Reducing Potential Impact of Invasive Marine Species in the Northwestern Hawaiian Islands Marine National Monument

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0.1 Conclusions

- Populations of non-indigenous marine species that have already colonized areas of the main Hawaiian Islands (MHI) represent the most likely source of invasive species in the Northwest Hawaiian Islands (NWHI) based on the proximity and pattern of ship movements associated with the MHI.

- The non-indigenous marine macroalgae, invertebrates and fish that are currently known from the MHI can be found from littoral zones to deep water coral beds. The few alien species known from the NWHI are restricted to the anthropogenic habitats of Midway Atoll and French Frigate Shoals. Only the marine hydroid *Pennaria disticha* and the snapper *Lutjanus kasmira* are found throughout the NWHI archipelago.

- Formal and developing regulations on the national level, such as National Aquatic Invasive Species Act 2005, provide guidelines for preventative measures for ballast water but other mechanisms of non-indigenous species transport associated with maritime activities, such as hull fouling, also exist and need attention.

- Marine debris has been shown to have the ability to transport non-indigenous species to the NWHI. Modes of transport such as derelict fish nets are problematic to manage but the impact of other anthropogenic debris, such as Fish Attraction Devices (FAD) deployed by the State of Hawai‘i, can be minimized.

0.2 Recommendations

0.2.1 Transport Mechanisms

- Establish formal administrative rules and codes of conduct to minimize exposure from the variety of potential transport mechanisms for non-invasive species transport to the Northwestern Hawaiian Islands Marine National Monument.
- Examples of these are as follows:

  - Marine Debris (e.g. derelict fishing gear, derelict Fishing Aggregation Devices or FAD’s)

  - Maritime Vessels
    - Research Platforms (public sector, academic, private sector)
    - Personal Craft
    - Commercial Platforms (cargo, fisheries, cruise/ecotourism)
    - Military (U.S. Navy, U. S. Coast Guard)

  - Research and Conservation Activities

- No release of any organism collected on another island
- Proper storage and disposal of marine debris
- No sand or soil transport
- Inspection and cleaning of marine construction material
- Inspection and sanitation of dive boats, SCUBA gear, and instrument arrays prior to entry into the Northwestern Hawaiian Islands Marine National Monument

➢ Fisheries Activities
- No aquaculture or small scale rearing of algae, invertebrates or fish
- No intentional introductions for any purpose
- No disposal of bait or seafood
- Sanitation of live wells and fishing gear prior to entry

• Establish management strategy for transport mechanisms based on:

➢ Pro-active Measures

- Monitoring: Strict monitoring of vessel traffic entering and operating in the Northwestern Hawaiian Islands Marine National Monument
- Vectors:

<u>Ballast Water and Sediments</u>: Preventative measures to minimize transport of non-invasive species by ballast water and sediments from source ports to the Northwestern Hawaiian Islands Marine National Monument are as follows:

1. Ballast water exchange in water deeper than 2000 m to flush out any surviving organisms taken in at ports, if pre-intake measures are not in place.
2. Pre-intake measures such as filtration, ultraviolet treatment, sonic treatment, or other measures that exist.
3. Do not take in water from global hotspots where organisms that may be a threat to the environment exist, such as from areas that are experiencing toxic algal blooms or waterborne disease outbreaks.
4. Do not take in ballast water at night since a more diverse assemblage of organisms may be present.
5. Avoid areas with high sedimentation or shallow waters, poor water quality, or regions near sewage discharge.
6. Post-intake extermination of organisms with biodegradable chemicals, heat, or electrical treatment.
7. Clean ballast tanks regularly and dispose of sediments properly.
8. Inspect deck surfaces and enclosed voids for sediment accumulations and remove and dispose of properly.

Hull Fouling: In order to prevent transfer of introduced species by vessel hull fouling, the inspection of all vessels planning to enter the Northwestern Hawaiian Islands Marine National Monument is imperative and should include all surfaces at and below the waterline. Preventative measures for vessels operating regularly in the Northwestern Hawaiian Islands Marine National Monument should include:

1. Frequent underwater visual or video inspections
2. Proper maintenance
3. Regular cleanings at shipyards
4. Sea chest and piping time-released biocides

- Reactive Measures
    - Rapid Response: Form partnerships with other agencies to create a core rapid response team that has the capacity to investigate a variety of disturbances, to include non-indigenous species introductions.

- Post Event Measures
    - Eradication: Although eradication in the marine environment is problematic, devise scheme for attempts to eliminate a non-indigenous species introduction that has been discovered in its early stages.

0.2.2 Information Collection and Dissemination

- In order to preserve the integrity of the Northwestern Hawaiian Islands Marine National Monument from the standpoint of marine non-indigenous species, there are preventative and defensive measures that can be implemented to reduce the risk of large-scale invasions. Many of these have been proven effective in other regions.

    1. Detect and eradicate introductions early before they have the opportunity to spread
    2. Prevention of accidental and deliberate introductions
    3. Better understanding of current patterns and oceanographic conditions that can favor or reduce dispersal and spread
    4. Monitoring to assess changing conditions
    5. Understanding dispersal patterns
    6. Continue activities pertaining to species richness and diversity as part of establishing baseline information, and pursue research pertaining to biogeography focused on connectivity and larval transport
    7. Include the issue of marine non-indigenous species in education and outreach activities

8. Integrate the concepts of marine non-indigenous species and invasive behavior into the mindset of monitoring and assessment activities occurring in the NWHI.

    - Develop reference materials of potential species from baseline MHI inventories
    - Provide reference materials of species established in NWHI
    - Recognize species (native and non-indigenous species) exhibiting invasive behavior

1. INTRODUCTION

Marine habitats can be considered robust when dealing with gradual disturbances such as climate change measured on a scale of thousands of years. When disturbances occur over shorter time scales, marine communities can be severely disrupted. Such short time frames and intense disturbances that are relevant to human society and the anthropogenic effects induced on marine habitats. The introduction of non-native marine organisms is one form of anthropogenic change that can cause irreversible alterations to marine communities that has become of great concern. This document reviews and synthesizes available information on the situation in the Northwestern Hawaiian Islands (NWHI) as related to the Main Hawaiian Islands (MHI). The document is arranged into four sections: First is a discussion of theories behind invasion ecology. The second covers mechanisms of introduction of marine non-indigenous species. The third section is a review of the present status of marine non-indigenous species in the Hawaiian Archipelago and the fourth section covers management options.

1.1 A Primer for Marine Non-indigenous Species Invasions

The native species of the marine and terrestrial environments of Hawai‘i arrived as natural biological events over a period of millions of years, and through evolution and adaptation evolved into the present communities uniquely associated with the archipelago. The islands of Hawai‘i are one of the most isolated areas in the world and all native plants and animals are derived to the pioneering species that settled here through natural mechanisms of dispersal. The advent of modern human technology has created a means for biological introductions that readily overcome the vast geographical barriers that formerly prevented invasions. Human activity has greatly accelerated the process of biological change and in many cases new introductions have led to the depletion or extinction of naturally occurring populations.

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, the species invasion process must be understood.

1.1.1 Species Invasions – Natural and Anthropogenic

Over an evolutionary time scale ecosystems experience a variety of disturbances, such as arrival of new species and climate change. Natural species invasions (i.e., range expansions) and the resulting competition between species have established the composition of distinct communities that exist at various locations across the globe. Natural disturbances, such as storms, help maintain the diversity in ecosystems such as coral reefs (Connell, 1978). Natural species introductions to new regions are rare on time scales measured from the human perspective because of the immense geographic barriers that must be overcome. In Hawai‘i's marine environment, examples of these natural barriers are the wide expanses of deep ocean, direction of currents and the distance from continental land masses and other island groups. It is theorized that marine species that colonized Hawai‘i before the presence of the first Polynesians arrived on flotsam such as logs (Hedgepeth, 1993) and pumice stones (Jokiel, 1984 and 1990). However, these natural species invasion events are very infrequent- on the order of thousands or millions of years.

