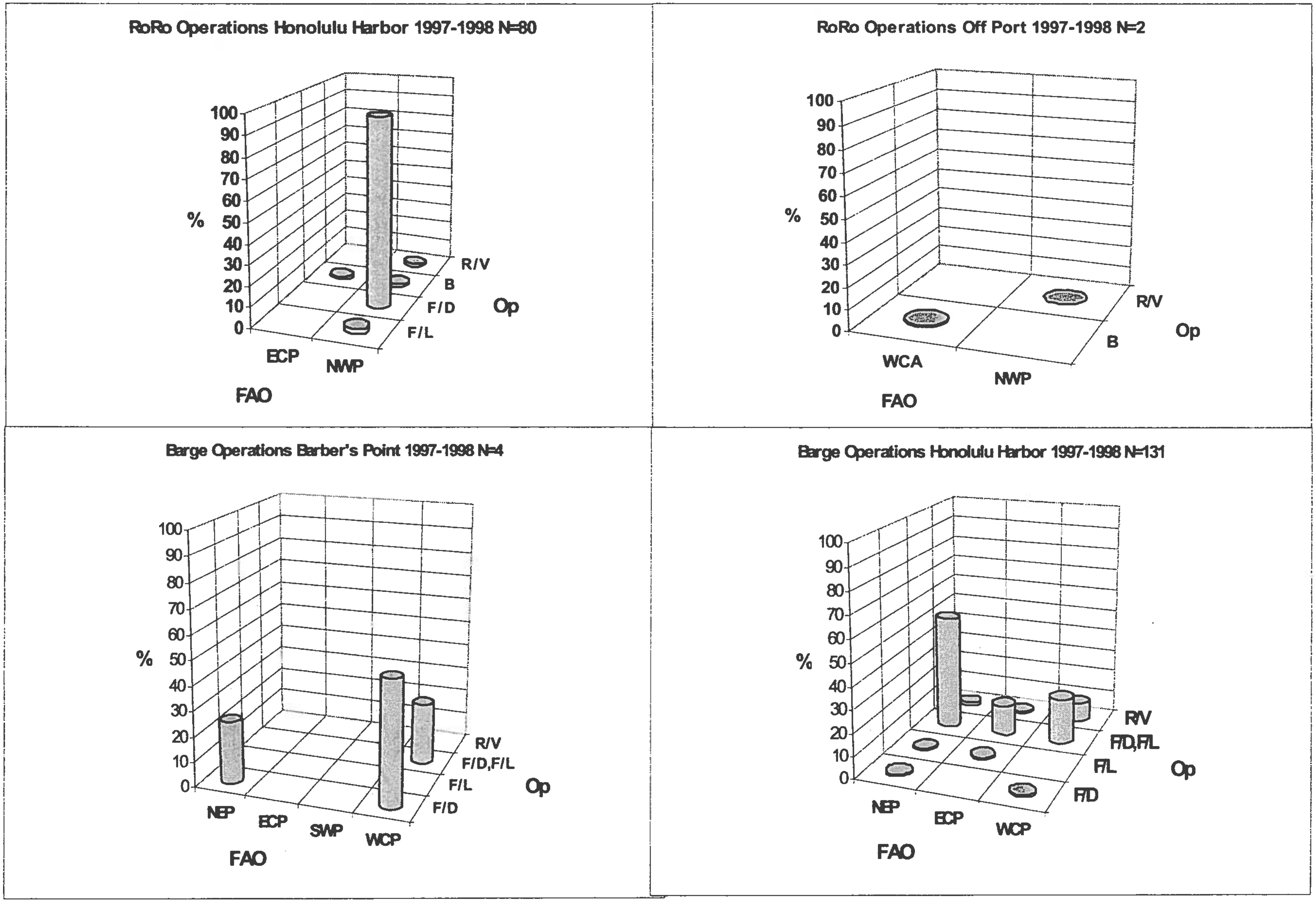
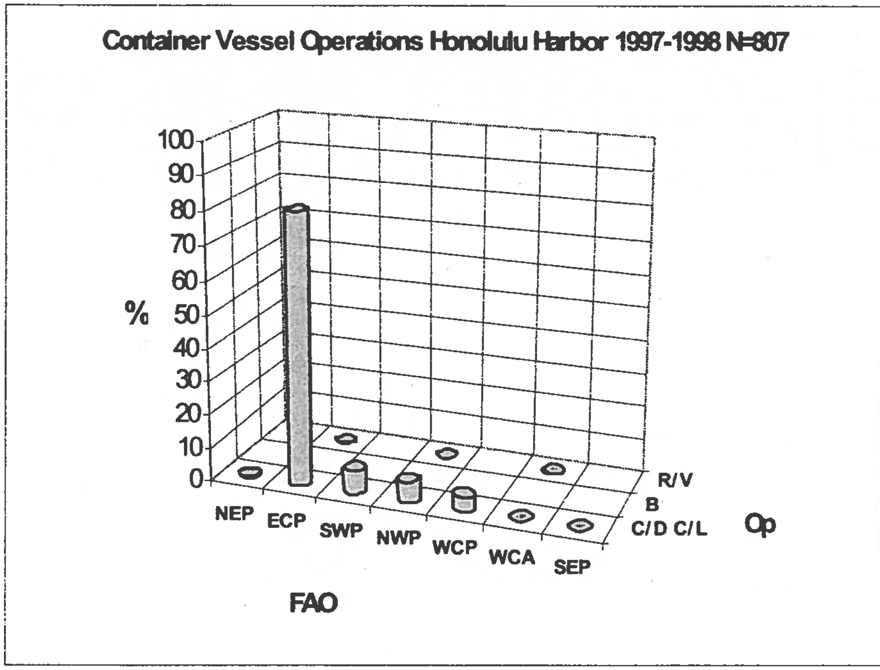


Figure 13. Roll-on Roll-off and overseas barge operations for Oahu 1997-1998



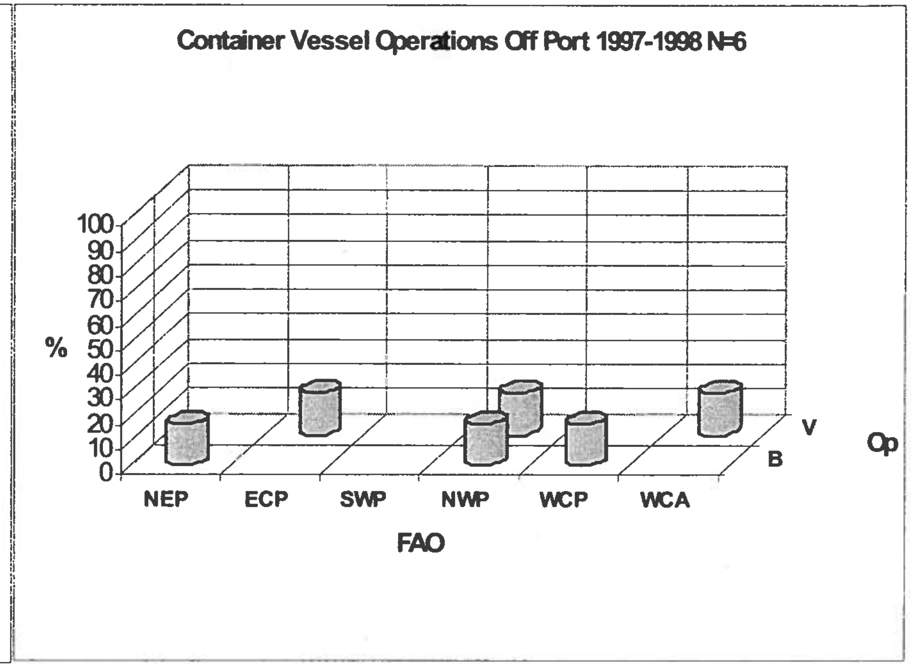


Figure 14. Container vessel operations for Oahu 1997-1998.

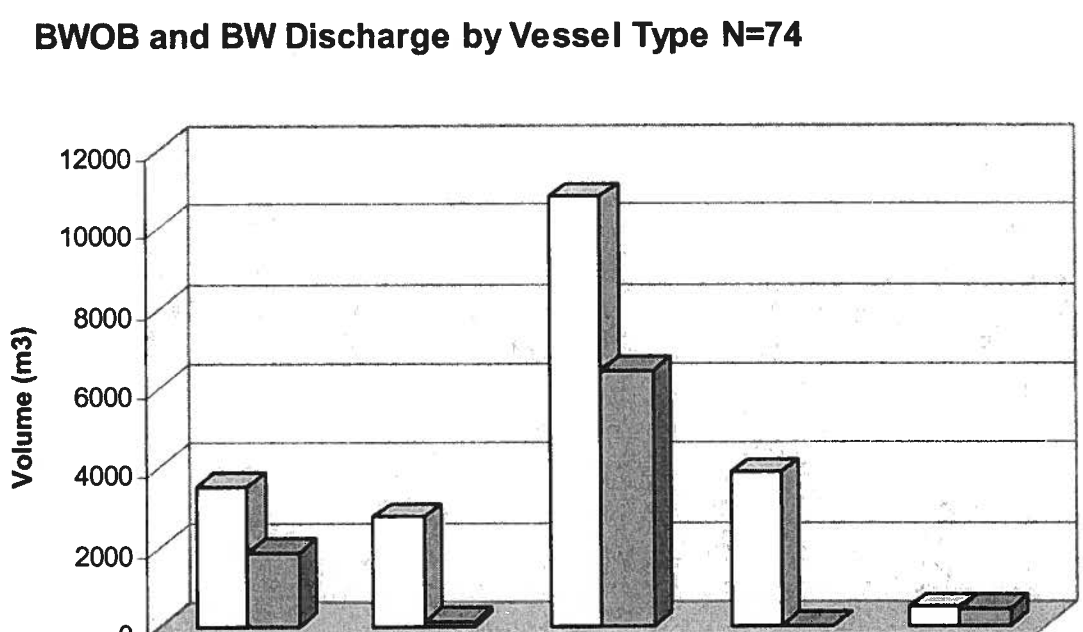
Tanker and bulk carriers operated in all three locations. Container vessels and RoRos operated in Honolulu Harbor, and on rare occasions they bunkered at the anchorage. Barge traffic was centered in Honolulu Harbor and Barber's Point Harbor

As stated above, the majority of vessels were conducting discharge and discharge/load operations at Honolulu Harbor and Barber's Point Harbor. Container vessels from California conducted weekly discharge and discharge/load operations, and container vessels from Australia and New Zealand conducted the same operations monthly. Japanese container vessels conducted a monthly circuit between Japan, Hawaii, and ports in the East Central Pacific, and conducted discharge/load operations in Honolulu Harbor. Bulk cargo vessels (tankers and bulk carriers) conducted discharge, loading, and bunkering operations at both harbors and the anchorage. Petroleum discharge operations were carried out in all three locations. Loading of petroleum products took place exclusively at Barber's Point Harbor. Bulk carriers discharged coal and clinker and loaded scrap metal at Barber's Point Harbor. Overseas barges were conducting discharge/load operations and RoRo vessels were only discharging cargo. Bunkering of primary vessels took place in Honolulu Harbor, Barber's Point Harbor and the Mamala Bay anchorage.

Vessel Boarding Survey

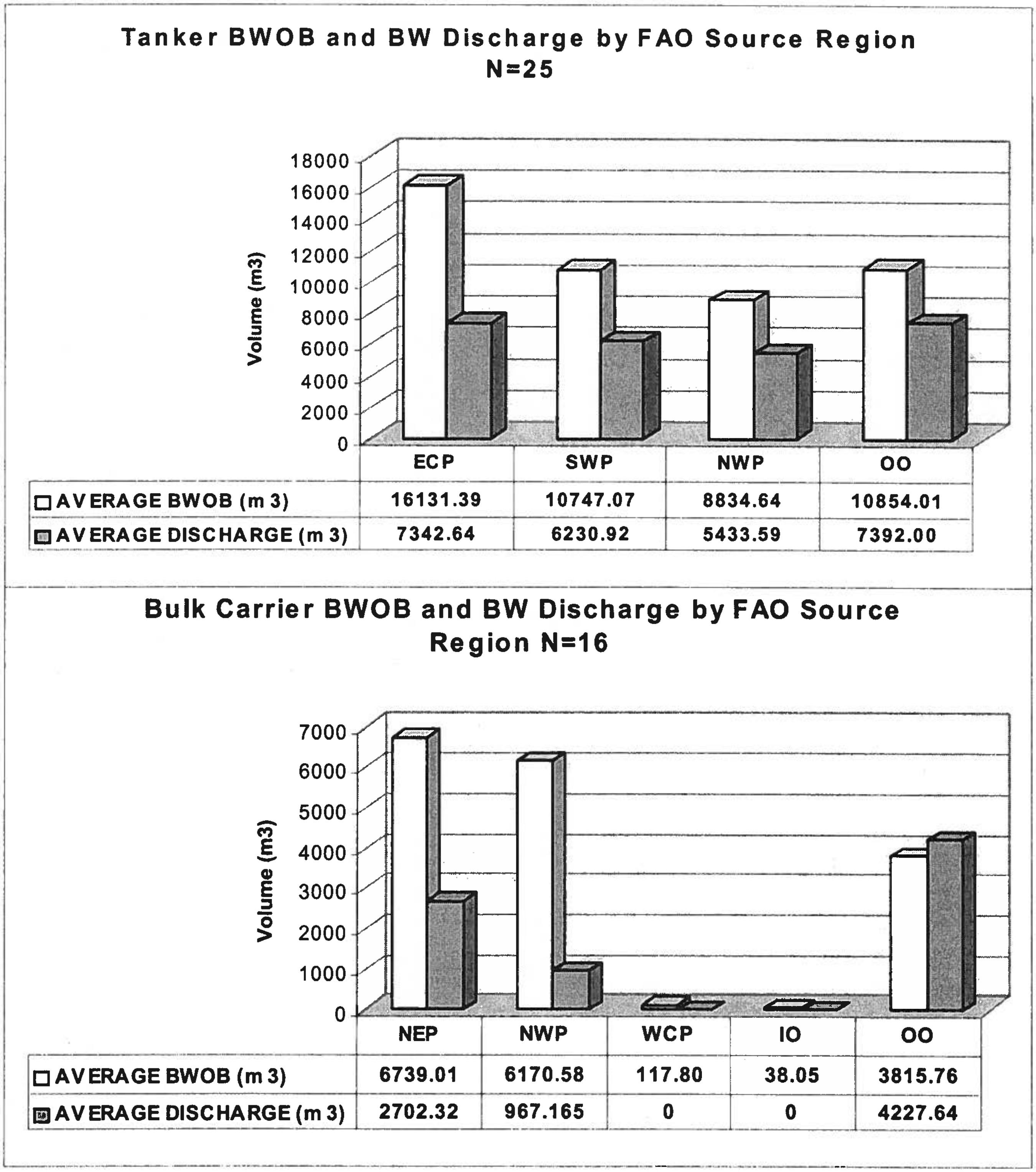
The analysis of vessel arrivals for the period of 1997-1998 provided an overall picture of vessel arrival patterns, and operations for the port system, but specific data from the primary vessels using the port was also needed. A total of 74 commercial vessels were boarded between March 1998 and December 1999 and interviews were conducted with vessel officers responsible for vessel cargo operations. The primary responsibility for cargo discharge and loading, and therefore ballast water operations, was the Chief Officer. In each case the Chief Officer was interviewed using a standardized data questionnaire (Appendix D). The data was used to form profiles of the primary vessels and relate this back to the trends in arrivals to the port system. All of the data was for vessels actually arriving to Honolulu Harbor and Barber's Point Harbor and does not include any vessels at the Mamala Bay anchorage. The vessel boarding component was also the point at which biological data for ballast water was collected, which is presented in the next section.

Focus was placed on ballast water on board (BWOB) when the vessel arrived and what ballast operations (if any) were being conducted. Figure 15 shows the average BWOB and average ballast water discharge volume for each of the primary vessel types. This was broken down further to show the actual BWOB source region and discharge level for each primary vessel type (Figures 16 through 18). The vessels that were discharging the most ballast water were tanker, bulk carrier, and barge vessels. In very few instances did container vessels discharge ballast water, and none of the RoRo vessels surveyed released any ballast water. Tanker vessels arrived with the largest volumes of BWOB and discharged the greatest volumes of ballast water. Bulk carriers ranked second in BWOB, and discharge volumes. Overseas barges carried less BWOB than all vessel types but discharge rates for the BWOB were over 90%. Container and RoRo vessels carried moderate amounts of BWOB but discharge was minimal or non-existent. The data for BWOB and discharge by FAO source region showed that tankers discharged ballast water from four primary regions (ECP, SWP, NWP, OO). The most common source regions for BWOB and discharge for bulk carriers was the NEP, NWP, and OO. Ports in the NEP region were the source for BWOB and discharge in overseas barges.