Invasions of non-indigenous species have occurred in terrestrial, freshwater and marine habitats worldwide due to the deliberate or unintentional transport of organisms throughout the world by humans. Anthropogenic introductions are much more prevalent than natural events and have caused major changes in ecosystems over short spans of time. Anthropogenic dispersal breaches the natural barriers that control the rate of invasion in the natural world. A species can become invasive in a new region when it escapes its normal predators competitors and diseases. In these situations the invasive species can cause the reduction or local extinction of native species

1.1.2 Dynamics of non-indigenous species introductions

How important is the introduction of a new species to a region such as the NWHI? In the realm of ecological research there is evidence that a single species can influence the structure of 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 that 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 non-indigenous species 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 non-indigenous species 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 non-indigenous species 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. out competing) 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 non-indigenous species 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 non-indigenous species) 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; Williamson and Fitter, 1996) and resistance to invasion by a community (Case, 1991; Baltz and Moyle, 1993; Trowbridge, 1995). Carlton (1996) proposed six scenarios (Table. 1.1.2-1) 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 non-indigenous species 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 non-indigenous species 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 non-indigenous species 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.

Table 1.1.2-1. Scenarios for when non-indigenous species invasions may occur (Based on Carlton, 1996)

Phenomenon	Process involved
Changes in donor region	*Environmental changes in donor region lead to:* • **Population increases of resident species (pre-exist with donor region) making more individuals available for transport.** • **Range expansion of local species into previously uninhabitable areas of donor region making these species available for transport.** *New introductions of non-indigenous species occur within donor region:* • **New species available for transport**
New donor regions	*New donor regions become available* • **New species available for transport** • **New genomes with different adaptive regimes than previously transported populations of the same species from other donor regions become available for transport.**
Changes in recipient region	*Any environmental changes in recipient region that lead to altered ecological, biological, chemical, or physical states, thus changing the susceptibility of the recipient region to invasion.* **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	*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 recipient region.*
Stochastic inoculation events	*The release of a very large number of inoculants into the recipient region, increasing potential reproductive success.*
Dispersal vector changes	*Vector size, speed, and quality increase lead to:* • **Increase in inoculant species diversity** • **Increase in abundance of inoculated species** • **Increase in number of post-transport 'fit' individuals** *New vector emerges from same donor region*

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 non-indigenous species introduction might be successful but there are also theories regarding the failure of biological invasions. Failure of a non-indigenous species to establish, despite seemingly suitable environmental conditions, can theoretically be attributed to the biological resistance of the receiving habitat. Table 1.1.2-2 shows the three common theories that support biological resistance as a factor in preventing establishment of non-indigenous species.

Table 2. Theories for biological resistance to species invasions
▪ **Species-rich communities may be more resistant to invasions by introduced species than species-poor communities (Elton, 1958; Diamond and Case, 1986; Case 1991)**
▪ **Invading species from "sophisticated" biotas (with highly competitive and defensive abilities) become established more frequently than species from "unsophisticated" biotas (Vermeij, 1991).**
▪ **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; Baltz and Moyle, 1993).**

The first theory has been repeatedly observed in stream fishes (Ross, 1991). 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.

1.1.3 Marine Non-indigenous Species Invasions

In the terrestrial environment the issue of non-indigenous species invasion and control has been dealt with as a management issue for some time. The concept of marine non-indigenous species is a relatively new issue, in comparison. In the Unites States, awareness of marine non-indigenous species 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.

Marine non-indigenous species invasions are a worldwide problem with economic and ecological consequences. Table 1.1.3-1 gives a few examples of marine non-indigenous species invasions worldwide and includes potential and proven impacts. These marine non-indigenous species 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 the alga, *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 an 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).

Table 1.1.3-1. Examples of marine non-indigenous species introductions worldwide.

Species	**Area(s) and Date of Introduction**	***Native Range***	**Impacts**
Asterias amurensis (sea star)	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.

Whether natural or anthropogenically facilitated, marine non-indigenous species 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, non-indigenous species invasions is one that has not historically been dealt with before. Communication of the issue of marine non-indigenous species to individuals responsible for decisions that affect the marine environment is the only way to prevent and control further impacts from this disturbance.

2. PATHWAYS AND MECHANISMS OF DISPERSAL.

Lack of adaptive radiation in Hawaiian corals, fish and invertebrates and high rates of endemism in marine fauna demonstrate isolation of the Hawaiian Archipelago from other Pacific island groups. In Hawai'i, genera containing multiple endemic species of marine invertebrates (Kay and Palumbi, 1987) corals (Jokiel, 1987) and fishes (Hourigan and Reese, 1987) seem to be derived from separate Indo-west Pacific species rather than radiating from a common ancestor. Thus, on an evolutionary time scale the geographic barriers between the different islands of the Hawaiian archipelago are insufficient to isolate marine populations long enough to allow speciation. The Archipelago is severely isolated from other islands of the Pacific so fish and invertebrates diverge into true Hawaiian endemic species. Overall about 30% of invertebrates other than corals, 20% of corals and 32% of nearshore fishes are endemic (Kay and Palumbi, 1987; Jokiel, 1987; Hourigan and Reese, 1987). These observations are important because they suggest once a species has gained a foothold in the Hawaiian Archipelago, it is only a matter of time before natural means of dispersal will allow it to colonize suitable habitat in all of the islands. Of course, the rate of spread can be accelerated by human activity.

Invasive species can be either intentionally or accidentally introduced through many different pathways. The majority of intentional introductions are associated with aquaculture or commercial fishing operations. Here in Hawai'i, a number of species of seaweed were introduced to assess their feasibility as an aquaculture product. Several species of fishes were also intentionally introduced to enhance recreational fishing. A sub-component of these intentional introductions is the epibiont and parasitic fauna associated with the individual species or their shipment medium. Unintentional introduction is the major mode that invasive species use to gain entry in most cases. These accidental introductions can occur through attachment to ship hulls, in ballast water, on anchors, seaplanes, or any floating object such as nets, buoys, or pumice. They have also been associated with fishing and SCUBA gear. Introductions can even come in with live seafood or its packing material that is improperly disposed of, or arrive as hitchhikers in live bait wells. Historically, the hulls of wooden sailing ships facilitated the transfer of wood-boring organisms, and sessile and mobile fauna were transported by dry ballast. (Carlton and Hodder, 1995). The single largest ship related source of introduction is through ballast water that is used by modern commercial vessels (Carlton, 1985). While over half of all North American invasions are associated with the shipping industry (Ruiz et al. 2000), in Florida, the release of fresh and saltwater aquarium species has been documented as the single most important means of introduction (Padilla and Williams 2004).

The probability of success of an introduction is very low and most introductions fail to establish and spread. It has been suggested by Williamson and Fritter's "rule of ten" (1996) that only one out of every ten introductions survive, only one tenth of these become established and spread, and only a tenth of these become invasive.

There are several challenges facing introduced species once they have survived the transport. They now must endure predators, hostile oceanic conditions, competition for resources, and disease that may not have been present at their origin. Some predators actually prefer introduced species. For some species that reproduce sexually, multiple introductions are necessary to avoid low genetic variability.

Once an introduction becomes established, it may take some time before it becomes invasive. This may be due to physiological adjustment to a different environment, time needed for growth and expansion, the availability of resources, or changes in environmental conditions. The ultimate success of an introduction depends strongly on its reproductive strategy, its capability of adapting to new environments, and its ability to compete for food and space.