	BULKER	CONTAINER	TANKER	RoRo	BARGE
AVERAGE BWOB (m3)	3517.97	2756.88	10786.70	3854.29	472.45
AVERAGE DISCHARGE (m3)	1838.01	126.41	6426.74	0.00	437.23

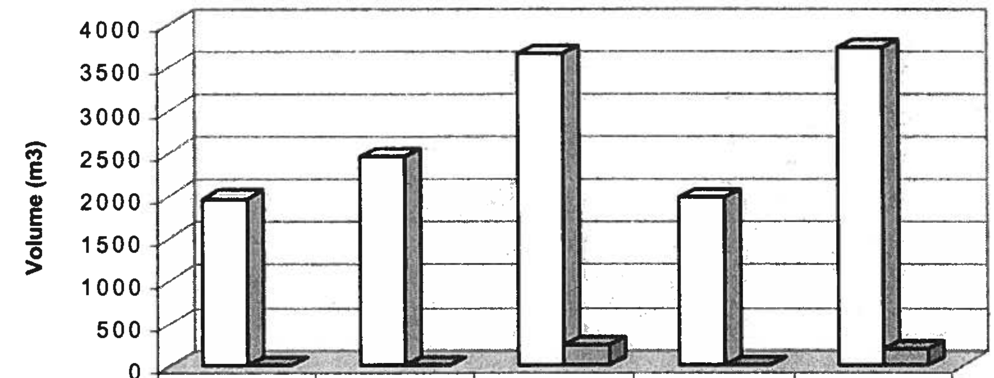
Figure 15. Ballast water on board (BWOB) and ballast water discharge volumes for primary vessels.



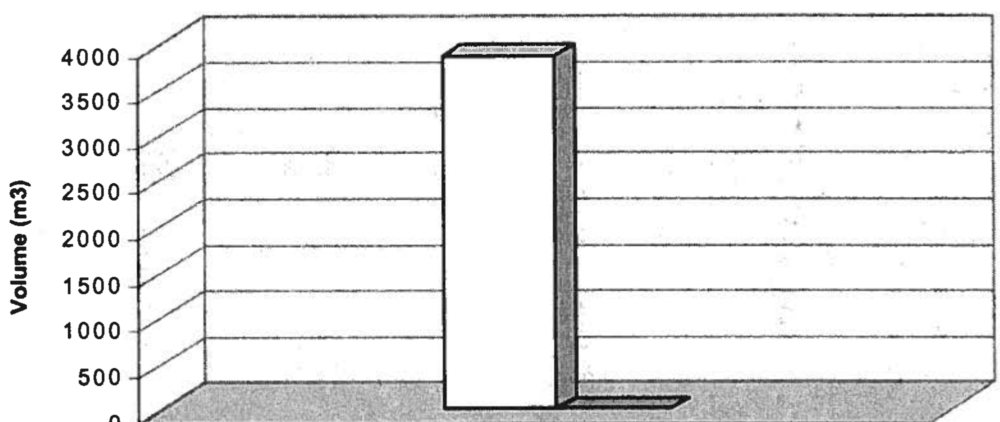
	ECP	SWP	NWP	OO
AVERAGE BWOB (m 3)	16131.39	10747.07	8834.64	10854.01
AVERAGE DISCHARGE (m 3)	7342.64	6230.92	5433.59	7392.00

	NEP	NWP	WCP	IO	OO
AVERAGE BWOB (m 3)	6739.01	6170.58	117.80	38.05	3815.76
AVERAGE DISCHARGE (m 3)	2702.32	967.165	0	0	4227.64

Figure 16. Tanker and Bulk Carrier BWOB and discharge by FAO region.



	ECP	SWP	NWP	WCP	OO
AVERAGE BWOB (m 3)	1960.07	2452.51	3659.59	1972.68	3738.05
AVERAGE DISCHARGE (m 3)	0	0	240.98	0	195.12



	NWP
AVERAGE BWOB (m 3)	3854.29
AVERAGE DISCHARGE (m 3)	0.00

Figure 17. Container vessel and Roll-on Roll-off vessel BWOB and discharge by FAO region.

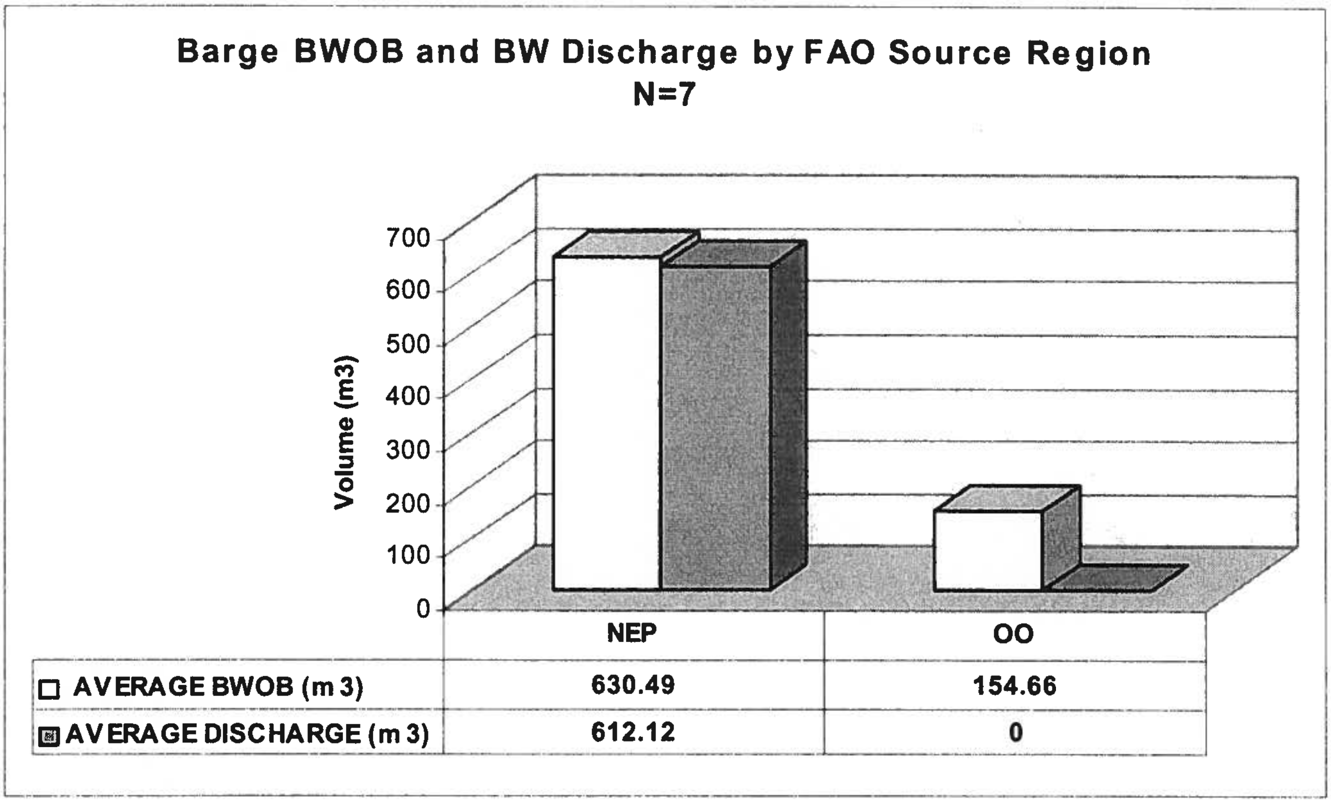


Figure 18. Overseas barge BWOB and discharge by FAO region.

B. Biological component

Three pathways associated with commercial maritime shipping were considered in the biological component. These were ballast water, ballast water sediments, and hull fouling. Ballast water samples were taken from a total of 32 vessels, ballast water sediment samples were obtained from 13 vessels, and 8 hull fouling surveys were conducted. Ballast water samples were all analyzed to record associated planktonic organisms and 10 of these were further assayed for the presence of *Vibrio cholerae* bacteria. Ballast water sediments were examined by live analysis and culture techniques to assay for encysted phytoplankton. Finally, qualitative analysis of organisms in hull fouling communities was accomplished by SCUBA surveys.

Ballast water

During vessel boarding interviews it was determined if access to ballast tanks was possible, and if so, a tank with water representative of the overall BWOB source region was identified. Tanks with the greatest volume of water and easiest access were chosen, and procedures described in the methods section were followed.

The average temperature and salinity values of ballast water from the various source regions, as well as the average for all the values measured at Honolulu Harbor and Barber's Point Harbor are shown in Table 2. Another physical parameter that was considered for each sample was the age of the ballast water. The average age of ballast water by FAO region, including minimum and maximum values was also determined.

FAO	BW Temp (C°)	BW Salinity (0/00)	Average Age	Min. Age	Max Age
NEP	25.05	21.00	11	12	5
ECP	22.95	20.75	7	10	4
SWP	26.54	37.70	10	14	7
NWP	26.18	35.50	10	6	13
WCP	25.87	36.33	14	19	7
OO*	25.99	38.00	10	30	2

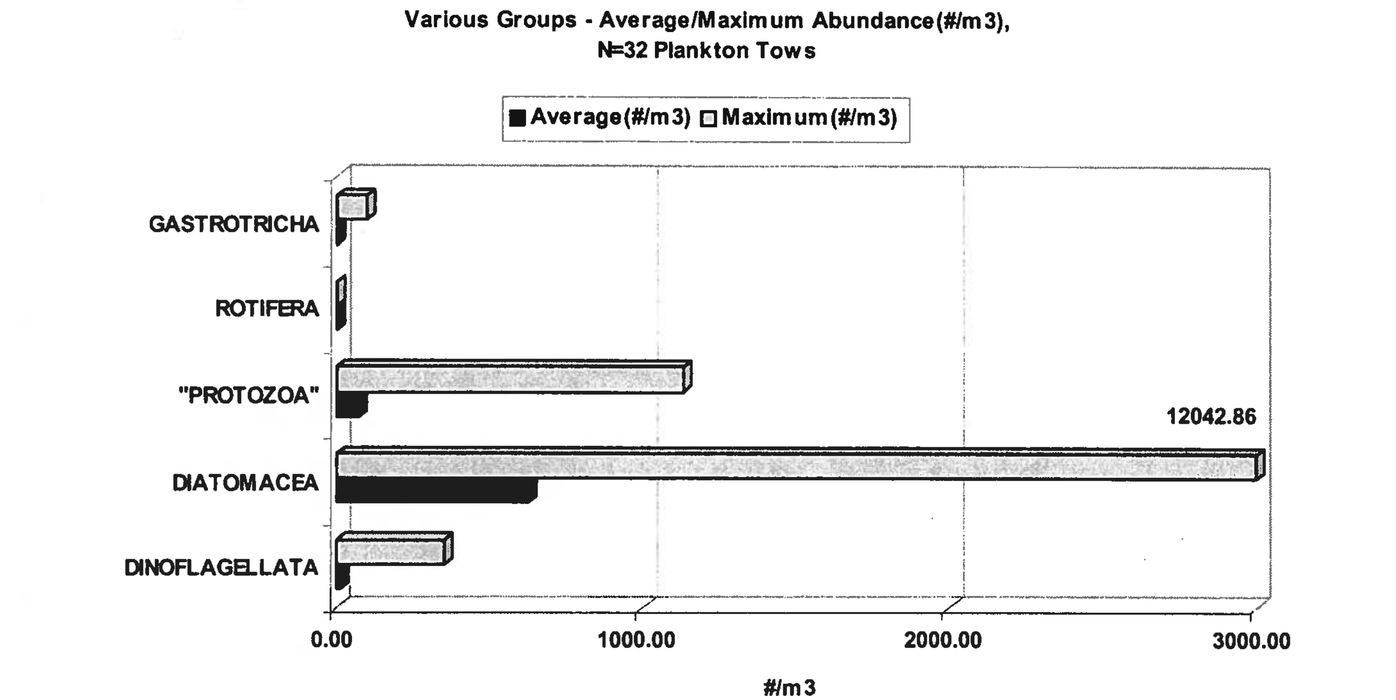
***Open Ocean**

Average Dockside Temp. (C°) - 25.21
Average Dockside Salinity (0/00) - 38.75

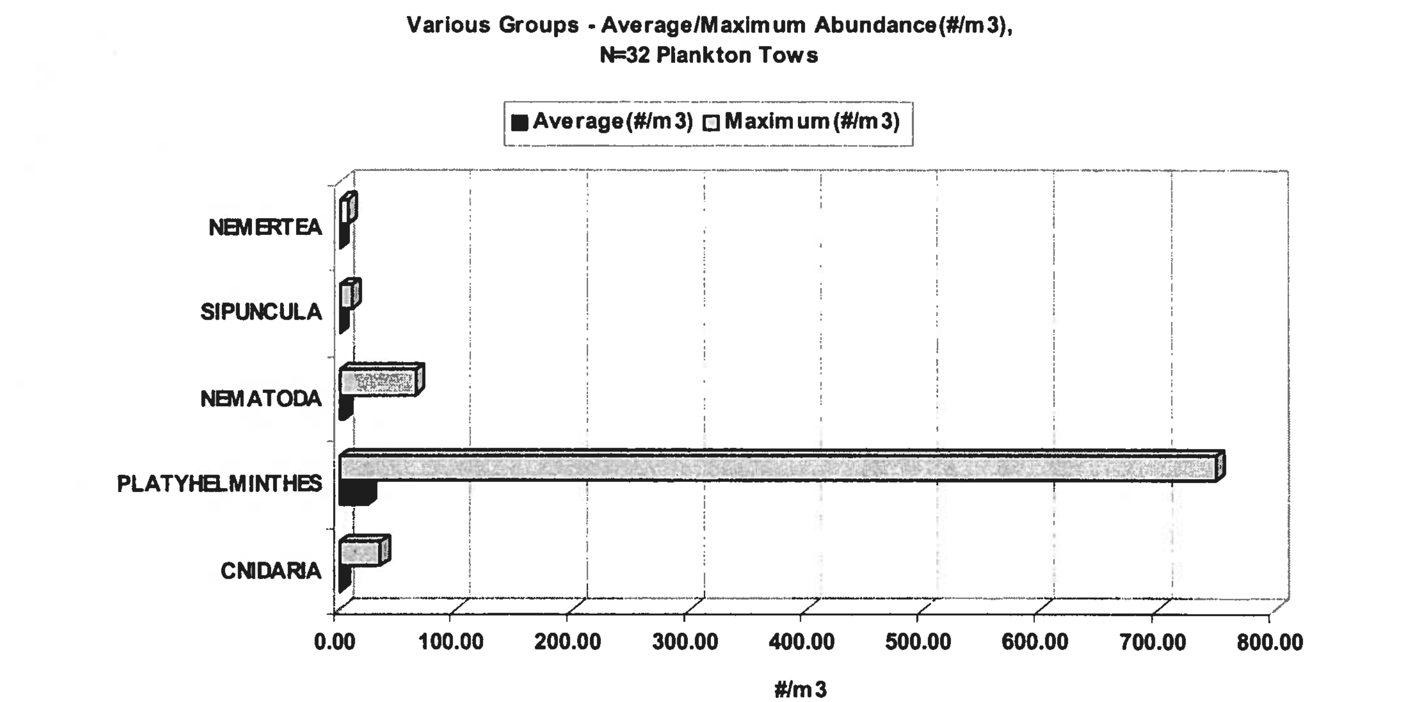
Table 2. Physical parameters of ballast water by FAO region and the average dockside values for Honolulu Harbor and Barber's Point Harbor.

Planktonic organisms present in the 32 ballast water samples were enumerated and are shown by taxa in Figures 19 and 20. Only the taxa that were noted as alive in the qualitative live analysis were counted. The abundance of taxa was presented as the average number of organisms per cubic meter, as well as the maximum abundance encountered within the overall sample set. The minimum number in all cases was zero since some samples analyzed contained no organisms. The phylum level was used to illustrate the data presented in Figures 19 and 20, with the exception of Diatomacea and Dinoflagellata. Certain abundant categories were broken down further by family or morphotype, which included: Protozoa, Mollusca, Annelida, and Crustacea, and are shown in Figures 21 through 24. The groups Gastrotricha, Nematoda, Platyhelminthes (Mueller's larvae), and Chaetognatha were also abundant but were only identified by morphotype.

Particular focus was placed on FAO regions from which certain abundant taxa originated. The most numerous holoplanktonic (Diatomacea, Dinoflagellata, and Copepoda) and meroplanktonic (Platyhelminthes, Annelida, Mollusca, Cirrepedia and Decapoda) organisms and their associated FAO regions are shown in Figures 25 and 26. The Copepoda grouping in Figure 26 included the presence of any larval and adult copepods within a sample from the particular region.