2.1 Natural

Due to Hawai'i's extreme geographic isolation, few species arrived naturally. In the terrestrial environment, only about 1,000 species of plants and animals formed the basis for radiation of the Hawaiian endemic species. The rate of colonization was slow, only one species per 70,000 years. Yet this same isolation and habitat diversity made Hawai'i the ideal place for speciation to occur. This is not the case in the marine environment where there are fewer species (1-2 species in a genus) and a lower number of endemics (approximately 20%) in contrast to the terrestrial environment (>90%). The distances between island is not sufficient to isolate populations so that speciation can occur. Larval dispersal and migration of organisms can bridge the gap between islands of the archipelago. Niches in the inshore marine environment were filled by constant immigration rather than by speciation.

The endemic biota of the Hawaiian Islands were severely isolated before the first intentionally introduced alien arrived. This is believed to have been an oyster, which was transplanted in Honolulu in 1866 and a species of salmon a decade later. Although neither one survived, many more successful introductions were to follow. Yet although aliens have become established worldwide and have been documented to compete with native species, there are only two marine species that have become extinct in modern times. Globally, the Caribbean monk seal and the North Atlantic limpet are the only reported species to have vanished but this may be due to the lack of broad taxonomic data.

2.1.1 Larval Competence and Dispersal Range

Larval dispersal is mainly dependant on transport by currents. When development is short, the larvae are retained locally. Variability in currents account for wide ranges for some species. The average larval life of Hawaiian fishes is 35 days. With average current velocities of approximately 15 cm/sec., it would take 50 days to travel from Johnston Atoll and 187 days from Wake Island, which are in the closest geographic proximity to Hawai'i

On a local scale, most of the corals of Hawai'i are widely distributed, not habitat specific. The supply of larvae reaching a destination depends on production, transport and mortality. Coral larvae vary in competency time. *Pocillopora damicornis* can survive over 100 days without settling. The larval stage of *Montipora capitata* was determined to be over 200 days but the long-term survival rates were extremely low once they settled (Kolinski, 2004). A life-strategy for many organisms is to try to increase in size as quickly as possible to lessen the effects of predation. By traveling on floating material (rafting), a coral is in the position to reproduce immediately upon arrival, increasing its chance of survival. This strategy reduces predatory activity due to the larger size of the coral colony. *Montipora capitata* can lie dormant at the one-polyp stage for over a year. At 5 years they are often less than $1cm^2$. This extends the time for predation, competition and disturbances to remove such a small organism.

2.1.2 Natural Dispersal by Rafting

An extensive body of information on the rafting of marine organisms has been documented. Corals larvae will attach and settle on floating objects along with algae, barnacles, various crustaceans, tunicates, and other benthic reef creatures (Jokiel 1989, 1990a). Various natural "rafts" that provide the means for such long-range dispersal include drift logs, wood, seeds, pumice, charcoal, and coconuts. Reef fish commonly are associated with floating drift logs and are encountered far out at sea. Such natural events provide a mechanism for brining non-indigenous species to the NWHI. Jokiel and Cox (2003) were able to establish a relationship between currents, drift material and species diversity of corals in Hawai‘i and Christmas Island. Jokiel (1990b) showed the potential genetic importance of rafted corals carried into the Great Barrier Reef.

2.1.3 Migration of Adults

2.1.3.1 Fishes

Sharks and other large fish are known to move freely throughout the archipelago and do not observe the artificial boundary created by humans (Holland and Meyer, personal communication). For example, one tiger shark (#005) tagged in the NWHI at East Island, French Frigate Shoals in July 2000 was detected by an array of acoustic receivers off the Kona coast of the island of Hawai‘i (approx. 1190 km straight line distance) from January through March 2003. Another tiger shark (#008) tagged at East Island, in July 2000 was detected by our array of acoustic receivers off Midway (approx. 1280 km straight line distance) from September through December 2002 (Lowe et al., in press). Movement of other species has not yet been studied, but it is most likely that some of these can bridge gaps between the islands as adults. In some cases they may drift under cover of floating logs or other debris (Jokiel, 1990a).

Most tropical marine species originated near Indonesia and the Philippines where species diversity is highest, decreasing with distance from this region. From this center of dispersal, animals spread by island hopping, moving along continental shores, or by crossing oceanic gaps. Large pelagic species of fishes can easily cross vast expanses while shallow water reef fishes are not all capable of traversing the gap. Ocean currents can assist fish larvae as they drift to new destinations but distance is a prime factor in determining which species will prevail. This natural filter has excluded fishes with short larval stages such as anemone fish (Family Pomacentridae), while selecting for those with long larval lives such as the surgeonfishes (Family Acanthuridae). Another limiting factor in the dispersal of fishes to Hawaiian waters is the cooler temperatures as compared to many tropical Pacific reefs. Geographic distance, temperature, and other factors limit the number of fish species found in Hawai‘i (680) (Hoover, 2003). Although species richness is low, endemics are often the most dominant species since they are well adapted to local conditions. This can be seen with the success of the Saddle Wrasse, *Thalassoma duperrey* and the Milletseed Butterflyfish, *Chaetodon miliaris*. The Saddle Wrasse, hinalea, is the most prevalent endemic species found in the MHI, according to the most comprehensive study to date (Rodgers, 2005), more commonly observed than any other species (frequency of occurrence=87%). Indigenous fish species, which are native but not unique to the Hawaiian Islands marine environment, comprise the vast majority of the abundance of fishes. Only a few percent of the total can be attributed to non-native species (Figure 2.1.3.1-1). The alien species recorded in the study include two introduced snappers, the Bluestripe Snapper, *Lutjanus kasmira*, (ta’ape) and the Blacktail Snapper, *L. fulvus* (to‘au) and a grouper, the Peacock Grouper, *Cephalopholis argus* (roi) (Rodgers 2005).