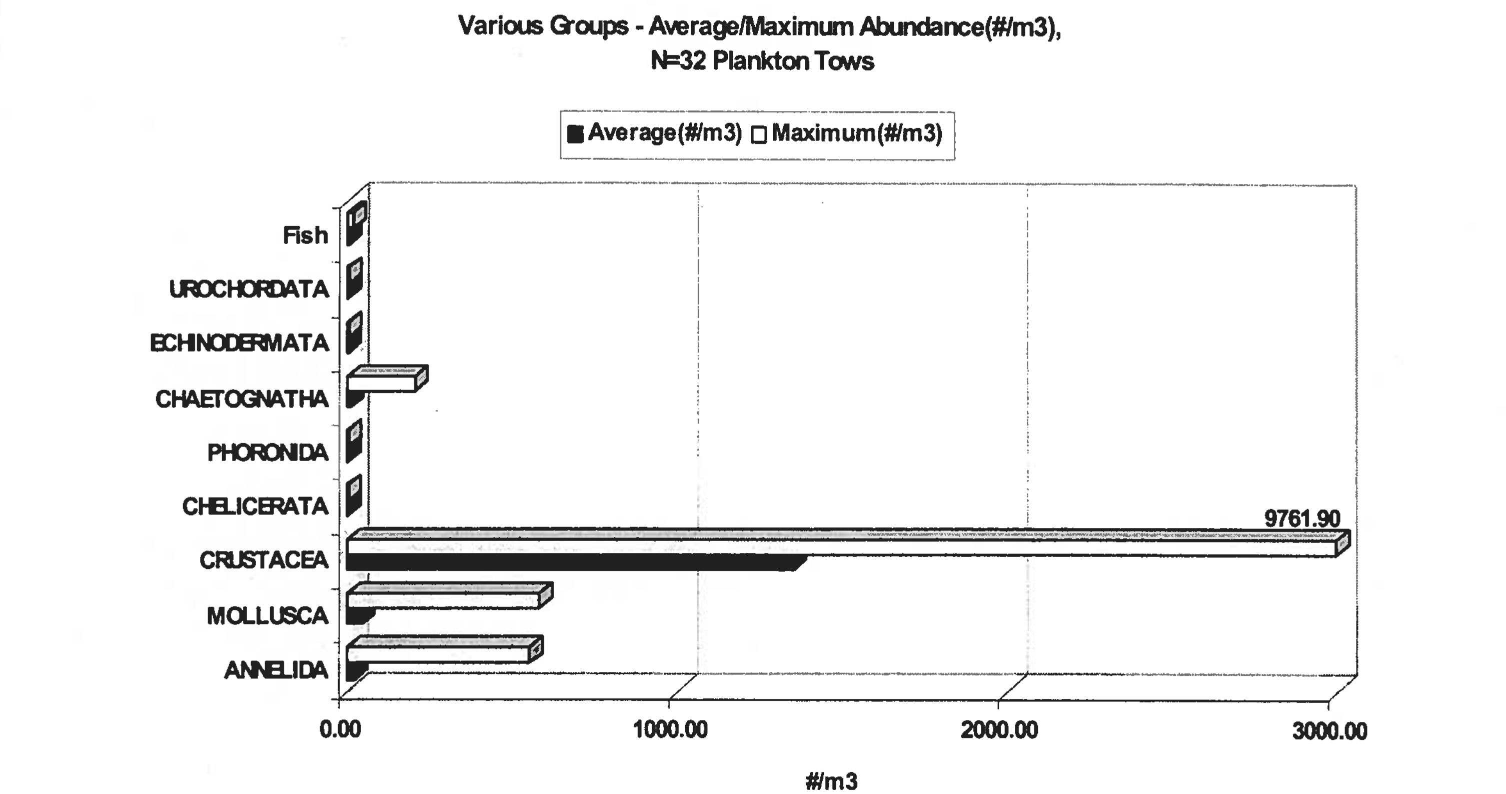


	DINOFLAGELLATA	DIATOMACEA	"PROTOZOA"	ROTIFERA	GASTROTRICHA
Maximum(#/m3)	357.00	12042.86	1133.33	1.92	96.15
Average(#/m3)	13.28	629.23	71.36	0.06	3.00



	CNIDARIA	PLATYHELMINTHES	NEMATODA	SIPUNCULA	NEMERTEA
Maximum(#/m3)	35.71	750.00	65.38	10.75	6.99
Average(#/m3)	1.35	24.55	4.59	0.34	0.24

Figure 19. The average and maximum abundance of various taxa from plankton tows.



	ANNELIDA	MOLLUSCA	CRUSTACEA	CHELICERATA	PHORONIDA	CHAETOGNATHA	ECHINODERMATA	UROCHORDATA	Fish
□ Maximum(#/m3)	550.00	580.00	9761.90	1.56	1.39	205.23	2.17	3.85	14.08
■ Average(#/m3)	19.45	44.94	1356.55	0.08	0.08	6.88	0.24	0.12	0.45

Figure 20. The average and maximum abundance of various taxa from plankton tows.

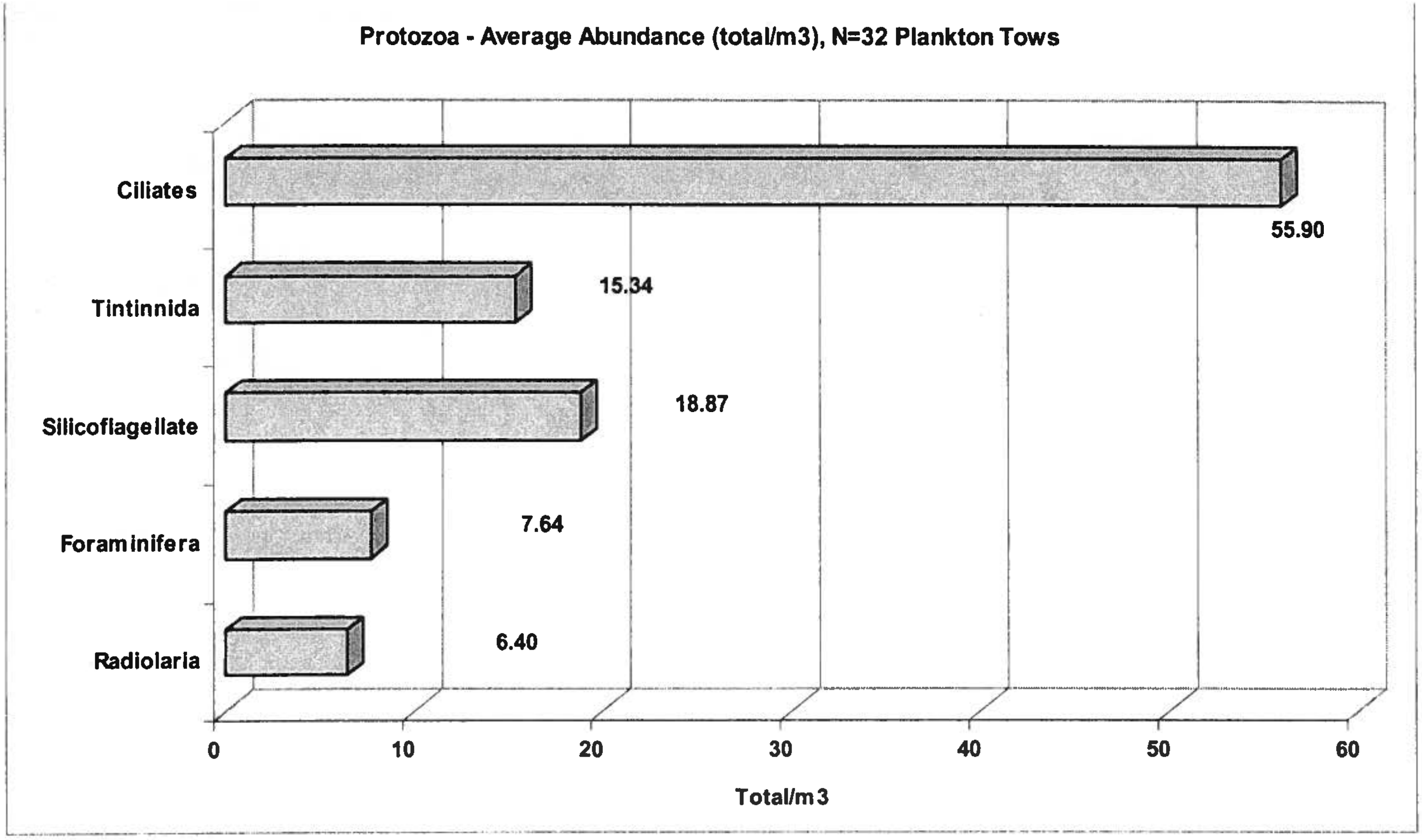


Figure 21. Average abundance of Protozoan taxa from plankton tows.

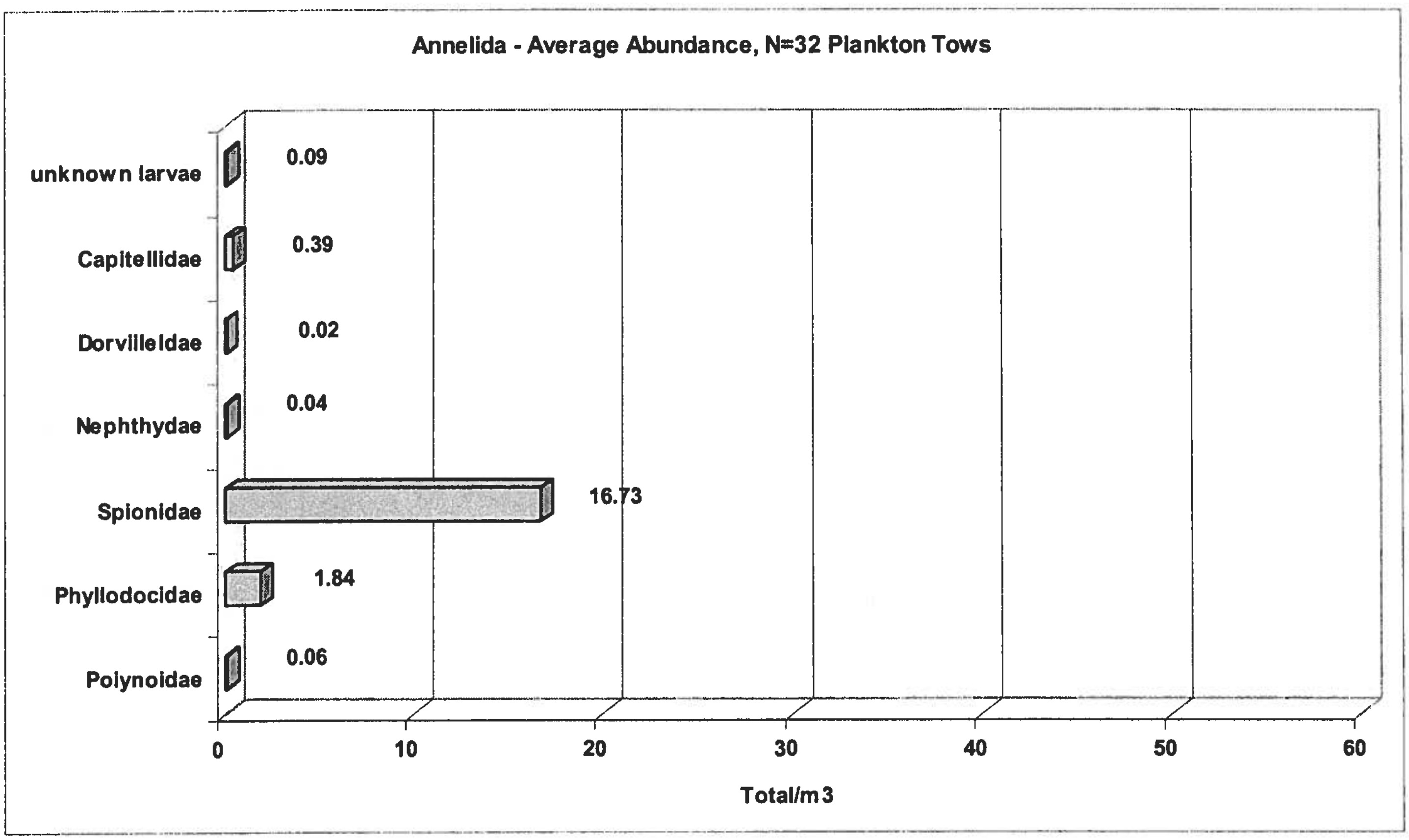


Figure 22. Average abundance of Annelida taxa from plankton tows

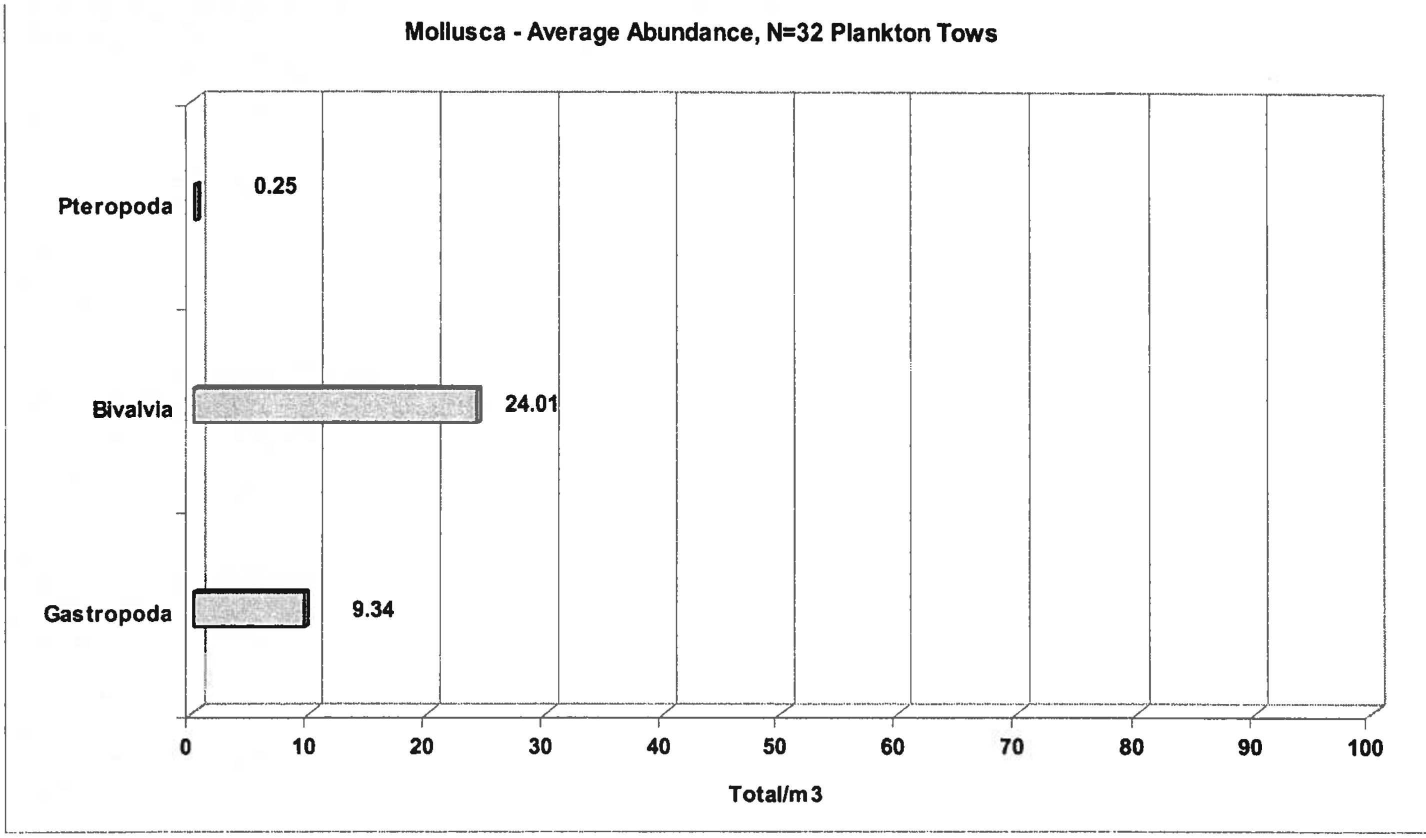


Figure 23. Average abundance of Mollusca taxa from plankton tows.