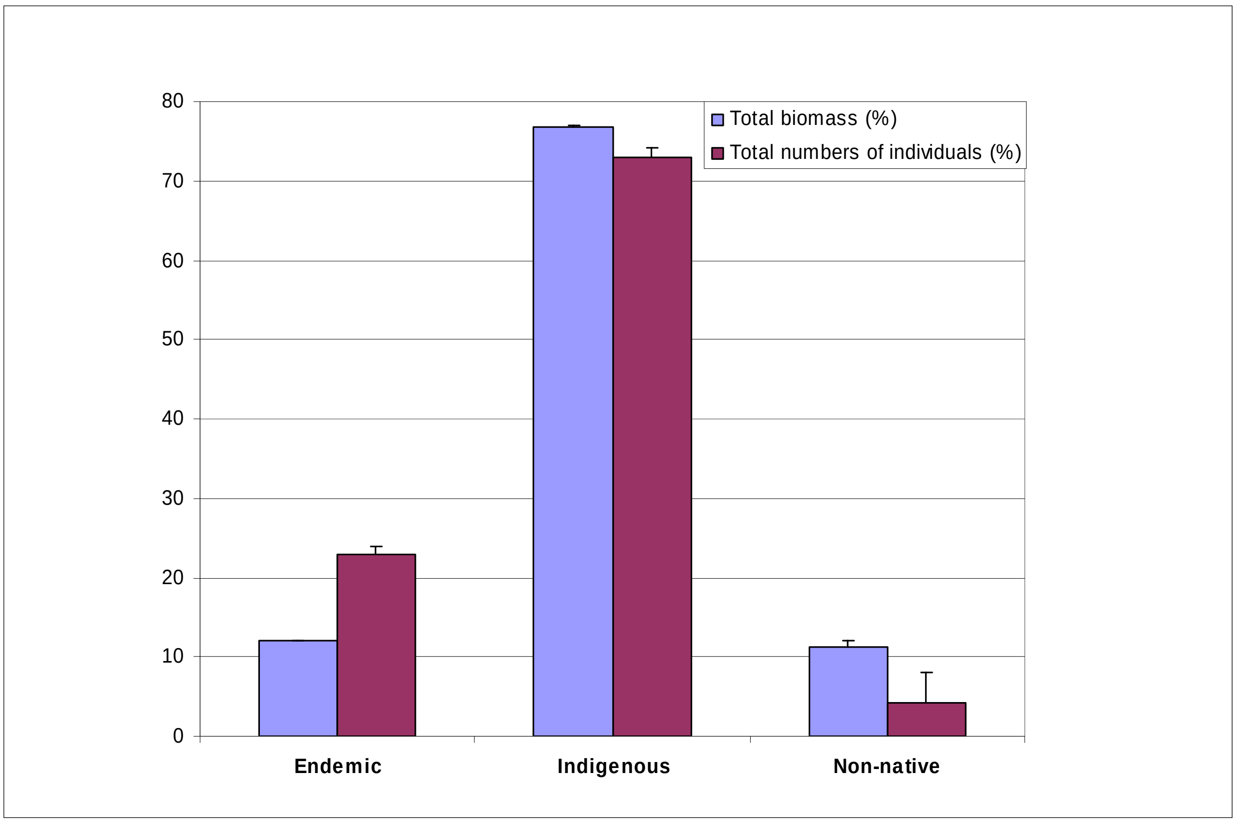

Figure 2.1.3.1-1. Biomass (%) and number of individual fishes (%) by endemic status (Rodgers, 2005).

2.1.3.2 Algae

The currents that brought algal propagules to the Hawaiian Islands are variable. The northeast tradewinds drive the North Pacific Current in a circular motion across the Pacific. Near the Hawaiian chain, eddies and current reversals can bring algae from other places. Local currents are also wind driven and highly variable between sites. Surface currents are seasonal with the majority coming from the East-northeast, turning northerly in the winter, and south in the summer as winds begin to slacken. Once propagules arrive, they must locate a suitable substrate. The depth at which an alga settles is dependant on light, temperature, and water motion. Its rapid horizontal expansion and invasion of new territories is a reflection of asexual means of reproduction, particularly fragmentation. Some algae such as the invasive, *Hypnea musciformis*, has tiny hooks to attach to other algal species. Others, such as *Gracilaria salicornia* can form large mats that will detach and float to other suitable destinations. Morphological plasticity allows algae to thrive in a variety of conditions.

Figure 2.1.3.3-1. Female Hawaiian monk seal *Monachus schauislandi* nursing newborn pup at Kalaupapa, Molokai. Photo by Bill Eichenlaub.

2.1.3.3 Monk Seals-*Monachus schauislandi*

Of the three species of monk seals worldwide, the Caribbean monk seal is extinct; the Mediterranean monk seal is endangered with as few as 500 individuals remaining, and the Hawaiian monk seal has approximately 1,200 remaining individuals. The majority of the endangered Hawaiian monk seals forage and pup in the NWHI (95%) although more individuals have recently been establishing populations in the MHI. At least 50 individuals have been observed in the MHI in recent years. (Baker and Johanos, 2005). These adults must have migrated as much as 15,000 miles to reach the MHI.

2.1.3.4 Green Sea Turtles-*Chelonia mydas*

Chelonia mydas, the green sea turtle can be found throughout the world. The Hawaiian population is genetically isolated from other populations found throughout the Pacific. This is a result of geographic isolation where these turtles tend to remain within the Hawaiian Archipelago throughout their entire lives. Although the adults use the MHI as foraging grounds, feeding on nearshore algae, the vast majority (90%) migrate to the

NWHI to mate and nest. Unlike the herbivorous adults, omnivorous juveniles also feed on floating plankton, fish eggs, and jellyfish. It is not known where turtles hatched in the NWHI live during their first 3-7 years. Subsequent to these "lost years" they remain in the MHI until they reach sexual maturity. This usually occurs at an age of approximately 25 years but can be as long as 50 years. This migration from the MHI foraging grounds to the NWHI nesting grounds occurs annually for males and every 2-4 years for females. The green sea turtle will return to nest at the location of their hatching. The majority migrate to French Frigate Shoals, a distance of about 800 miles. This continues throughout their lifetime, which can last 80 years or longer.

Figure 2.1.3.4-1.The green sea turtle *Chelonia mydas* migrates extensively throughout the archipelago. Photo Credit: F. Ferrell

2.2 Anthropogenic

The Hawaiian Islands are the most isolated archipelago in the world. Located 1,600 km from the nearest islands and 4,000 km away from the closest continent, this geographic isolation has resulted in unique, endemic biota. With the advent of human habitation both accidental and intentional introductions have occurred. With the increase in population in recent times, an increase in shipping activity has accelerated the introduction of marine species into Hawai'i at an alarming rate. Although most of these newcomers don't survive, a few persistent species have become a source of serious ecological and economic impacts to the state.

Some of the non-indigenous species that have become established in the MHI have dispersed more rapidly to other islands because of anthropogenic interisland transport. The potential of these species to threaten the NWHI through anthropogenic mechanisms of transport also exists. The global transfer of alien species by human activities is recognized as a leading threat to aquatic ecosystems throughout the world. Increased activities associated with the movement of humans and commodities have allowed barriers to naturally occurring biological invasions, such as the isolation of the Hawai'i Archipelago, to be overcome more readily. Examples of these activities are maritime vessel traffic, live seafood and bait shipments, aquaculture and fisheries activities, shipments of commercial and institutional aquarium species, and activities of education and research institutions. In the MHI, 343 alien marine species have been documented and inventoried (Eldredge and Carlton, 2002). Invertebrate species dominate with 287 species, followed by algae (24), fishes (20), and flowering plants (12). Based on historical literature and recent surveys, the pathways of introduction for non-native marine invertebrates to Hawai‘i have been determined (Table 2.2-1).

Organisms may reach the NWHI as larvae in vessel ballast water or as adults or larvae associated with biofouling and sediments of vessel hulls and piping systems (e.g Apte et al. 2000, Godwin and Eldredge 2001, Godwin et al. 2004). Therefore the likelihood of non-indigenous species reaching the NWHI is a function of the proximity and pattern of ship movements associated with the MHI.

Table 2.2-1. Hawai‘i non-indigenous species introduction mechanisms for marine invertebrate (Eldredge and Carlton 2002).

Mechanism	Species Number
Hull fouling	212
Solid ballast	21
Ballast water	18
Intentional release: Fishery	18
Parasites associated with AIS	8
Organisms associated with commercial oyster shipments	7
Aquarium release	3

Oahu is the hub of the commercial harbor system in the state of Hawai‘i. All overseas maritime 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 (Godwin & Eldredge, 2001a). Honolulu Harbor, the major port for the state, handles over 11 million tons of cargo every year. The harbor serves as the primary distribution center for the state of Hawai‘i. Over 80% of all resources consumed in the state are imported. Of this, 98% is shipped in from locations throughout the world. In 1998, 1,100 foreign deep draft ships entered Honolulu Harbor. Hawai‘i is considered the "Crossroads of the Pacific" and receives a variety of cargo for import and trans-shipment to other destinations. Therefore the primary receiving areas in Hawai‘i for non-indigenous species are Honolulu and Barber's Point Harbors.

2.2.1 Ship Movement

2.2.1.1 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.

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. 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.

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 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 (Ruiz et al., 2000a).

2.2.1.2 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 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.

These 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. Only a few of the studies listed have dealt with ballast sediments. The most notable are the studies by Hallegraeff et al. (1990), Hallegraeff & Bolch (1992), and Kelly et al. (1993) that demonstrated the presence of viable resting stages of phytoplankton species in ballast sediments. These studies connected the introduction of the toxic dinoflagellates that are transported as cysts to ballast sediments. In the first two studies, the toxic dinoflagellates *Gymnodinium catenatum* and *Alexandrium catenella*, which cause paralytic shellfish poisoning, were identified from ballast sediments sampled from commercial cargo vessels arriving to southern Australia. 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.