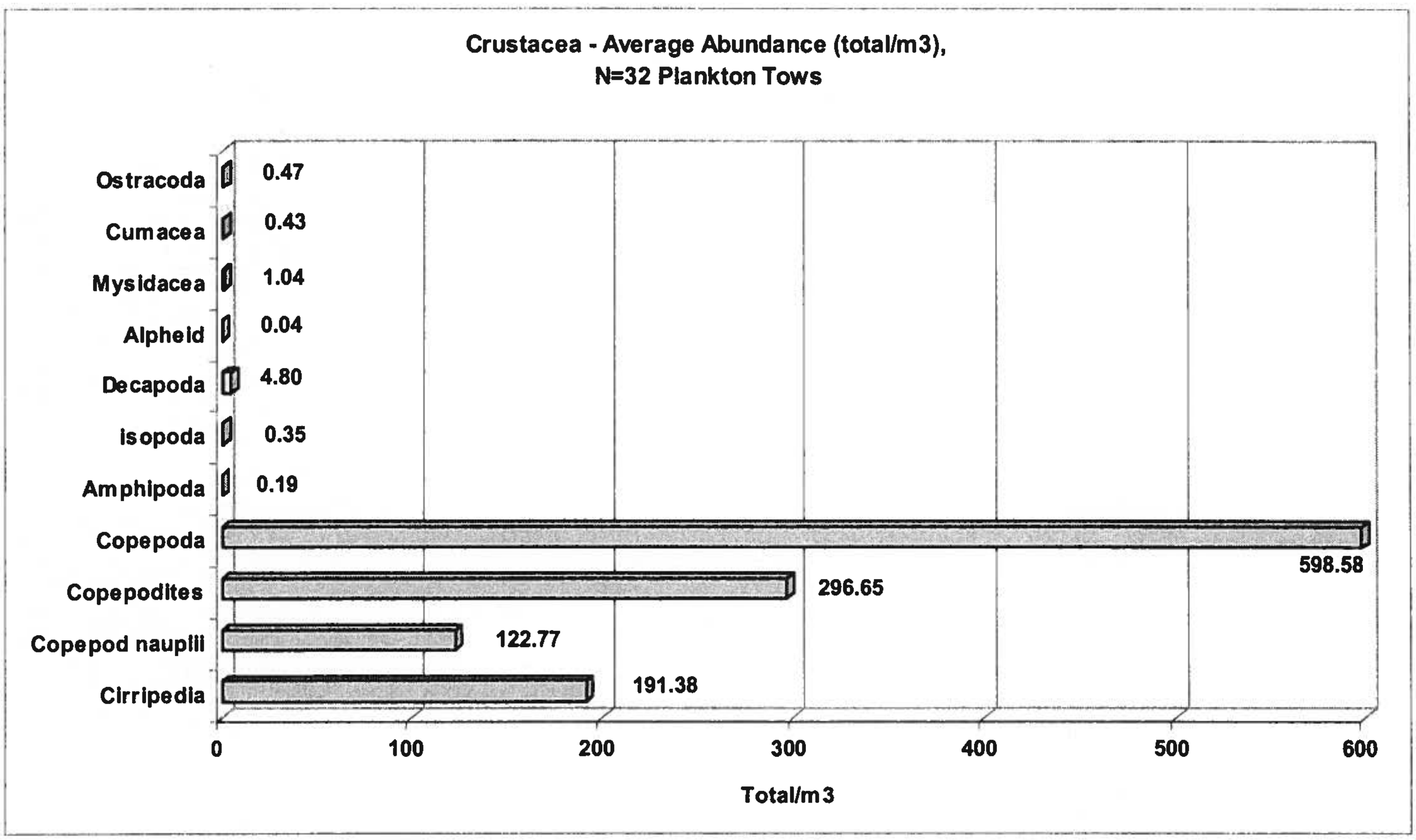
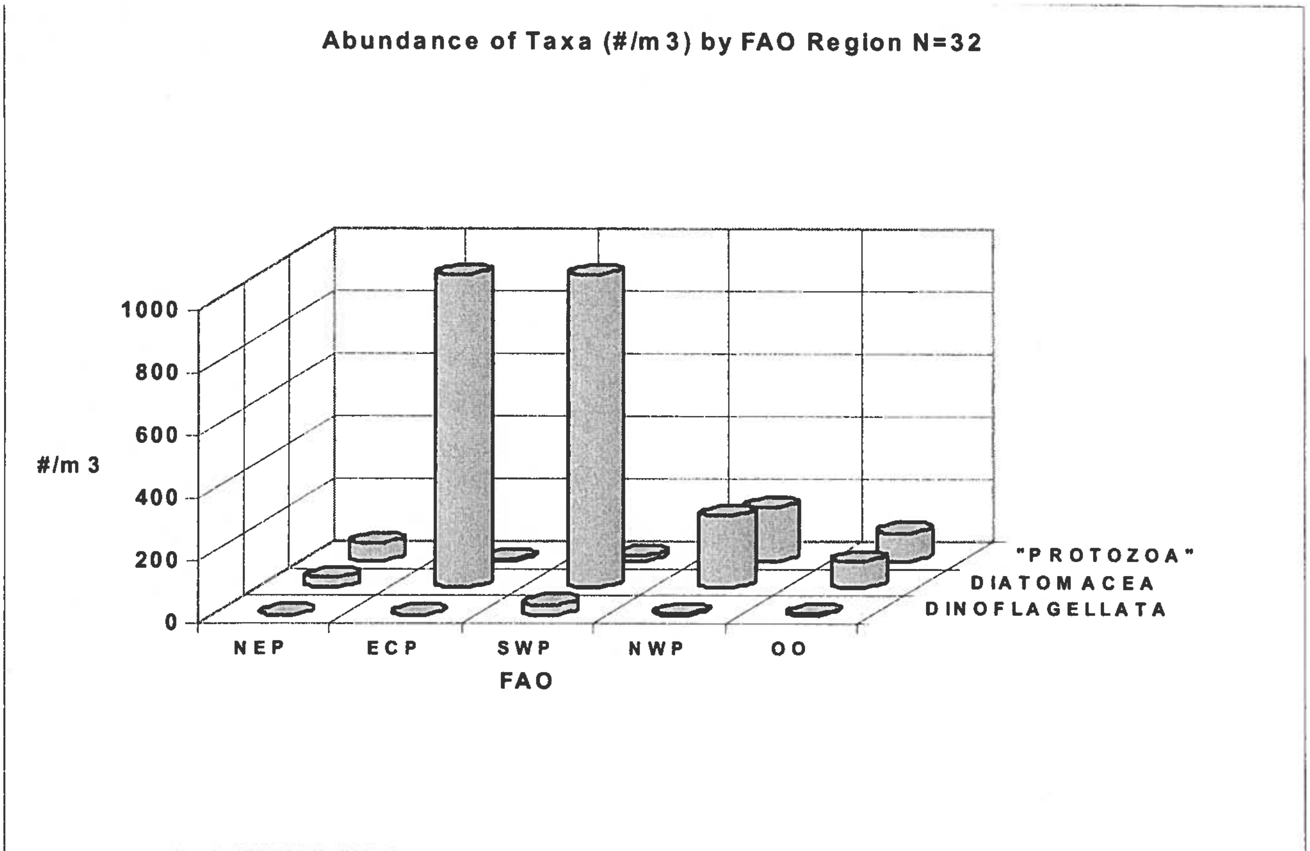


Figure 24. Average abundance of Crustacea taxa from plankton tows.



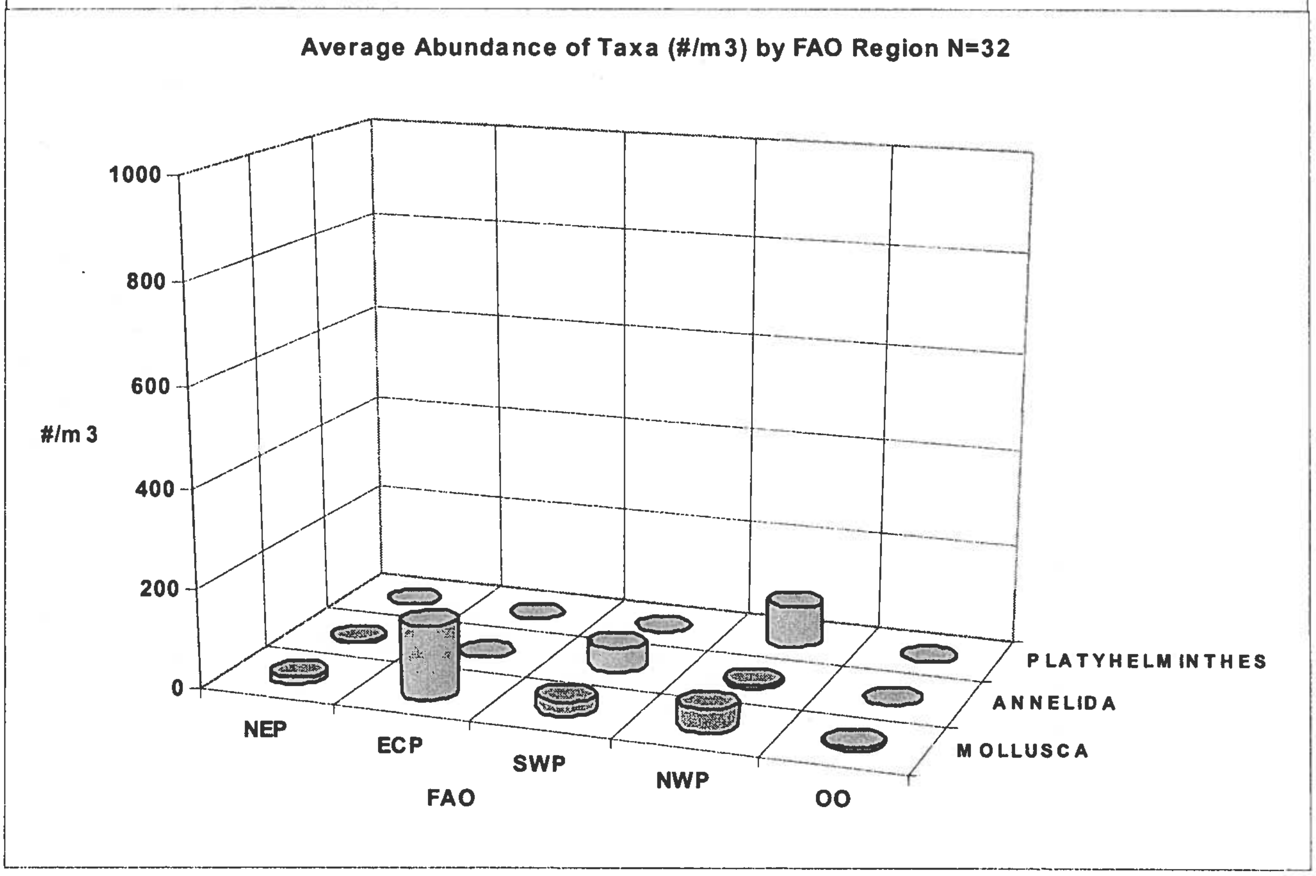


Figure 25. Average abundance of various taxa from plankton tows by FAO region.

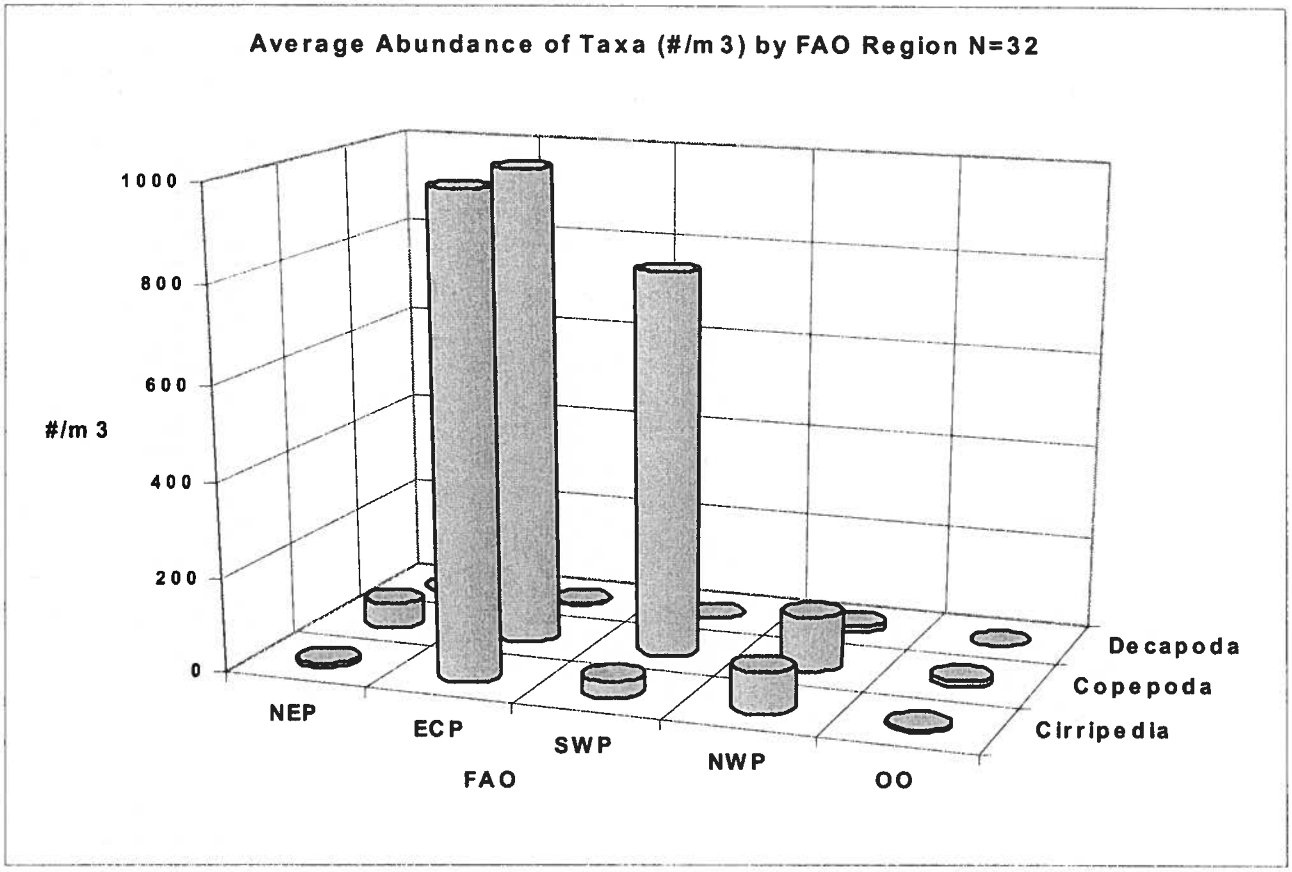


Figure 26. Average abundance of Crustacea taxa from plankton tows by FAO region.

As stated earlier, 10 ballast water samples of the overall 32 were assayed for *Vibrio cholerae* bacteria. Table 3 shows the results of the DFA analysis technique for both the 01 and 0139 serogroups of *Vibrio cholerae* and the particular port and FAO region that the ballast water originated. Three FAO regions are represented: SWP (n=5), NWP (n=4), and a single sample from Tanjung Barat, Indonesia (WCP). The results represent the density of cells per milliliter for 01 and 0139 serogroups from plankton tows and whole water samples.

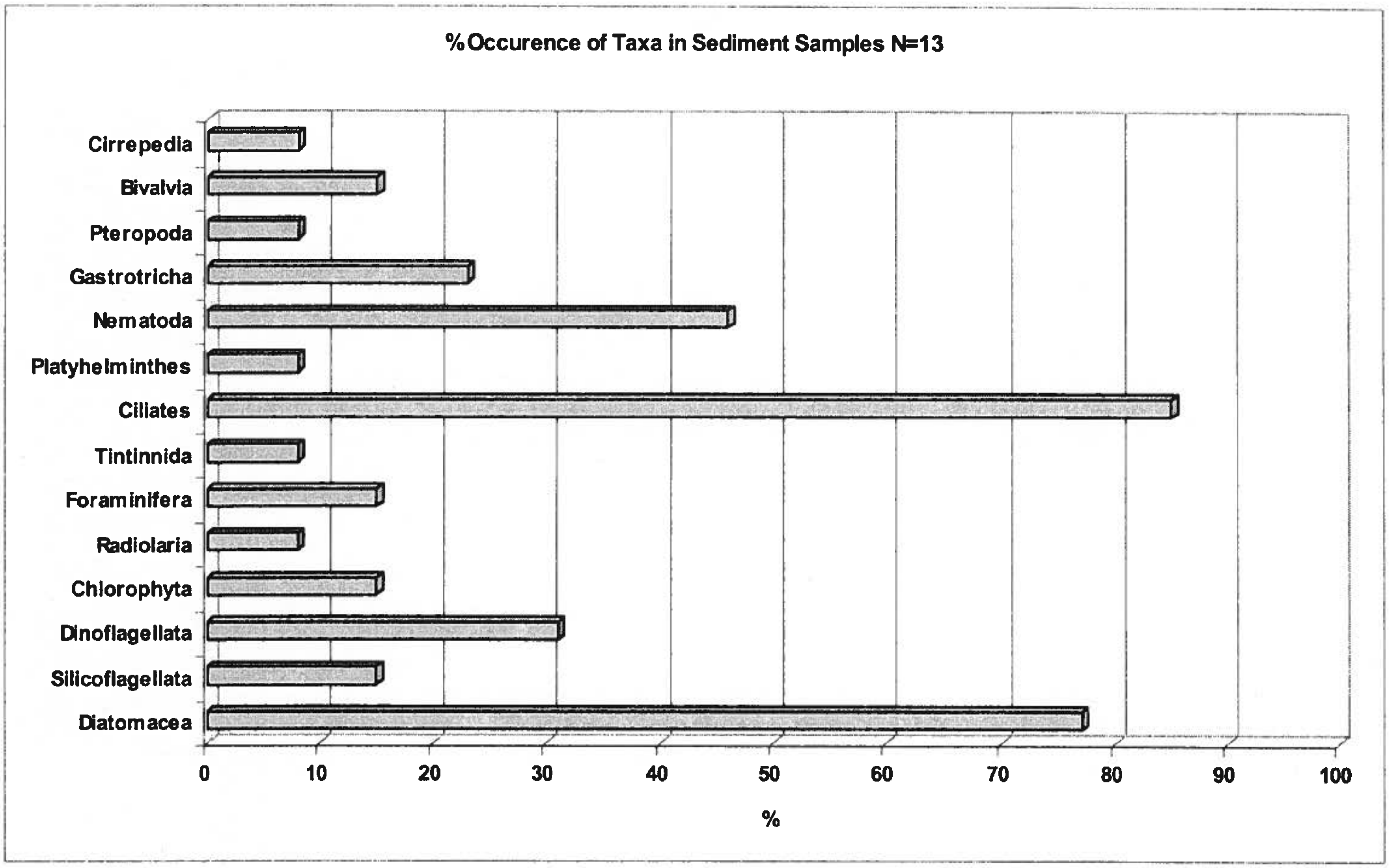
Sample #	*Ballast water source*	*Density 01 (cells/ml)*	*Density 0139 (cells/ml)*
HI-003	Auckland, NZ	0.190 (PT)	0 (PT)
		12.63 (WW)	0 (WW)
HI-007	Pago Pago, Am. Samoa	.070 (PT)	0 (PT)
		62.15 (WW)	0 (WW)
HI_008	Yokohama, Japan	0 (PT)	0 (PT)
		0 (WW)	0 (WW)
HI-017	Tanjung Barat, Indonesia	0 (PT)	0 (PT)
		0 (WW)	0 (WW)
HI-018	Chiba, Japan	0 (PT)	0 (PT)
		0 (WW)	0 (WW)
HI-033	Pago Pago, Am. Samoa	.064 (PT)	0 (PT)
		38.73 (WW)	0 (WW)
HI-035	Mizushima, Japan	.012 (PT)	0 (PT)
		24.77 (WW)	0 (WW)
HI-038	Chiba, Japan	.809 (PT)	0 (PT)
		33.51 (WW)	0 (WW)
HI-040	Pago Pago, Am. Samoa	0 (PT)	0 (PT)
		0 (WW)	0 (WW)
HI-044	Papette, Tahiti	0 (PT)	0 (PT)
		0 (WW)	0 (WW)

Table 3. Density values for 01 and 0139 *Vibrio* serogroups from plankton tows (PT) and whole water samples (WW).

Ballast water sediments

Results from the live analysis and culture process for sediment samples were combined, and represented by percent occurrence among the 13 samples taken (Figure 27). The FAO source region could not be accurately determined and was not included in the analysis. In the case of the Protozoa, the Ciliates, Diatomacea, and Dinoflagellata were most numerous. All of the Protozoa, with the exception of the Dinoflagellata, were present during the live analysis and were viable enough to become healthy populations during the culture process. The resting cysts and motile stages of dinoflagellates were never noted during live analysis of sediments but motile stages appeared during the culturing process. The remainder of the taxa in Figure 27 were recorded during live analysis as adult stages (Nematoda, Gastrotricha, Pteropoda, and Bivalvia) and motile larvae that settled from the water column (Cirripedia and Platyhelminthes).

Figure 27. Taxa occurring in sediment samples.

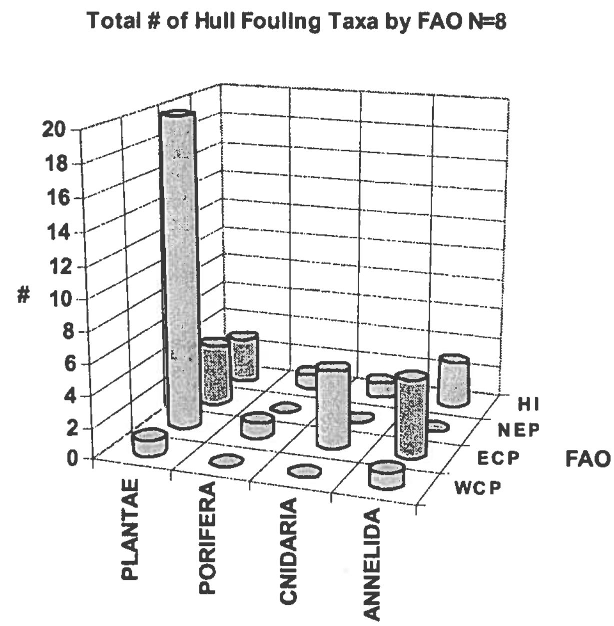


<u>Hull fouling</u>

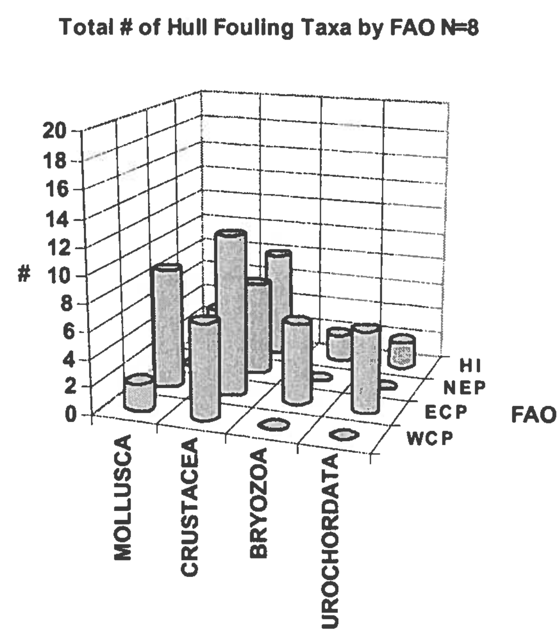
Samples for the hull fouling aspect of the study were taken from 7 towed cargo barges and 1 towed floating drydock, which were numbered HIHF-001 through HIHF-008. HIHF-003 and HIHF-004 were local interisland barges and their region of origin is recorded as HI. HIHF-008 was a floating drydock originating from San Diego (ECP) and the remaining samples were cargo barges from the ECP and NEP regions.

A species list for each vessel sampled was produced (Appendix E). Organisms were identified to the lowest taxonomic level, if this was not possible, presence was noted by an "X". The species name or the "X" notation with an asterisk (*) denote organisms not described from Hawaii or are likely not native, and a question mark indicates an unidentified species that is likely not native. The total number of different taxa and the corresponding FAO region of origin was determined and recorded (Figure 28). Figure 29 presents the number of NIS present within the total number for each group in Figure 28.

Macroalgae was the dominant organism from the samples, due to the 20 species recorded from the HIHF-002 and HIHF-008 samples, and crustaceans were the next most abundant due to the consistent presence of barnacles across samples. These two groups and the Mollusca represented the bulk of marine NIS from the overall number of recorded organisms. The HIHF-008 sample contained 15 nonindigenous macroalgae, as well as many marine invertebrates not native to Hawaii. The common marine NIS recorded from the other samples was the introduced barnacle *Chthamalus proteus*, which was common on the two interisland cargo barges sampled during the study.



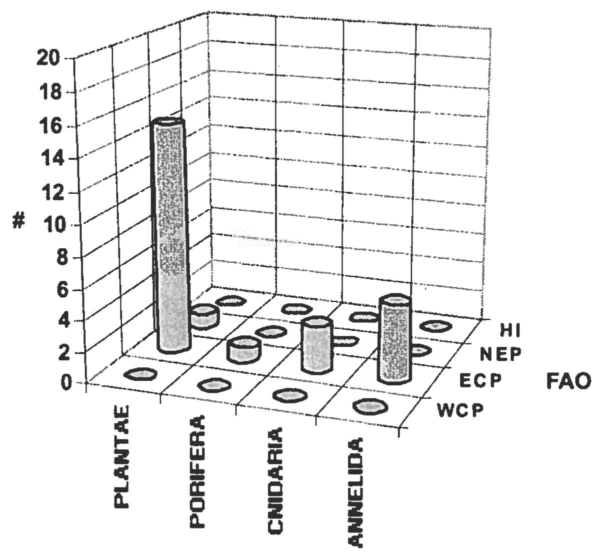
	PLANTAE	PORIFERA	CNIDARIA	ANNELIDA
WCP	1	0	0	1
ECP	20	1	5	5
NEP	4	0	0	0
HI	3	1	1	3



	MOLLUSCA	CRUSTACEA	BRYOZOA	UROCHORDATA
WCP	2	7	0	0
ECP	9	12	6	6
NEP	0	7	0	0
HI	3	8	2	2

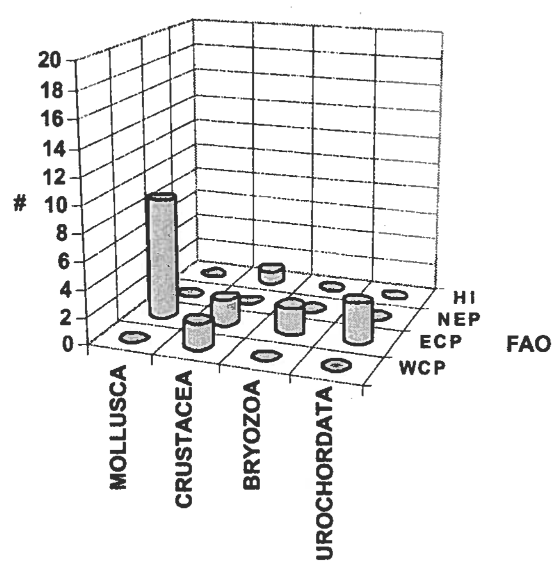
Figure 28. Total hull fouling taxa identified from HIHF-001 through HIHF-008 by vessel FAO region of operation.

Hull Fouling NIS Taxa by FAO N=8



	PLANTAE	PORIFERA	CNIDARIA	ANNELIDA
WCP	0	0	0	0
ECP	15	1	3	5
NEP	1	0	0	0
HI	0	0	0	0

Hull Fouling NIS Taxa by FAO N=8



	MOLLUSCA	CRUSTACEA	BRYOZOA	UROCHORDATA
WCP	0	2	0	0
ECP	9	2	2	3
NEP	0	0	0	0
HI	0	1	0	0

Figure 29. NIS taxa identified from HIHF-001 through HIHF-008.

VIII. DISCUSSION

The ports of Honolulu Harbor and Barber's Point Harbor are the hubs of commercial maritime shipping traffic in Hawaii. These two ports are potentially the main receiving areas for marine NIS invasions facilitated by commercial shipping. This would also create a situation in which Honolulu Harbor and Barber's Point Harbor would act as points of establishment and further spread of marine NIS to the remainder of the Hawaiian archipelago.

The types of vessels using a port and the operations they conduct relate directly to the level of ballast water discharge. In a port that exports a great deal of bulk commodities (i.e. coal, grain, and petroleum products), tankers and bulk carriers would carry and discharge the greatest amounts of ballast water. This is the case for the majority of ports that have had studies like the South Oahu Marine Invasion Shipping Study performed. Figure 30 shows average values for ballast water on board tankers and bulk carriers for some major ports in the United States, with a comparison to Hawaii. Any large commercial vessel arriving at a port to conduct bulk loading operations, whether it be a bulk carrier or tanker, will be the most likely to discharge ballast water. In the case of Hawaii, these vessels are bulk carriers and tankers operating at Barber's Point Harbor. These two vessel types carry and discharge the largest amounts of ballast water in Hawaii (Figure 15). The values in Figure 15 were based on data collected during the boarding survey component of the study and only represent a small fraction of the arriving bulk carriers and tankers. Most bulk carriers and tankers arriving to Hawaii were conducting discharge operations exclusively (see Figures 11 and 12) and were not discharging ballast water. The overseas barges were conducting discharge/load operations primarily in Honolulu Harbor (Figure 13) and most of the ballast water on board was discharged during the loading phase. Container vessels conduct discharge/load operations exclusively in Honolulu Harbor (Figure 14), but rarely discharge any ballast because of their greater stability. Of the four RoRo vessels boarded, none reported ever having to deballast while in Hawaii, and only conducted ballast operations when loading large quantities of cargo at other locations overseas. Container and RoRo vessels represented the least chance of ballast water discharge during any operations in Hawaii. The three vessels commonly conducting loading operations (overseas barges, bulk carriers, and tankers) represented the greatest source of ballast water discharge.

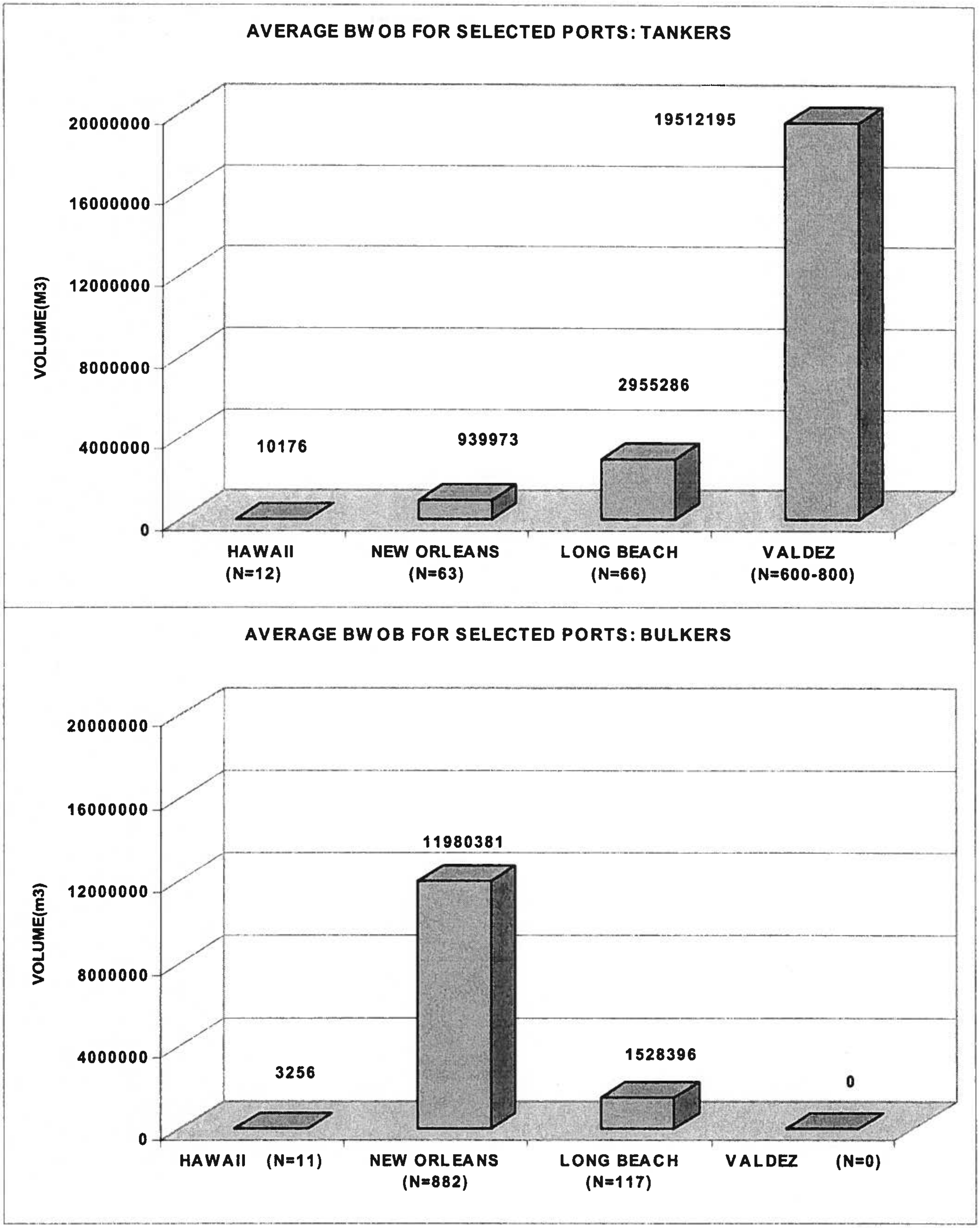


Figure 30. Average ballast water on board for tankers and bulk carriers for selected U.S ports (Carlton et.al. 1995 and Ruiz and Hines 1997).

The majority of commercial vessels arriving to Hawaii during 1997 and 1998 were container vessels and foreign fishing boats, and were followed by tankers, bulk carriers, overseas barges, and RoRos respectively (Figure 7). Container vessels were the most numerous arrival because of the domestic traffic every week from California (ECP), and the less frequent traffic from Japan (NWP) and Australia/New Zealand (SWP). These weekly arrivals from California rarely had a need to discharge ballast but the arrivals from Japan discharged on rare occasions (see Figure 17). Fishing boats were the second most common vessel type arriving to Hawaii and accounted for the majority of vessels arriving from the NWP region. The foreign fishing fleet proved to be difficult to survey because of the flexible nature of arrival patterns and short residence times in port. Overall, the foreign fishing boats were small (<150 feet) and either lacked ballast water systems or had ballast water systems that were only used in emergencies, and were not included in the study as a primary vessel. Most of the tankers were discharging cargo offshore and did not deballast. Tankers loading cargo at Barber's Point Harbor discharged roughly three-quarters of their ballast water on board. Bulk carriers conducted both discharge and loading operations at Barber's Point Harbor. The bulk carriers loading scrap metal at Barber's Point Harbor discharged all ballast water on board during these operations. Honolulu Harbor received a small amount of ballast water discharge from overseas barges and container vessels. The bulk of ballast water inputs to the port system were at Barber's Point Harbor and were connected to tankers and bulk carriers loading cargo.