There are sediment accumulations associated with maritime vessel activity that are not due to ballast water operations. A source common to any type of vessel is the sediment found on anchors and anchor chains, which can accumulate in the chain locker compartment. These areas of the vessel can provide a sheltered habitat for a variety of animals that are adapted to an intertidal existence along coastlines and others that can exist in an encysted stage, such as the microalgae mentioned earlier. Vessels that conduct unique operations such as dredging and those that function as work platforms (i.e., barges, floating drydocks) have to be considered as well. These vessels can transport sediments associated with deck surfaces and the gear associated with their unique operations. Very little has been done to survey this type of sediment transport due to the random nature of these arrivals to port systems.

2.2.1.3 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 combined with anti-fouling coatings. The steps taken by large ocean going vessels and personal craft to eliminate hull fouling are not completely effective though, and organisms are still being transported by this means.

The organisms that generally foul vessel hulls are the typical species found in natural marine intertidal and subtidal fouling communities. The typical invertebrate organisms associated with marine fouling communities are arthropoda (barnacles, amphipods, and crabs), mollusca (mussels, clams, and sea slugs), porifera (sponges), bryozoa, coelenterata (hydroids and anemones), protozoa, annelida (marine worms), and chordata (sea squirts and fish), as well as macroalgae (seaweed). If these fouling communities become very developed they can also provide micro-habitats for mobile organisms such as fish. Initial settlement of fouling organisms tends to be in sheltered areas of the hull, such as sea chest intakes and rudder posts, and develop in areas where anti-fouling coatings have been compromised (Ranier, 1995; James & Hayden, 2000; Godwin, 2003; Coutts & Taylor, 2004; Godwin et al., 2004). Anti-fouling coatings wear off along the bilge keel and weld seams, and are inadequately applied in some cases, all which make the surfaces susceptible to settlement by fouling organisms. Further work has focused on the transport of hull fouling organisms on personal craft throughout the tropical Pacific (Floerl and Inglis, 2001).

Recent non-indigenous species introductions to Hawai‘i are directly attributed to hull fouling. The bivalve mollusk *Chama elatensis* and the sponge *Gelliodes fibrosa* both were introduced from the fouling community on the hull of a floating drydock towed to Hawai‘i from the Philippines in 1992 (DeFelice, 1999). The barnacle *Chthamalus proteus*, which is listed in Table 3.1-1, is native to the Caribbean, was not recorded in Hawai‘i before 1973 (Southward et al, 1997). The larvae of *C. proteus* would not have a good chance at surviving the journey from the Caribbean in a ballast tank, and were likely introduced by larvae spawned from adults that were part of a vessel hull fouling community. Apte et al., (2000) recorded such a scenario with blue mussels (*Mytilus galloprovincialis*), which were part of the fouling community on the hull of the U.S.S. Missouri (Defelice and Godwin, 1999), which was towed to Pearl Harbor from Bremerton, Washington. These mussels, which are alien to Hawai‘i, were observed spawning upon arrival to Pearl Harbor; three months later, settled juveniles were recorded in the harbor, and identified as *M. galloprovincialis* through molecular techniques. Establishment of this species in Hawai‘i has not been determined.

2.2.2 Marine Debris Transport

Marine debris such as plastics, glass bottles, packing crates, fishing net debris, and smaller components that are products of physical degradation of these items can cause injury and death to marine organisms. This debris can injure marine organisms through physical contact or cause mortality through ingestion, entanglement or smothering (Andre and Ittner, 1980; Conant, 1984; Balaz, 1985). Net debris affecting the Hawaiian archipelago comes from commercial fishing activities throughout the Pacific. Oceanic currents transport net debris from as far away as Alaska (Kubota, 1994). This creates a situation in which drifting debris can act as a pathway for non-indigenous species. This unique pathway can affect remote locations with little other anthropogenic influence, such as the NWHI, as well as populated regions such as the MHI. Drifting net debris can overcome the barriers of isolation and management by providing a mechanism of transport for marine non-indigenous species (Godwin, 2001b).

2.2.2.1 Biofouling on Marine Debris

Since 1996 a multi-agency effort [National Oceanic and Atmospheric Administration (NOAA), Ocean Conservancy, University of Hawaiʻi Sea Grant, US Coast Guard, U. S. Navy and others] has been removing derelict marine debris from Hawaiian waters in order to prevent damage to the reef and entanglement with endangered marine species. Efforts have been focused on French Frigate Shoals, Maro Reef, Lisianski Island, Midway Atoll, Kure Atoll, and Pearl and Hermes Reef. Over 100 metric tons per year has been removed over the past several years, but debris is continually drifting onto the reefs. Results from the 2000 NOAA, National Marine Fisheries Service (NMFS) effort identified marine invertebrate biofouling on net debris. Most species were common species indigenous to Hawaiʻi that are well known in fouling and benthic communities. The majority of the organisms recorded likely took up residence or recruited to the nets after arrival in the NWHI (Godwin, 2000). The one non-indigenous species, the sea anemone *Diadumene lineata*, found associated with net debris provides evidence that derelict fishing gear can act as a mechanism of transport for invasive species to the NWHI (Zabin et al., 2004). Approximately 100 individuals were found in 2000 in Pearl and Hermes lagoon on a commercial trawl net. Since there are no commercial fishing vessels in Hawaiʻi that use trawl nets it could have originated anywhere from Japan to the Pacific Northwest. Since it is not known whether this anemone could survive such a long journey, it is possible that it had passed through the MHI where this species has been identified in Kāneʻohe Bay. *Diadumene lineata* has been globally successful, possessing many of the traits necessary to survive and spread in diverse conditions. In order to survive adverse conditions, this anemone can encase itself in a hard cyst surviving a wide variety of unfavorable conditions until more favorable circumstances prevail. This response to lack of resources, high water temperatures, or fluctuations in salinity can give this organism the advantage to survive long periods of transport (Zabin et al., 2004). *Diadumene lineata* has not been observed since the original sighting but full scale species inventories are not conducted in marine habitats in the NWHI. Two other species of introduced anemones have been described from Oʻahu, *Diadumene leucolena,* originally from the Western Atlantic and *D. franciscana* of unknown origin but previously described from California. The danger that these two alien anemones will reach the NWHI by similar means is highly probable and concerning.

2.2.2.2 Rafting of Organisms with Debris.

Rafting describes the behavior of marine organisms, usually fish, when they aggregate near or under natural or anthropogenic sourced debris (Jokiel, 1992; Day and Shaw, 2003). A great deal is known about the sources, distribution and fate of anthropogenic marine debris (Shomura and Godfrey, 1990). There is information on the quantitative distribution and characteristics of marine debris in the North Pacific (Day and Shaw, 1990), and there is information on patterns of circulation and drift. Derelict nets can definitely act as an anthropogenic pathway for the transport of marine organisms, especially fishes. The ocean current regime in the area allows nets to be readily transported from a variety of locations. Over the past few years several large Fish Aggregation Devices (FADs) that broke away from mooring in the main Hawaiian Islands have come aground on the reefs of the NWHI, demonstrating the potential for rafting of marine invasive species from the main Hawaiian Islands into the NWHI.

Management activities and protocols currently in use by NOAA-NMFS and the US Fish and Wildlife Service (USFWS) are ineffective against such disturbances. Although the obvious effects of entanglement of wildlife and physical damage to benthic marine habitats are easy to convey to the general public, the transport of non-indigenous species is less apparent. The problem must be dealt with at the international level and must involve public sector resource managers and commercial fishing interests. The consequence of irresponsible disposal and accidental loss of fishing gear and research and fisheries buoys to wildlife must be brought to the attention of the commercial fishing industry and the public sector so that solutions can be formulated that will decrease the magnitude of this significant problem.