The biological data showed a diverse assemblage of organisms present in ballast water samples. The most numerous of the common organisms tended to be from the ECP, SWP and NWP source regions (Figures 25 and 26). The holoplankton component was dominated by ciliated protozoans, diatoms, and copepods. The meroplankton was dominated by Platyhelminthes, Annelida, Mollusca, Decapoda and Cirrepedia. When the physical parameters of the ballast water from the ECP, SWP and NWP were compared to the local conditions (Table 2), SWP and NWP were the most similar to Hawaii. The low salinity values for the ballast water from the ECP region were deceptive. The majority of vessels that arrived to Hawaii from the ECP were from California ports that are estuarine in nature, which accounted for the lower salinity numbers. Vessels arrived with less frequency from ports in the ECP that had higher salinity, (i.e., Mexico) so this region should not be discounted as a source for marine NIS introduced through ballast water. The SWP, NWP, and ECP were common source regions for ballast water discharged by tankers during loading operations at Barber's Point Harbor. Bulk carriers loading scrap metal at Barber's Point Harbor

(Figure 12) discharged ballast water from the NWP and NEP regions (Figure 16). The discharge by overseas barges was from the NEP and OO. The OO source represents exchanged ballast water but cannot be totally discounted since Figure 25 shows coastal organisms such as mollusc larvae still present.

The results from the analysis for *Vibrio cholerae* bacteria showed the presence of cholera bacteria at low levels in 50% of the ten vessel samples (Table 3). These samples were non-random and were specifically focused on ballast water from sources in the WCP, SWP and NWP regions. Ballast water from the NWP and SWP source regions had low levels of the 01 *Vibrio cholerae* serogroup and the presence of the 0139 serogroup was not detected in any of the samples. These results indicated that cholera bacteria are being transported at low levels in the ballast water of vessels arriving to Hawaii. As developing nations enter the global market and develop harbor systems, this issue may become of more importance to Hawaii. The variability in regulations dealing with sewage discharge in ports and the increasing populations developing in coastal regions can make ballast water discharge from these source regions problematic. Knowledge of the existence of this issue is the best preventative measure for the port system of Hawaii.

The results from the analysis of ballast water sediments (Figure 27) showed that motile and resting stage organisms were present. There were no clear indications of the danger of sediments being discharged or dumped by vessels using Hawaii's port system. Vessels operated by large international shipping companies have guidelines for dealing with sediments, which are based on International Maritime Organization (IMO) regulations (IMO 1998). The possibility of inadvertent discharge of sediments exists if these IMO regulations are disregarded. It is important to realize that harmful species such as toxic dinoflagellates can dwell in this medium for years and that the potential exists for introduction. Ballast water sediments can be overlooked as a marine NIS pathway due to the extreme focus on ballast water. The sediments that collected at the bottom of ballast water tanks should be considered in conjunction with ballast water as a marine NIS pathway.

Hull fouling is overlooked as a marine NIS pathway. The difficulties of monitoring this pathway are the largest obstacle to control. The majority of vessels surveyed during SOMISS had low levels of fouling. Marine NIS that have previously been documented for Oahu were found regularly on interisland cargo barges, and these vessels may be acting as agents for the further distribution of some alien species to the other main islands. The introduced barnacle *Chthamalus proteus* was present in great numbers on the two interisland barges surveyed and this may explain its presence on all of the main islands of Hawaii except Kaho'olawe, which does not receive commercial traffic. The largest source region for hull fouling species was the ECP region (Figures 28 and 29). One sample point from the ECP region (HIHF-008, see Appendix E) had a high abundance of fouling, which created this artifact in the data. The most serious hull fouling vectors were vessels that were poorly maintained or have been inactive for long periods. The HIHF-008 sample was a vessel of this type and it had 19 species of algae (of which 14 were NIS), and representatives from seven marine invertebrate phylum, which included 16 known marine NIS. Efforts should be made to identify vessels fitting this description and to deal proactively with them before they enter the port system of Hawaii. Hull fouling must receive greater attention as a pathway for marine NIS introductions in the Hawaii and other port systems throughout the world.

Hawaii is a net importer of consumer and manufactured goods, as well as bulk cargoes. This creates a different situation from the majority of port systems that have had studies of this type. The various studies listed in Section III.C were conducted in port systems that export a great deal of bulk cargoes, such as grain, coal and petroleum products. With this type of port dynamic, bulk carriers and tankers are arriving empty of cargo and loaded with ballast, which is eventually discharged during loading operations. Since the dynamics of the port system of Hawaii are the reverse situation, it would seem that the chance for marine NIS introductions by commercial maritime shipping would not exist, but this may not necessarily be the case. The level of ballast water discharge cannot be assumed to directly correlate to the likelihood of invasion. San Francisco Bay has the highest level of invasion by marine NIS in the United States, with 230 confirmed and 125 undetermined species (Cohen 1998), but receives a relatively small amount of ballast water discharge, which is estimated at 308.8 million ga/year (Cohen 1998). The Chesapeake Bay on the Mid-Atlantic Coast of North America receives an estimated 2.3 billion ga/ year (National Ballast Water Clearinghouse 2000) of ballast water and has around 116 recorded marine NIS introductions (Ruiz et al., 1997). The quality of ballast water may be of more importance than the quantity, when determining the importance of this mechanism. A supply of quality ballast water with characteristics and organisms compatible with the discharge port could prove to be of greater importance than measures of overall quantity. Ballast water discharge is occurring at low levels in comparison to other port systems but the threat still exists because of the singular or combined effects of ballast water, ballast water sediments, and hull fouling. Maritime shipping should be considered as an anthropogenic vehicle that has the potential to introduce marine NIS no matter what operations are being conducted.

The National Invasive Species Act of 1996 (NISA) mentioned in Section IV has begun to influence ballast water operations of commercial vessels. The OO source region used in this report refers to ballast water coming from an open ocean source and is because the vessels performed either an exchange or chose to ballast after departing a port. This OO source accounted for 17% of the total ballast water on board and represents action being taken by commercial vessels to comply with voluntary guidelines described in NISA 1996. During the boarding survey all but one vessel was knowledgeable of the ballast water issue worldwide and in the United States. Many commercial shipping companies in the United States and abroad have initiated ballast water exchange protocols for their vessels, which are a proactive measure influenced by impending regulations. At present, the reporting of ballast water information from all vessels entering U.S. ports became mandatory July 1, 1999 under NISA 1996. The National Ballast Water Clearinghouse at the Smithsonian Environmental Research Center, Edgewater, Maryland collects this data and will use it to measure compliance to voluntary ballast water exchange guidelines. Legislation concerning maritime shipping as a pathway for introducing marine NIS needs to broaden its scope and consider all pathways associated with a vessel.

SOMISS was focused on a suite of mechanisms associated with maritime shipping that contribute to an overall pathway for marine NIS introductions. This study has shown that viable organisms exist in association with ballast water, ballast water sediments, and hull fouling, and are being transported to the port system of Hawaii. At present, there is no completely encompassing legislation that would provide guidance to the port authorities in Hawaii for dealing with marine NIS. Collaborative efforts by the State of Hawaii Department of Transportation and Department of Land and Natural Resources, the commercial shipping industry, the United States Coast Guard, and the scientific community will be needed to guard against future marine NIS introductions. Awareness of the marine NIS issue and its connection to maritime shipping activities, both domestic and international, will be an important component in the future efforts in protecting the marine environment of Hawaii in the face of a growing global economy.

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*Data from the National Ballast Water Information Clearinghouse, and all interpretations should be viewed as preliminary and the responsibility of the user.

APPENDIX A
A Primer for Marine Nonindigenous Species Invasion

A Primer for Marine Nonindigenous Species (NIS) Invasions

The native species of the marine and terrestrial environments of Hawaii arrived as natural biological invasions through historical time, and through evolution and adaptation became the present communities associated with the archipelago. The islands of Hawaii are one of the most isolated areas in the world and all native plants and animals exist due to the pioneering species that settled here originally. The advent of modern history has created new human – mediated, or anthropogenic, biological invasions through non-natural mechanisms.

Presently, the world is experiencing great ecological change in the coastal marine environments in every region. These areas that provide fisheries, recreation and aesthetic value are being altered by biological invasions facilitated by anthropogenic mechanisms. These invasions are decreasing biodiversity through the homogenization of distinctly separate biological communities that have evolved over millions of years. To truly understand the importance of these invasions by non-indigenous species (NIS), the species invasion process has to be understood.

SPECIES INVASIONS – NATURAL AND ANTHROPOGENIC

Over an evolutionary time scale ecosystems experience a variety of disturbances, such as species invasions and climate change. Natural species invasions (i.e., range expansions) and the resulting competition between species have established the make-up of the distinct communities that exist across the globe. In fact, natural disturbances, such as storms, encountered at intermediate levels, help maintain the diversity in ecosystems like coral reefs (Connell 1978). In terms of natural disturbance, species invasions to new regions are rare in time scales measured from the human perspective because of the barriers that must be overcome. In Hawaii's marine environment, examples of these natural barriers are ocean currents and distance from continental land masses. It is theorized that marine species that colonized Hawaii before the presence of the first Polynesians arrived on flotsam such as logs (Hedgepeth 1993) and pumice stones (Jokiel

1984, 1990). As mentioned previously, these natural species invasion events are rare and measured on the scale of geological time.

Invasions of NIS facilitated by anthropogenic influences have occurred in terrestrial, freshwater and marine habitats worldwide. Anthropogenically facilitated NIS invasions are much more prevalent and occur within noticeable spans of time. Anthropogenic dispersal breaches the natural barriers that control the rate of invasion in the natural world. If a species breaches the natural barriers and becomes established in a new region it can benefit from natural and anthropogenic dispersal mechanisms for expansion.

DYNAMICS OF NON-INDIGENOUS SPECIES INTRODUCTIONS

How important is the introduction of a new species to a region? In the realm of ecological research there have been many studies that have shown the importance of single species in controlling entire communities. In the aquatic environment, research by Paine (1966) helped to develop the theory of "keystone species" that showed the importance of a single species in structuring a shoreline community. Another example by Estes and Palmisano (1974) showed that the decline of sea otters in the Aleutian Islands led to population explosions of sea urchins; a favored food of the otters; which in turn consumed and reduced the Kelp that forms the distinctive community in the region. Further experimental evidence by Barkai and McQuaid (1988) in South Africa shows that two identical coastal island communities differing only by the density of one particular species can be very different. These are examples that show how the absence or lower occurrence of a single species can completely change the balance of a natural community. A single species in a naturally occurring community has great importance.

When the subject turns to a NIS introduction to a new region, a single species can make a difference by altering the biotic and abiotic factors that control a community. The extent and cumulative impacts of NIS introductions around the world have been documented (Elton, 1958; Mooney and Drake, 1986; Carlton, 1989) and could prove to be enormous. The effect of a single introduced species is demonstrated well with freshwater shrimp that were stocked into Flathead Lake in Glacier National Park, Montana, which reduced the salmon population through food resource competition, in turn, reducing a major nutritional source for bald eagles (Spencer et al. 1991). This is a case of an introduced species not represented at all in the receiver environment. A terrestrial example is the tree *Melaleuca* that has invaded the Florida Everglades (Ewel 1986), which has the ability to change wetlands to forest. In the Pacific, the Brown Tree Snake has invaded Guam, which has no native snakes, and it has caused the extinction of native bird species (Savidge 1987). These examples are extreme cases of NIS that are not represented by identical or similar species in the regions that they have invaded and have caused obvious ecosystem changes.

Ecologists that study the process of biological invasion still debate as to why some species are successful invaders, while similar species are not. Natural communities are made up of a number of coexisting species that utilize a common pool of resources. The natural community theoretically utilizes its resources to their full extent. If a disturbance such as a biological invasion occurs the community could react in different ways. One way would be the successful invasion of a species by its addition to the community and its allocation of resources without denying other community members. Another outcome would be the addition of a species and allocation of resources used by other community members (i.e. outcompeting) causing local extinction of one (or more) individuals. A third outcome would be the failure of the biological invasion due to factors such as unsuitability of resources and/or environment, and competition. These points only describe, in theory, the outcomes of a natural or NIS invasion to a natural community and do not allow prediction of success or failure in biological invasions.

Many efforts have been made historically to introduce organisms for aesthetic or economic reasons and these provide examples of the unpredictability of invasion success. Of six species of serranid fishes (groupers and their relatives) purposely introduced to Hawaiian waters for economic reasons in the 1950's only one (*Cephalopholis argus*) was successful, despite the fact that the serranid fauna in the area are not well represented (i.e. no competition with similar species). The same case exists with four Lutjanidae (snapper) species introduced during the same period, of which only two survived (*Lutjanus kasmira* and *Lutjanus fulvus*) in a region where this group is poorly represented (Randall and Kanayama 1972; Maciolek 1984). Another example is the house sparrow (*Passer domescticus*), which occupied the entire United States only 50 years after it was deliberately introduced for aesthetic reasons. The closely related tree sparrow (*Passer montanus*) was also intentionally introduced but has not spread too far outside the original area of introduction after over 100 years (Ehrlich 1986).

Invasions (natural and NIS) occur for many reasons, but mainly it can be attributed to the ease by which a species can colonize a new habitat. There has been research into the topics of invasion success (Pimm 1989, Carlton 1996 and Williamson and Fitter 1996) and resistance to invasion by a community (Case 1991, Baltz and Moyle 1993 and Trowbridge 1995). Carlton (1996) proposed six scenarios (Appendix Table 1) to provide a framework for understanding when invasions will occur. The scenarios assume that the successful establishment of a species is rarely related to any one environmental parameter (Crawley, 1989). A successful NIS invasion is a result of the compatibility of the needs of the invading organism and the characteristics of the invaded habitat. Accurate prediction of successful NIS invasion events has not been accomplished due to the fact that the factors governing the process are complex, and not always obvious. Factors ranging from subtle shifts in physical parameters such as temperature, salinity, and time of day combined with unlimited unique variables of the donor and receiver regions make it difficult to predict the outcome of NIS invasions. This being the case, organisms capable of adapting to a variety of environmental parameters and possessing a high reproductive rate would tend to have greater chance of invasion success. A good example would be the European green crab, *Carcinus maenus*.

The European green crab is a native to coastal regions in Western Europe and the British Isles and can thrive in a broad range of temperature, salinity, and habitats. It is an aggressive competitor for food and feeds on a wide variety of plants and animals. This species colonized eastern North America in the early 19th Century and has expanded its range throughout the world (Cohen et al 1995) (Appendix Figure 1). The introduction of *Carcinus maenus* in both eastern North America and South Africa has proven to have impacts to the native communities through allocation of food resources (Glude 1955; Griffiths et al. 1992).

Phenomenon	Process involved
Changes in donor region(DR)	<u>Environmental changes in DR lead to:</u> • Population increases of resident species(pre-exist with DR) making more individuals available for transport. • Range expansion of local species into previously uninhabitable areas of DR making these species available for transport. <u>Resident and local species may be either native or introduced</u> <u>New introductions of non-indigenous species occur within DR:</u> • New species available for transport
New donor regions	<u>New DRs become available</u> • New species available for transport • New genomes with different adaptive regimes than previously transported populations of the same species from other DRs become available for transport.
Changes in recipient region(RR)	<u>Any environmental changes in RR that lead to altered ecological, biological, chemical or physical states, thus changing the susceptibility of the RR to invasion.</u> For example, altered water quality conditions lead to: • Increased ability of pollution-intolerant species to invade. • Increased ability of pollution-tolerant species to invade.
Invasion windows	<u>Invasions occur when the proper combination of colonizing conditions occur followed by the proper combination of conditions that permit the long term establishment of reproducing populations. May or may not be dependent on changes in the RR.</u>
Stochastic inoculation events	<u>The release of a very large number of inoculants into the RR, increasing potential reproductive success.</u>
Dispersal vector changes	<u>Vector size, speed, and quality increase lead to:</u> • Increase in inoculant species diversity • Increase in abundance of inoculated species • Increase in number of post-transport 'fit' individuals <u>New vector emerges from same donor region</u>

Table 1. Scenarios for when NIS invasions may occur.

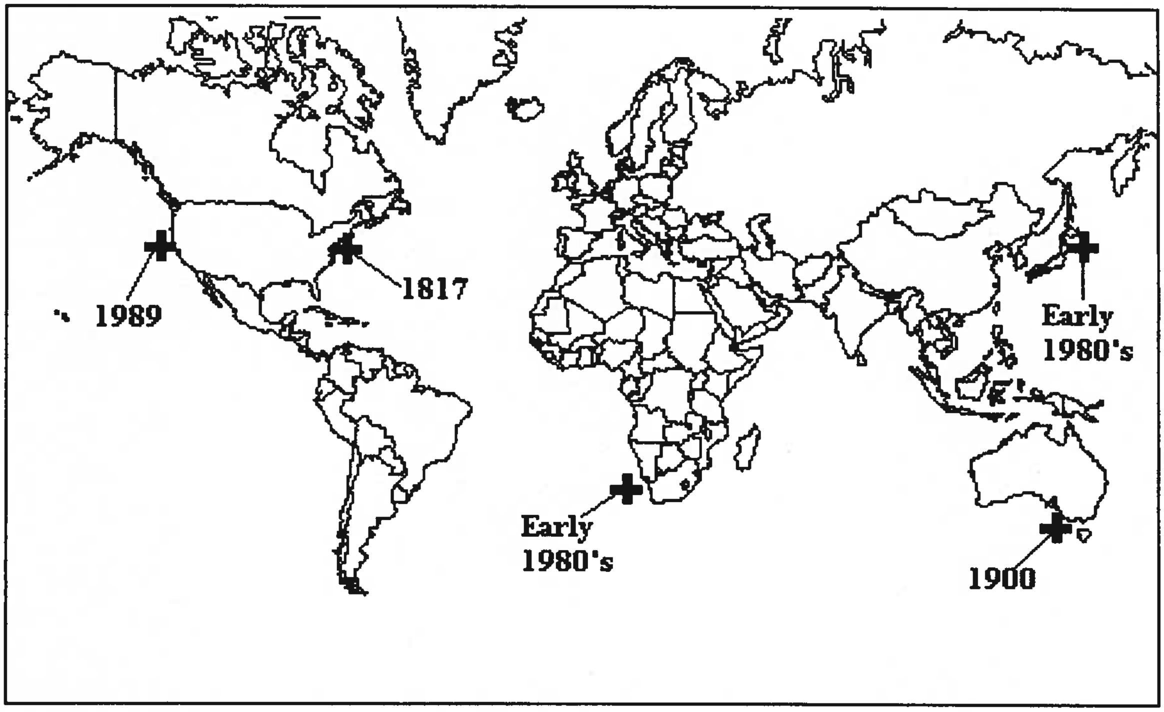


Figure 1. European Green Crab Introductions Worldwide

This type of flexible lifestyle has made the green crab a very successful NIS invader. Organisms with more rigid requirements have also proven to be good invaders. An organism could be adapted to specific predators and habitats and be introduced to an area that is devoid of similar predators, has a lower degree of competitors, and available habitat. So the deciding factor for invasion success would be the receiving habitat instead of flexibility in the invader. The ideal example of this scenario is *Spartina alterniflora*, Atlantic smooth cordgrass, which is the basis of the extensive saltmarsh habitats of the North American Atlantic Coast. These saltmarsh habitats support a unique ecosystem that is typically associated with this region, which can be contrasted with the mudflat habitats of the Pacific Coast of North America. There are subtle similarities between these systems but overall they are unique. *Spartina* has been introduced to the state of Washington and has become a pest species that could potentially cause great harm as it blankets the mudflats (Washington Sea Grant 1998).

These points cover theories as to why a NIS introduction might be successful but there are also theories regarding the failure of biological invasions. Failure of a NIS to establish, despite seemingly suitable environmental conditions, can theoretically be attributed to the biological resistance of the receiving habitat.Appendix Table 2 shows the three common theories that support biological resistance as a factor in preventing establishment of NIS.

Table 2. Theories for biological resistance to species invasions

1) Species-rich communities may be more resistant to invasions by introduced species than species-poor communities (Elton 1958, Diamond and Case 1986 and Case 1991)
2) Invading species from "sophisticated" biotas (with highly competitive and defensive abilities) become established more frequently than species from "unsophisticated" biotas (Vermeij 1991).
3) The presence of indigenous species ecologically and/or taxonomically similar to the invading species may contribute to biotic or community resistance (Moulton and Pimm 1984, Diamond and Case 1986 and Baltz and Moyle 1993).

The first theory has been repeatedly observed (review by Ross 1991) in species such as stream fishes. Continental species tend to invade island communities more successfully than the reverse situation, which is an example of the second proposed theory. Diamond and Case (1986) refer to communities that are "naïve" in relation to the third theory. This means that a community has had no experience with similar species and is therefore easier to invade by this "novel" species. These are theories to explain biotic resistance, although the underlying mechanisms are not understood.

MARINE NON-INDIGENOUS SPECIES INVASIONS

Marine habitats can be considered robust when dealing with disturbances such as climate change and glaciation measured over millions of years. When disturbances are more intense over shorter time scales, the marine environment can be considered to be fragile. It is these short time frames and intense disturbances that are relevant to human society and the anthropogenic effects induced on marine habitats. The introduction of marine NIS can cause irreversible alterations to marine communities and is an anthropogenic disturbance that has become of great concern.

In the terrestrial environment the issue of NIS invasion and control has been dealt with as a management issue for some time. The concept of marine NIS is a relatively new issue, in comparison (Office of Technology Assessment 1993). In the Unites States, awareness of marine NIS in the federal government and the scientific community has increased more since the late 1980's than in the past 30 years (Carlton 1993). This can be attributed to the invasion of the Eurasian Zebra Mussel *Dreissena polymorpha*, which was first collected in the Great Lakes in 1988 (Nalepa and Schloesser 1993). The Zebra Mussel has overwhelmed the benthic communities of the Great Lakes but the economic impacts and not the ecological ramifications are what brought it to the attention of public officials. The Zebra Mussel is a prolific fouling organism in its new environment - the Great Lakes - and one of the consequences is the clogging of cooling intakes of power plants. The cost of control of the Zebra Mussel is expected to reach US$500 million by the year 2000(USA Ballast Book 1998).

Marine NIS invasions are a worldwide problem with economic and ecological consequences. Appendix Table 3 gives a few examples of marine NIS invasions worldwide and includes potential and proven impacts. These marine NIS demonstrate the variety of organisms that have invaded coastal habitats due to anthropogenic facilitation. Maritime shipping activity is blamed for the introduction of all the species listed, with the exception of *Caulerpa taxifola*, which was accidentally released from the Monaco Aquarium. Incidentally, *Rapana venosa*, which was discovered in the southern Chesapeake Bay in 1998 (Harding and Mann 1999), was likely introduced from the Black Sea, where it is and alien species introduced from Japan. *Carcinus maenus* and *Asterias amurensis* both are likely to cause ecological changes, as epibenthic predators, in the areas in which they have been introduced. *Potamocorbula amurensis* has become the most numerous benthic invertebrate in its new habitat in San Francisco Bay and could cause drastic changes due to its ability to filter out large quantities of plankton from the water column, thus changing the base of the food chain in this habitat (Cohen and Carlton 1995).

The species listed in Appendix Table 4 are examples of marine NIS that have invaded Hawaii. The macroalgae *Kappaphycus* and the snapper *Lutjanus kasmira* both were intentionally introduced and appear to have effects on the communities in which they are present. *Chthamalus proteus*, *Mycale armata* and *Carijoa riisei* all have been reported recently but likely have present in Hawaii for some time (Southward et al, 1997, Coles et al, 1997).

Species	Area(s) and Date of Introduction	Native Range	Impacts
Asterias amurensis (starfish)	Australia(1980's)	Japan, Korea	Negative impacts on the shellfish industry and local coastal ecology.
Carcinus maenus (crab)	North America (late 1800's-Atlantic coast, 1990's-Pacific coast), South Africa(1990's), Japan(1980's), Australia(early 20th century)	Western Europe, British Isles	Negative impacts on shellfish industry and local coastal ecology.
Caulerpa taxifola (macroalgae)	Mediterranean(1980's)	West Indies	Overgrowth of local species and habitats with impacts on local ecology.
Potamocorbula amurensis (clam)	San Francisco Bay(1980's)	Asia	Drastic change in local ecosystem with unknown long term effects.
Rapana venosa (snail)	North America-Atlantic coast(1990's)	Japan	Potential impacts to shellfish industry with unknown long term ecosystem impacts.

Table 3. Examples of marine NIS introductions worldwide.

Species	**Area(s) and Date of introduction**	**Native Range**	**Impacts**
Chthamalus proteus (barnacle)	Main Hawaiian Islands (after 1973)	Tropical western Atlantic	Impacts unknown
Mycale armata (sponge)	Pearl harbor, Oahu (recorded in 1996)	Australia, Indo-Malaysia	Impacts unknown
Kappaphycus sp. (macroalgae)	Kaneohe Bay (1970's)	Philippines	Overgrowth of coral reefs
Carijoa riisei (octocoral)	Main Hawaiian Islands (after 1974)	Tropical western Atlantic	Impacts unknown
Lutjanus kasmira (fish)	Oahu, Intentionally introduced (1950's)	Marquesas	Competition with native reef fish

Table 4. Examples of marine NIS introductions in Hawaii.

MARINE NIS PATHWAYS

Earlier, it was mentioned that biological invasions by NIS occur by both natural and anthropogenic means. Biological invasions by marine NIS brought about by anthropogenic influences have occurred throughout the world through a variety of mechanisms including maritime shipping, live seafood and bait shipments, aquaculture, shipments of commercial and institutional aquarium species and the activities of education and research institutions.

Aquaculture and Aquarium Industry

A) Introduction of target organisms
- Accidental release from commercial culture and holding facilities
- Accidental release from research facilities
- Accidental release during shipment to and from facilities
- Deliberate release

B) Introduction of non-target organisms
- Release of by-catch species shipped with target organisms
- Release of epibionts associated with target species
  - Parasites
  - Disease
- Release of organisms from transport medium
  - Biota associated with holding water
    - Plankton and bacteria
  - Biota associated with sediments, detritus, and packing materials
    - Adult and juvenile invertebrate organisms
    - Resting stages of phytoplankton
    - Bacteria
- Deliberate release

Fisheries

A) Introduction of organism by fisheries activities
- Movement of species in bait stocks
  - Bait species
  - Associated biota in transport media (see above)
  - Epibionts (see above)
- Water in holding wells in vessels
  - Plankton and bacteria
- Fouling organisms on fishing gear

Table 5. Pathways for NIS introduction through activities associated with aquaculture, the aquarium industry, and fisheries activities

The intentional movement of marine species for the purpose of aquaculture or fisheries enhancement is part of the history of human movement patterns and also continues today for commercial reasons. The intentional movement of aquaculture and fisheries species worldwide is second only to ships in the historical role of introducing marine NIS (Carlton 1992). These intentional introductions have also provided a transport pathway for epibiota (parasites, pathogens, and diseases) that accompany the species (Carlton 1992). Appendix Table 5 gives a breakdown of activities and mechanisms associated with aquaculture/fisheries that have contributed to marine NIS introductions. This list is inclusive for private, commercial, institutional, and government activities.

Another anthropogenic influence is the altering of the landscape to such a degree that natural land barriers are eliminated. In the marine realm this is demonstrated by the construction of canals. The classic example is the Suez Canal, which was opened in 1869. Since the completion of the canal, there has been a unidirectional migration of species from the Red Sea to the eastern Mediterranean, referred to as a "Lessepsian migration" (Por 1978). This event has introduced an estimated 500 species to the eastern Mediterranean and most have successfully colonized and spread.

The maritime shipping industry has moved marine species around the world unintentionally for centuries. Wooden hull vessels carried large communities of fouling species wherever they went and are likely to be responsible for the worldwide distribution of some species of shipworms, which bore into wooden substrate. The advent of modern metal ships and advanced anti-fouling coatings would seem to have eliminated the problem of marine NIS introduction by maritime vessels. This is far from the case. New and larger vessels carry marine larvae and adults within ballast water tanks and fouling organisms still colonize vessel hulls in certain sheltered areas and locations where fouling paint is compromised. The primary pathway identified for marine NIS introductions has been maritime vessel traffic to ports around the world through ballast water discharge (Williams et al., 1988; Carlton & Geller 1993). Adult and larval forms of species can be transported from previous areas of vessel operation and these organisms are discharged at ports of call worldwide.

Whether natural or anthropogenically facilitated, marine NIS invasions are a complex issue. Presently, the world is experiencing great ecological change in the coastal marine environments in every region. These areas are being altered by biological invasions facilitated by anthropogenic mechanisms. The health of these environments is crucial to the services and resources that provide a form of security to the global community. There are many issues that effect the health of marine environments, NIS invasions is one that has not historically been dealt with before. Communication of the issue of marine NIS to individuals responsible for decisions that affect the marine environment is the only way to prevent and control further impacts from this disturbance.

APPENDIX B
Ballast Water Capacity of Various Vessel Types

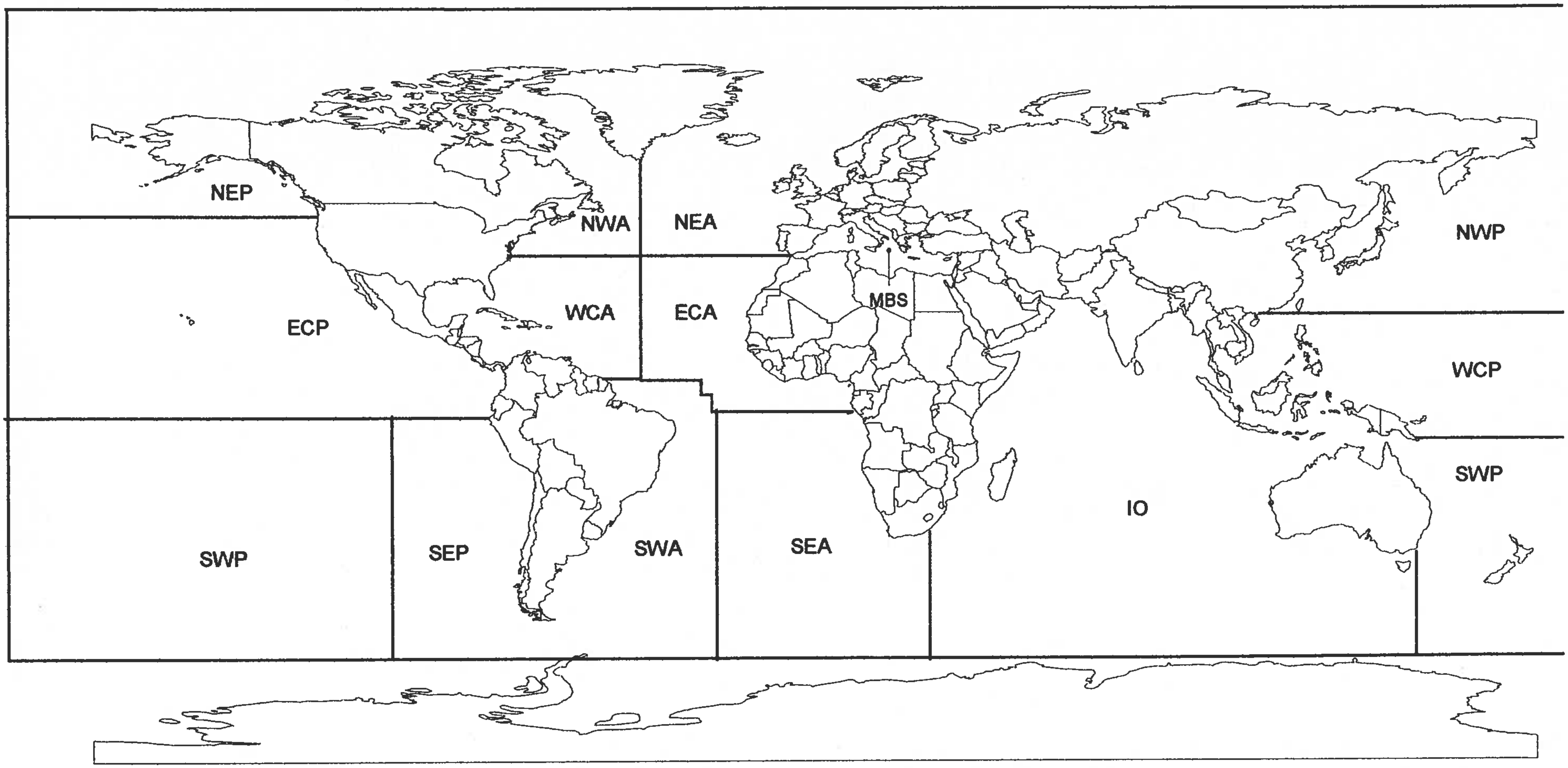
APPENDIX B

SPECIFICATIONS OF BALLAST WATER (BW) CAPACITIES AND SPECIFIC BALLAST TANK VOLUMES FOR CERTAIN VESSELS (SOMISS 2000)*

Vessel Type (length in ft)	Total BW Capacity (m^3)	Tank Type and BW Volume (m^3)	
Tanker (< 700)	12507	Forepeak	965
		Afterpeak	359
		Wing Tank	2947
Container (<700)	6165	Forepeak	408
		Afterpeak	281
		Double Bottom	291
Container (>700)	14186	Forepeak	317
		Afterpeak	244
		Double Bottom	327
Roll-on Roll-off	8437	Forepeak	656
		Afterpeak	908
		Double Bottom	1223
Bulk Carrier (>700)	48035	Forepeak	1905
		Afterpeak	615
		Wing Tank	2945
		Center Cargo Hold	12514
Bulk Carrier (<700)	18662	Forepeak	918
		After peak	187
		Wing Tank	455
		Center Cargo Hold	8875
Barge	4570	Afterpeak	1101
		Wing Tank	893

*** Vessels rarely carry the full ballast capacity and the ballast tank volumes given were chosen randomly. Ballast tank volumes vary greatly between and within vessel types.**

APPENDIX C
United Nations Food and Agricultural Organization (FAO)
Waters of the World



Waters of the world by United Nations' Food and Agricultural Organization (FAO) region. ECP, Eastern Central Pacific; IO, Indian Ocean; MBS, Mediterranean - Black Sea; NEA, Northeast Atlantic; NEP, Northeast Pacific; NWA, Northwest Atlantic; NWP, Northwest Pacific; SEA, Southeast Atlantic; SEP, Southeast Pacific; SWA, Southwest Atlantic; SWP, Southwest Pacific; WCA, West Central Atlantic; WCP, West Central Pacific.