2.2.3 Fisheries Activities and Other Pathways

Extractive fisheries activities using gear such as floats, nets, traps, trawls, and dredges can unintentionally transport introduced species by biofouling or entrainment of mobile species or propagules. Fresh or frozen bait may harbor introduced organisms in form of the primary organism but can also include its epibionts and parasites. During efforts to introduce new species of snappers to Hawaii in the 1950's there were additional introductions of fish unintentionally included in transport tanks (See section 3.1).

A variety of algae, crustaceans, mollusks, echinoderms and fish have been intentionally introduced to the MHI for the purpose of aquaculture. These activities have been responsible for unintentional introductions of epibionts associated with the primary species. Examples are the mud blister worm *Polydora websteri* that arrived on oyster spat from U.S. west coast hatcheries and another polychaete worm *Polydora nuchalis*, which was probably transported here from Mexico with live shrimp (Eldredge, 1994).

Other means of transporting non-native species to the Northwestern Hawaiian Islands Marine National Monument falls under the rubric of research and conservation activities. The increase in coral reef monitoring efforts forces the inclusion of small boat outboards, diving equipment, instrument platforms, and towboards previously used in the MHI as vectors for non-indigenous species transport. This is possible through the unintentional transport of apical cells or fragments of macroalgae and encysted invertebrate larvae on surfaces or within sediments. Additionally, sand, soil and construction materials (i.e. riprap, sheet pilings) transported for maintenance and terrestrial conservation activities should also be considered for its potential for aquatic non-indigenous species transport to the Northwestern Hawaiian Islands Marine National Monument. All of the vectors within this section should be thought of as mechanisms for transportation from the MHI but also interisland within the Northwestern Hawaiian Islands Marine National Monument.

3.0 MARINE NON-INDIGENOUS SPECIES IN THE HAWAIIAN ARCHIPELAGO

Recent compilations of marine alien species in Hawaiʻi (Eldredge and Carlton, 2002) include some 343 species: 287 invertebrates, 24 algae, 20 fish, and 12 flowering plants. Ecological and economic consequences for these alien species invasions remain unclear but examples of negative impacts by introduced aquatic invertebrates in other areas of the Pacific have been documented:

- The tube dwelling polychaete *Sabella spallanzanii* introduced to Australia from the Mediterranean overgrows commercially important shellfish populations.
- *Asterias amurensis*, a starfish introduced into Australia from Japan is a major predator on commercially important species and has caused major ecological impacts.
- The hydroid *Eudendrium cameum* was introduced into the Republic of Palau and its spread could have ecological effects on coral reef resources.

For Hawaiʻi, some examples of alien marine invertebrates are the following:

- The bivalve mollusk *Chama macerophylla* and the sponge *Gelliodes fibrosa* both were introduced from the fouling community on the hull of a floating dry-dock towed to Hawaiʻi from the Philippines in 1992.
- The barnacle, *Chthamalus proteus*, which is common in the high littoral zone in Hawaiʻi, is native to the Caribbean, and was not recorded in Hawaiʻi before 1973.
- The snowflake coral *Carijoa riisei* was once believed to be introduced from the Caribbean and has recently been shown to have originated from the Indo-Pacific (Toonen, pers. comm.) now appears to be poised to impact unique deep-water habitats by overgrowth of endemic corals.

The remainder of this section will provide a synopsis of fish and invertebrates, and an in-depth coverage of algae, as related to both the MHI and NWHI.

3.1 Marine Non-indigenous Species and the NWHI

The activities that have provided information concerning marine aquatic invasive species of NWHI are recent, and the judgments as to whether organisms are invasive or native are based on the knowledge of marine aquatic invasive species that has been gained in the MHI over the last decade. This is due both to the status of the taxonomy for many invertebrate groups and the historical sampling effort in the NWHI. The status of the taxonomy of many non-coral marine invertebrate groups and algae is not fully developed for the NWHI and this does not allow comprehensive species inventories to be produced, although efforts to correct this are presently underway. In addition, when large scale faunal surveys began in shallow water coral reef habitats in the NWHI in 2000 only two expeditions with such a focus had ever been to the area during the previous 100 years.

The data concerning marine aquatic invasive species in the NWHI was collected from a single focused marine invasive species survey by the Bishop Museum at Midway Atoll and from multidiscipline efforts conducted under the auspices of the Northwestern Hawaiian Islands Rapid Assessment and Monitoring Program (NOW-RAMP) in 2000, 2002 and the National Oceanic and Atmospheric Administration-National Marine Fisheries Service, Coral Reef Ecosystem Division (CRED) efforts in 2000, 2002 and 2003.

The results of these efforts have recorded a total of 11 aquatic invasive marine fish, invertebrate, and algae species in the NWHI. Table 3.1-1 shows the species, the native range of each, their present status in the NWHI, and the hypothesized or documented mechanism of introduction.

Table 3.1-1. Marine non-indigenous species in the NWHI. NIH=Nihoa, NEC= Necker Island, FFS=French Frigate Shoals, MAR=Maro Reef, PHR=Pearl and Hermes Reef, LAY=Laysan Island, LIS=Lisianski Island, MID= Midway Atoll KUR=Kure Atoll, (Zabin et al., 2004 Godwin 2002, DeFelice et al. 2002, Godwin 2000, DeFelice et al. 1998).

Species	Native Range	Present Status in NWHI	Mechanism of Introduction
Hypnea musciformes (algae)	Unknown; Cosmopolitan	Unknown; in drift and on lobster traps (MAR and NEC)	Intentional introduction to MHI (documented)
Diadumene lineata (anemone)	Asia	Unknown; on derelict net only (PHR)	Derelict fishing net debris (documented)
Pennaria disticha (hydroid)	Unknown; Cosmopolitan	Established (FFS, PHR, LAY, LIS, KUR and MID)	Fouling on ship hulls (hypothesized)
Amathia distans (bryozoan)	Unknown; Cosmopolitan	Established (MID)	Fouling on ship hulls (hypothesized)
Schizoporella errata (bryozoan)	Unknown; Cosmopolitan	Established (MID)	Fouling on ship hulls (hypothesized)
Balanus reticulates (barnacle)	Atlantic	Established (FFS)	Fouling on ship hulls (hypothesized)
Balanus venustus (barnacle)	Atlantic and Caribbean	Not Established; on vessel hull only (MID)	Fouling on ship hulls (documented)
Chthamalus proteus (barnacle)	Caribbean	Established (MID)	Fouling on ship hulls (hypothesized)
Lutjanus fulvus (fish)	Indo-Pacific	Established (NIH, FFS)	Intentional introduction to MHI (documented)
Lutjanus kasmira (fish)	Indo-Pacific	Established (NIH, NEC, FFS, MAR, LAY, and MID)	Intentional introduction to MHI (documented)
Cephalopholis argus (fish)	Indo-Pacific	Established (NIH, NEC and FFS)	Intentional introduction to MHI (documented)

3.2 Fishes

3.2.1 Introduction

In the MHI, 21 marine fishes were intentionally introduced although few survived and reproduced. Yet, along with those intentional introductions came five unintentional alien fishes. The introduction of the Kandu, *Valamugil engeli*, the striped goatfish, *Upenneus vittatus*, and the gold-spot herring, *Herklotsichthys quadrimaculatus* were associated with the unsuccessful introduction of the Marquesan sardine, *Sardinella marquesensis*. Presently, most intentional introductions now require safeguards to assure history isn't repeated.

3.2.2 *Lutjanus kasmira*

Description

Ta'ape, was introduced from the Marquesas in 1958 and although only 3,200 ta'ape were released on the island of O'ahu, they have increased their range to include the entire Hawaiian archipelago. 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.

Figure 3.2.2-1. Blue-Lined Snapper (also known as Ta'ape or *Lutjanus kasmira*). Photo by K. Stender

History

Since most snappers occurring in Hawai'i have historically been highly prized food fish ('opakapaka, ehu, onaga), but inhabit depths of over 60 m, the Hawai'i Fish and Game introduced three shallow water snappers from the South Pacific and Mexico in the mid 1950s and early 1960s in hopes of stimulating the commercial fisheries. These are among the 11 demersal species introduced within a 5-year period. *Lutjanus kasmira* (ta'ape) and *L. fulvus* (to'au) have become widely established in the MHI, while the third species, *L. gibbus* is extremely rare. None of these species has been widely accepted as a food fish among the local population or become successful in the commercial fisheries and the ecological effects of these aliens have only recently been realized.

Current Distribution

Three species of reef fish introduced in the MHI *L. kasmira*, *L. fulvus*, and *C. argus* have become established in the NWHI. The only species to have successfully expanded along the entire NWHI chain is the ta'ape *L. kasmira.*

Ecology

This species occurs throughout the Indo-Pacific region and is known from depths of 2-265 meters but generally is found in depths no greater than 15 meters. It is a common coral reef species that feeds mainly on crustaceans and forms stationary schools by day and feeds individually at night.

Threats

Histological reports from Work et al. (2003) found that nearly half of the ta'ape examined from O'ahu were infected with an apicomplexan protozoan. Furthermore, 26% were infected with an epitheliocystic-like organism with potential transmission to endemic reef fishes. In addition, ta'ape from Hilo were found to host the nematode *Spirocamallanus istiblenni* (Font and Rigby, 2000). Species of goatfish (weke and kūmū), a popular food fish for humans, may be displaced by ta'ape, which has also expanded its range into deeper water where 'opakapaka reside. Friedlander and Parrish (1998) looked at patterns of habitat use to determine predation and resource competition between ta'ape and several native species within Hanalei Bay, Kaua'i, but found no strong ecological relationships.

3.2.3 *Cephalopholis argus*

Figure 3.2.3-1. The Peacock grouper, *Cephalopholis argus* introduced to Hawai'i in the 1950's. Photo by J. Randall

Description

Groupers are solitary predators that are poorly represented in the Hawaiian Archipelago. The peacock grouper, *Cephalopholis argus* (roi) is covered with blue spots with a series of light colored vertical bars towards the rear half of the body (Figure 3.2.3-1).

History

This species, which was intentionally introduced by the state for commercial purposes in 1956 from Moorea, French Polynesia, initially had more popularity as a food fish than the introduced snappers, the Bluestripe Snapper, *Lutjanus kasmira*, (ta'ape) and the Blacktail Snapper, *L. fulvus* (to'au). Its attractiveness as a food fish rapidly declined as cases of ciguatera poisoning increased. This opportunistic feeder is perceived by many local fishermen as unsafe to consume.

Current Distribution

Cephalopholis argus can be found throughout the MHI but has only been recorded at Nihoa Island, Necker Island, and French Frigate Shoals in the NWHI.

Ecology

The peacock grouper occurs in both lagoon and seaward reef habitats at depths up to 40 m, particularly in areas of high coral growth and clear water. They feed both day and night, primarily on small fish and occasionally on crustaceans.

Threats

Dierking et. al (2005) investigated the feeding biology and levels of ciguatoxins in *C. argus* at sites on the islands of O'ahu and Hawai'i. According to this study, roi impact on native species is less than formerly believed but could be a function of their low population numbers. Contrary to popular belief, they found that the majority of roi are relatively safe to consume, with approximately 4% containing levels of toxin high enough to cause ciguatera poisoning. However, 20% of samples contained some level of ciguatoxin. Although a strong site specific correlation occurred with the highest percentage of toxic roi found on the island of Hawai'i, nearly all of the 28 locations on both islands contained fish that tested positive for ciguatoxins. Toxin concentration in tissues were found to be only slightly higher in larger individuals, resulting in findings that smaller roi are not significantly safer for consumption than fish of larger size.

3.3 Invertebrates

3.3.1 Introduction

In sharp contrast to the MHI that harbors 287 introduced and cryptogenic (unknown origin) invertebrate species, only five introduced invertebrates have become established and two more have been recorded but do not appear to be established in the NWHI (Friedlander et al., 2005; Eldredge, 2005). Not surprisingly, the majority of invertebrate introductions (4) are found on Midway Atoll, which has a long history of anthropogenic activity. These include the hydroid, *Pennaria disticha*, two bryozoans, *Amathia distans* and *Schizoporella errata*, and the barnacle, *Chthamalus proteus*. *Pennaria disticha* is the only species that has spread to multiple locations within the NWHI (Godwin, 2002; Friedlander et al., 2005). The anemone *Diadumene lineata* was recorded as associated with a derelict fishing net in the NWHI (Godwin, 2000) but has not been confirmed as established but appears to be established in a discrete location within Kaneohe Bay on Oahu in the MHI (Zabin et al., 2004). A single record of the barnacle *Balanus venustus* was recorded at Midway Atoll on the hull of a vessel in 2003 but is unlikely to be established (Godwin et al., 2004).

Figure 3.3.1-1. The anemone *Diadumene lineata.* Photo credit R. Manuel

The majority of the invertebrate introductions found in the MHI are recorded from bays and harbors and are thought to have arrived through fouling on vessel hulls or through ship ballast water from the Indo-Pacific. The distribution of introductions in the NWHI provides evidence to support this, with most of the non-native species found in the only harbor in the NWHI at Midway. The majority of these invertebrate introductions found in harbors have not been described from Hawai‘i’s coral reefs. In the guide to invasive invertebrates in Hawai‘i (DeFelice et al., 2001), only four have been reported on coral reefs and only one of these is considered invasive. Coles and Eldredge (2002) believe that unlike invasive algae, this dearth of invertebrate species may be attributed to either a lack of opportunities to invade these highly diverse communities or a deficiency of surveys. The lag period that exists between establishment and actual invasive behavior must also be taken into account.

There being such a large number of established AIS in the MHI there is the potential for the introduction of other species from both natural and anthropogenic means. Two introduced invertebrates established in Hawai‘i, *Carijoa riisei* and *Chthamalus proteus*, will be reviewed more in-depth. The octocoral *Carijoa riisei* has recently begun exhibiting invasive qualities in the MHI after a lag period of many decades. Also covered will be the barnacle *Chthamalus proteus*, which exhibits a disjunct distribution on an interisland and archipelago scale.

3.3.2 *Carijoa riisei*

Description

Each polyp of *Carajoa riisei* is white in color with eight tentacles resembling a tiny snowflake. It is often found growing on pier pilings where it can readily cover all exposed parts of the structures. This soft coral is not a reef builder. Its skeleton is a rigid structure composed of spicules, similar to material found in sponges, and microscopic needles of calcium carbonate, imbedded in a chitin-like material. *Carijoa* *riisei* is utilized by many other organisms that colonize this octocoral, living on or within the skeleton.

Figure 3.3.2-1. The octocoral *Carijoa riisei*. Photo by S. Khang.

History

The "snowflake coral" originally observed in Pearl Harbor was thought to have arrived from the Caribbean but genetic research has shown that it may have originated in the Indo-Pacific region and arrived as part of ship hull fouling or in ballast water.

Current distribution

In the Caribbean, it is only found in shallow waters as part of the fouling community on pier pilings. It is also found in the western Pacific, Australia and Asia. In Hawai'i, along with this preferred habitat, it has also spread rapidly to invade deeper waters. This eight tentacled coral attaches with a root-like structure in areas where light doesn't fully penetrate.