APPENDIX D
South Oahu Marine Invasion Shipping Study
Standardized Data Sheets

APPENDIX 1: BALLAST WATER REPORTING FORM

(TO BE PROVIDED TO PORT STATE AUTHORITY UPON REQUEST)

1. VESSEL INFORMATION

Vessel Name:	Type:	IMO Number:
Owner:	GT:	Call Sign:
Flag:	Arrival Date:	Agent:
Last Port and Country:		Arrival Port:
Next Port and Country:		

2. BALLAST WATER

Specify units: m^3, MT, LT, ST
Total Ballast Water on Board:
Total Ballast Water Capacity:

3. BALLAST WATER TANKS BALLAST WATER MANAGEMENT PLAN ON BOARD? YES ____ NO ____ MANAGEMENT PLAN IMPLEMENTED? YES___ NO___

TOTAL NO. OF TANKS ON BOARD _______ NO. OF TANKS IN BALLAST _______ **IF NONE IN BALLAST, GO TO NO. 5.**

NO. OF TANKS EXCHANGED _______ NO. OF TANKS NOT EXCHANGED _______

4. BALLAST WATER HISTORY: RECORD ALL TANKS THAT WILL BE DEBALLASTED IN PORT STATE OF ARRIVAL; IF NONE GO TO NO. 5.

Tanks/Holds (List multiple sources/tank separately)	BW SOURCE				BW EXCHANGE circle one: Empty/Refill or Flow Through					BW DISCHARGE			
	DATE DDMMYY	PORT or LAT. LONG.	VOLUME (units)	TEMP (units)	DATE DDMMYY	ENDPOINT LAT. LONG.	VOLUME (units)	% Exch.	SEA Hgt. (m)	DATE DDMMYY	PORT or LAT. LONG.	VOLUME (units)	SALINITY (units)

Ballast Water Tank Codes: Forepeak=FP, Aftpeak=AP, Double Bottom=DB, Wing=WT, Topside=TS, Cargo Hold=CH, O=Other

IF EXCHANGES WERE NOT CONDUCTED, STATE OTHER CONTROL ACTION(S) TAKEN: ________________

IF NONE, STATE REASON WHY NOT: ________________

5. IMO BALLAST WATER GUIDELINES ON BOARD (RES. A....(20))? YES ____ NO ____

Date:______________ **BALLAST DATA SHEET** **HI - ____________**

Boarding Party:

	TANK 1		TANK 2
Tank/hold # and name			
Date(s) ballasted			
BW Source(s)			
BW Capacity of Tank (units?)			
BW Quantity in Tank (units?)			
Water Depth in Tank (m)			

BALLAST SAMPLES TANK 1

Sample Type	Jar #	Tow Hgt (m) or Whole Water
	1-1	
	1-2	
	1-3	
	1-4	
	1-5	
	1-6	

BALLAST SAMPLES TANK 2

Sample Type	Jar #	Tow Hgt (m) or Whole Water
	2-1	
	2-2	
	2-3	
	2-4	
	2-5	
	2-6	

BALLAST WATER MEASUREMENTS

TANK1

DEPTH (m)	TEMP (C°)	SALINITY (ppt)	DO (mg/l)

TANK 2

DEPTH (m)	TEMP (C°)	SALINITY (ppt)	DO (mg/l)

SHIPSIDE WATER MEASUREMENTS

DEPTH (m)	TEMP (C°)	SALINITY (ppt)	DO (mg/l)

NOTES:

____

____

____

____

____

____

____

BALLAST TANK PARTICULARS

VESSEL NAME:

DATE:

HI -

VESSEL TYPE:

TANK TYPE	CAPACITY	UNITS?	BWOB	UNITS?

BALLAST ANALYSIS DATA SHEET

Analysis Date: ____________________ Ship Name: ________________________________

Analysis Time: ____________________ Your Initials: ____________

General Notes: ____

____

	LIVE ANALYSIS						DEAD ANALYSIS								
TAXON	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Cultured? (#)	NOTES	Abundant (>100)	Common (10-100)	Rare (<10)	Voucher? (#)	Photos(roll,slide#)	Subsample 1	Subsample 2	Split	NOTES
DINOFLAGELLATA															
Ceratium															
Peridinium															
DIATOMACEA															
Discoid															
Centrate															
Pennate															
"PROTOZOA"															
Radiolaria															
Foraminifera															
Tintinnida															
Ciliates															
CNIDARIA															
Hydrozoa															
Anthozoa															
Scyphozoa															
unid. medusa															
CTENOPHORA															
PLATYHELMINTHES															
Turbellaria															
Müller's or Götte's larvae															
NEMATODA															
ROTIFERA															
GASTROTRICHA															
SIPUNCULA															
NEMERTEA															

	LIVE ANALYSIS						DEAD ANALYSIS								
TAXON	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Cultured? (#)	NOTES	Abundant (>100)	Common (10-100)	Rare (<10)	Voucher? (#)	Photos(roll,slide#)	Subsample 1	Subsample 2	Split	NOTES
ANNELIDA															
Polynoidae															
Phyllodocidae															
Spionidae															
Nephthydae															
Unknown poly. larv.															
MOLLUSCA															
Gastropoda															
Bivalvia															
Pteropoda															
CRUSTACEA															
Cirripedia															
nauplii															
cyprids															
Copepoda															
nauplii															
copepodites															
Harpacticoida															
Calanoida															
Cyclopoida															

	LIVE ANALYSIS						DEAD ANALYSIS								
TAXON	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Cultured? (#)	NOTES	Abundant (>100)	Common (10-100)	Rare (<10)	Voucher? (#)	Photos(roll,slide#)	Subsample 1	Subsample 2	Split	NOTES
Poecilostome															
other															
Amphipoda															
Gammaridea															
Hyperiidea															
Caprellidea															
Isopoda															
Decapoda															
zoea															
megalopa															
Brachyura															
Caridea															
Cladoceran															
Anomura															
pagurid zoea															
porcellanid zoea															
megalops															
Tanaidacea															
Mysidacea															
Cumacea															
Stomatopoda															
Euphausiacea															
Ostracoda															
other Crustacean nauplii															
CHELICERATA															
BRYOZOA															
Cyphonautes larvae															
PHORONIDA															
BRACHIOPODA															
CHAETOGNATHA															
ECHINODERMATA															
Asteroidea															
Ophiuroidea															
Echinoidea															
Holothuroidea															
Unknown															
HEMICHORDATA															

	LIVE ANALYSIS						DEAD ANALYSIS								
TAXON	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Cultured? (#)	NOTES	Abundant (>100)	Common (10-100)	Rare (<10)	Voucher? (#)	Photos(roll,slide#)	Subsample 1	Subsample 2	Split	NOTES
CHORDATA															
Ascidiacea															
Thaliacea															
Larvacea															
Fish															
OTHER															
Eggs															
Planuloids															
Trochophores															
"PLANTAE"															
Rhodophyta															
Chlorophyta															
Phaeophyta															
Zosteraceae															

HULL FOULING ANALYSIS DATA SHEET

Analysis Date: ____________________
Analysis Time: ____________________

Ship Name: ____________________
Your Initials: ______________

General Notes: ____
____

TAXON	HULL VISUAL ANALYSIS: Present?	Abundant (>100)	Common (10-100)	Rare (<10)	LAB ANALYSIS: Present?			Cultured? (s)	NOTES
"PLANTAE"									
Rhodophyta									
Chlorophyta									
Phaeophyta									
Zosteraceae									
"PROTOZOA"									
Radiolaria									
Foraminifera									
Tintinnida									
Ciliates									
HYDROZOA									
CTENOPHORA									
PORIFERA									
PLATYHELMINTHES									
Turbellaria									
Müller's or Götte's larvae									
NEMATODA									
ROTIFERA									
GASTROTRICHA									
SIPUNCULA									
NEMERTEA									
ANNELIDA									
Spionidae									
Serpulidae									
Nereid									
Gastropoda									
Bivalvia									
Pteropoda									
CRUSTACEA									
Cirripedia									
nauplii									
cyprids									
Copepoda									
nauplii									
copepodites									
Harpacticoida									
Calanoida									
Cyclopoida									
Poecilostome									

TAXON	HULL VISUAL ANALYSIS				LAB ANALYSIS				NOTES
	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Present?			Cultured ? (#)	
Amphipoda									
Gammaridea									
Hyperiidea									
Caprellidea									
Isopoda									
Decapoda									
zoea									
megalopa									
Brachyura									
Caridea									
Cladoceran									
Anomura									
pagurid zoea									
porcellanid zoea									
megalops									
Tanaidacea									
Mysidacea									
Cumacea									
Stomatopoda									
Euphausiacea									
Ostracoda									
other Crustacean nauplii									
CHELICERATA									
BRYOZOA									
Cyphonautes larvae									
PHORONIDA									
BRACHIOPODA									
ECHINODERMATA									
Asteroidea									
Ophiuroidea									
Echinoidea									
Holothuroidea									
Unknown									
HEMICHORDATA									
CHORDATA									
Ascidiacea									
Fish									
OTHER									
Eggs									
Planuloids									

BALLAST SEDIMENT ANALYSIS DATA SHEET

Analysis Date: ____________________
Analysis Time: ____________________

Ship Name: ________________________________
Your Initials: ____________

General Notes:____

	80 Micron Filtrate							25 Micron Filtrate								
TAXON	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Subsample 1	Subsample 2	Split	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Subsample 1	Subsample 2	Split	Cultured? (#)	Notes
DINOFLAGELLATA																
SILICOFLAGELLATES																
DIATOMACEA																
Discoid																
Centrate																
Pennate																
"PROTOZOA"																
Radiolaria																
Foraminifera																
Tintinnida																
Ciliates																
CTENOPHORA																
PLATYHELMINTHES																
Turbellaria																
Müller's or Götte's larvae																
NEMATODA																
ROTIFERA																
GASTROTRICHA																
SIPUNCULA																
NEMERTEA																

TAXON	80 Micron Filtrate							25 Micron Filtrate								Notes
	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Subsample1	Subsample 2	Split	Present	Abundant (>100)	Common (10-100)	Rare (<10)	Subsample 1	Subsample 2	Split	Cultured? (#)	
ANNELIDA																
Polynoidae																
Phyllodocidae																
Spionidae																
Nephthydae																
Unknown poly. larv.																
MOLLUSCA																
Gastropoda																
Bivalvia																
Pteropoda																
CRUSTACEA																
Cirripedia																
nauplii																
cyprids																
Copepoda																
nauplii																
copepodites																
Harpacticoida																
Calanoida																
Cyclopoida																

	80 Micron Filtrate							25 Micron Filtrate								
TAXON	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Subsample 1	Subsample 2	Split	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Subsample 1	Subsample 2	Split	Cultured? (#)	Notes
Poecilostome																
other																
Amphipoda																
Gammaridea																
Hyperiidea																
Caprellidea																
Isopoda																
Decapoda																
zoea																
megalopa																
Brachyura																
Caridea																
Cladoceran																
Anomura																
pagurid zoea																
porcellanid zoea																
megalops																
Tanaidacea																
Mysidacea																
Cumacea																
Stomatopoda																
Euphausiacea																
Ostracoda																
other Crustacean nauplii																
CHELICERATA																
BRYOZOA																
Cyphonautes larvae																
PHORONIDA																
BRACHIOPODA																
CHAETOGNATHA																
ECHINODERMATA																
Asteroidea																

Ophiuroidea																
Echinoidea																
Holothuroidea																
Unknown																
HEMICHORDATA																

	80 Micron Filtrate							25 Micron Filtrate								
TAXON	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Subsample 1	Subsample 2	Split	Present?	Abundant (>100)	Common (10-100)	Rare (<10)	Subsample 1	Subsample 2	Split	Cultured? (#)	Notes
CHORDATA																
Ascidiacea																
Thaliacea																
Larvacea																
Fish																
OTHER																
Eggs																
Planuloids																
Trochophores																
"PLANTAE"																
Rhodophyta																
Chlorophyta																
Phaeophyta																
Zosteraceae																

APPENDIX E
South Oahu Marine Invasion Shipping Study
Hull Fouling Survey Species List

Vessel/ FAO Region	HIHF-001/WCP	HIHF-002/ECP	HIHF-003/HI	HIHF-004/H	HIHF-005/NEP	HIHF-006/NEP	HIHF-007/NEP	HIHF-008/ECP
PLANTAE								
Rhodophyta				Amphiroa sp.				Ceramium gardneri*
								Agloathamnion cordatum*
								Dasya sinicola*
								Pterosiphonia bipinnata*
								Brachioglossum woodii*
								Ceramium sp
								Grateloupia sp.*
								Rhodoptilum plumosum*
								Schizymenia dawsonii*
								Antithamnion hubbsii*
								Halymenia sp*
								Callithamnion acutum*
								Antithamnion sp.*
Chlorophyta	Enteromorpha sp.	Enteromorpha sp.	Enteromorpha clathrata	Hincksia sp.	Enteromorpha clathrata	Enteromorpha prolifera	Pilayella sp *	Enteromorpha intestinalis
						Feldmania indica		Ulva rigida
								Enteromorpha clathrata (var. crinata)*
Phaeophyta								Dictyota flabellata*
								Sargassum muticum*
								Hincksia mitchelliae
PORIFERA			X	X				X(?)
CNIDARIA								
Hydrozoa		Obelia dichotoma						X(?)
Anthozoa								Order Actiniaria-Diadumene leucolena*
								Order Corallimorpharia-Corynactus californica*
								Order Scleractinia-Balanophyllia elegans*

[*]=NIS to Hawaii
[X]=Unidentified
[X(?)]=Unidentified,likely NIS

Vessel/FAO Region	HIHF-001/WCP	HIHF-002/ECP	HIHF-003/HI	HIHF-004/HI	HIHF-005/NEP	HIHF-006/NEP	HIHF-007/NEP	HIHF-008/ECP
ANNELIDA								
Syllidae								X
Nereid				X				X
Spionodae			Polydora sp.					
Serpulidae	Hydroides sp.			Hydroides sp.				X*
Sabellidae								X*
Polynoidae								X*
MOLLUSCA								
Vermetidae								Serpulorbis squamigerus*
Nudibranchia								Cuthona lagunae*
Gastropoda	Crepidula sp.		Crepidula sp.					Crepidula lingulata*
								Crepidula onyx*
Bivalvia	Ostrea sandvichensis		Ostrea sandvichensis	Ostrea sandvichensis				Mytilus galloprovincialis*
								Ostrea conchaphila*
								Protothaca laciniata*
								Pseudochama sp.*
								Musculus sp.*

[*]=NIS to Hawaii
[X]=Unidentified
[X(?)]=Unidentified,likely NIS

Vessel/FAO Region	HIHF-001/WCP	HIHF-002/ECP	HIHF-003/HI	HIHF-004/HI	HIHF-005/NEP	HIHF-006/NEP	HIHF-007/NEP	HIHF-008/ECP
CRUSTACEA								
Cirrepedia	Chthamalus proteus*	Chthamalus proteus*	Chthamalus proteus*	Chthamalus proteus*	Chthamalus proteus*	Lepas anatifera	Lepas anatifera	Balanus amphitrite
	Euraphia hembelli	Megabalanus californicus*	Balanus reticulatus	Balanus reticulatus	Balanus reticulatus			
	Nesochthamalus intertexus	Lepas anatifera	Balanus amphitrite	Euraphia hembelli	Balanus amphitrite			
	Tesseropora pacifica	Conchoderma virginatum	Megabalanus tanagrae	Megabalanus tanagrae				
	Megabalanus californicus*	Conchoderma auritum						
Gammaridea	Jassa falcata*	X				Hyale laie		X
						Jassa lilipuna		
Isopoda	Anatanais insularis							Sphaeroma sp.
Decapoda								Plagusia immaculata
								Pachygrapsus crassipes
								Pilumnus oahuensis
BRYOZOA			X	X				Bugula flabellata*
								Bugula stolonifera
								Bugula neritina
								Zoobotryon verticillatum
								Celleporaria brunnea*
								Schizoporella unicornus
UROCHORDATA								
Ascidiacea			Microcosmus exasperatus	Microcosmus exasperatus				Microcosmus squamiger*
								Perophora annectens
								Symplegma reptans*
								Botryllus (=Botrylloides) simodensis
								Botryllus (=Botrylloides) perspicuus*
								Styela canopus

[*]=NIS to Hawaii
[X]=Unidentified
[X(?)]=Unidentified,likely NIS