Ecology

C. riisei avoids well lit habitats, preferring dark cracks, undersides of rocks, shaded pier pilings and deeper waters. It is a suspension feeder, consuming tiny zooplankton from the water column.

Threats

Initially, it was not considered a threat to the ecosystem since it was thought to inhabit an underutilized habitat. Yet in just seven years, *C. riisei* has expanded its range to include sites from Koko Head to Haleiwa. Expansion continued and by 1990 it was recorded from all islands in the MHI chain. Results from a 2001 survey using the Hawai'i Undersea Research Laboratory's Pisces V, found *C. riisei* had spread into waters up to 110 meters and is competing with the native black corals. They both feed on the same zooplankton and are competing for space. This octocoral is overgrowing the black coral at an alarming rate. *Carijoa riisei* can grow up to 8 cm a month while the precious black coral takes over a year to match that growth rate. As it blankets anything in its path, the biodiversity of the area is drastically reduced. It has been reported that black corals are completely decimated in some areas in the deep trench (75-110 m) between West Maui and Lanaʻi (Grigg, 2003). The black coral industry generates over $15 million annually in revenues for the state of Hawaiʻi (Grigg, 2001). Hawaiian corals are especially susceptible to displacement by fast-growing octocorals since few are native to the area. It is usually found approximately 60 m. from shore in moderate water motion and has no known predators. This prolific rate of spread illustrates the need to determine the ecology, distribution, abundance, range, and tolerances of this potentially devastating invasive.

A joint effort by the State of Hawaiʻi Department of Land and Natural Resources, Division of Aquatic Resources and the University of Hawaiʻi to eradicate *C. riisei* is currently under way. Divers, utilizing two strategies, manually cleared two sites on Kaua'i. In some areas, large clumps of the octocoral were removed while in others, the entire area was cleared of the invasive by smothering with plastic sheeting. The effectiveness of the methods will be evaluated during subsequent monitoring of sites. The rationale to concentrate eradication efforts on the Island of Kauaʻi is two-fold. Since it has only been documented from two sites, it may be possible to contain its spread and if its spread is not contained it is highly probable that it will advance to the NWHI, with Kauaʻi creating a stepping stone to this near pristine environment. Although there exists a possibility that ship traffic from Oʻahu can also potentially extend the reach of *C. riisei* to the NWHI, attempts at eradication on Oʻahu is futile due to the extent of its spread.

3.3.3 *Chthamalus proteus*

Description

Chthamalus proteus is a small grayish-white barnacle that grows to about 1cm in diameter. It has a conical shape that is varied depending on the age and level of crowding with other conspecifics. Older *C. proteus* resemble the native barnacle *Nesochthamalus intertextus,* which lives in the same habitat. The interleaving shell plates of *N. intertextus* and its purplish color differentiate it from *C. proteus*.

Figure 3.3.3-1. The barnacle *Chthamalus proteus*. Photo by C. Zabin

History

Due to the supratidal nature of this species it is unlikely it was overlooked in barnacle surveys conducted in the Pacific prior to the mid-1900's (Pilsbry, 1927; Hiro, 1939; Henry, 1942; Edmondson, 1946; Gordon, 1970). It also was not recorded during a comprehensive survey of intertidal barnacle fauna of Hawai'i in 1973 (Matsuda, 1973).

Chthamalus proteus was well established on Oahu, Maui, and Kauai by the time it was noticed in 1995 (Southward et al., 1998). It was recorded in the NWHI in the harbor at Midway Atoll in 1998 (DeFelice et al., 1998), and was later discovered in Guam (Southward et al., 1998).

Current distribution

Chthamalus proteus is native to the Caribbean, Gulf of Mexico and the Western Atlantic and has several congeners throughout the Atlantic and Pacific. It has become established in a disjunct pattern between islands and within the archipelago. Intertidal faunal surveys have been conducted on all MHI except Ni'ihau, and is found on all except Kaho'olawe.

Ecology

This barnacle colonizes supratidal anthropogenic structures such as pier pilings and sea walls but has spread to natural intertidal boulder habitat. The native chthamalid barnacle *Nesochthamalus intertextus* inhabits similar natural habitats but is rarely found in harbors and man-made embayments. *Chthamalus proteus* can grow in high densities on both natural and man-made surfaces. These barnacles are hermaphrodites but cross-fertilization can occur in high density populations. Specialized paired appendages called cirri extract food particles directly from the water with continuous motions in and out of the shell.

Threats

A potential threat of this species is alteration of natural substrates through dense colonization. This would alter settlement patterns of native species and exclude algal grazers such as opihi. This species has shown a propensity for settlement on vessel hulls (Godwin, 2003; Godwin et al., 2004) and its disjunct distribution along the Hawaiian Archipelago is likely due to this mechanism of transport. This mechanism of transport is difficult to manage and can involve any size of vessel. Its establishment in the harbor at Midway Atoll has provided a "stepping stone" within the NWHI that cannot be discounted. The original establishment site in the MHI was within the harbor system on Oahu and it has expanded within and beyond this to both natural and man-made habitats. This potential exists for the population established on Midway Atoll and measures have to be taken to minimize expansion.

3.4 Algae

3.4.1 Introduction

Since 1950, at least nineteen species of algae have become established on O‘ahu. Through commercial, experimental and accidental introductions from several South Pacific locations, Florida, California, and Japan, many of these invasives have spread to the outer islands (Russell, 1992). Three of the most successful in expanding their abundance and distribution are *Acanthophora spicifera, Hypnea musciformis,* and *Gracilaria salicornia* (Table 3.4.1-1).

Aliens with the extraordinary capabilities of rapid growth and reproduction and the ability to change their form have spread out to compete among the natives. Many expand their territories through fragmentation, by regeneration of small pieces, or attach themselves to other species as epiphytes. Other reasons for their success may be their escape from their natural predators or reduced grazing pressure in their new home. These ecological invasions can advance rapidly and have negative effects on marine ecosystems. Since 1950, 19 species of seaweeds that were either intentionally or accidentally introduced to Hawai’i, have become permanent or unwelcome residents. Many were first identified in harbors or bays, where ships from foreign destinations visited, escaping from ballast water or fouling on hulls. Some spread throughout the archipelago, while others have remained exclusively at the origin of introduction on O’ahu. Although over half of these species were introduced into Kāne’ohe Bay, only a few have become widespread and invasive, displacing native seaweeds and overgrowing corals in some areas.

Native seaweeds can also gain a competitive advantage over corals and become invasive when excess nutrients are available. A “phase shift” from a coral to an algal dominance occurred in Kāne’ohe Bay, beginning in the 1950’s and peaking in the 1970’s, due to sewage discharge, slowly allowing the take over of the “bubble algae”, *Dictyosphaeria cavernosa*. Overfishing may also favor seaweeds over corals when fewer herbivorous fishes are available to subdue fast growing algae.

Each species has unique biological and ecological characteristics that affect their probability of establishment, rate of spread, reproductive success and interaction with native species. Investigating and understanding these distinctive traits is critical to ecosystem conservation and ecological management.

Rapid growth rates, morphological plasticity, and effective propagation can accelerate the spread of alien algal species into areas where they have not previously been established (Carpenter, 1990).

Table 3.4.1-1. Partial list of macroalgae that were intentionally introduced into O'ahu since 1950 (Russell, 1992; UH Botany, 2005).						
Species	**O'ahu locale**	**Date**	**Origin**	**Success**	**Product Value**	**Competition**
Acanthophora spicifera	Pearl Harbor and/or Waikiki	After 1950	Guam	highly successful	none	*Laurencia* spp.
Avrainvillea amadelpha	Koko Head, Kahe Pt	After 1981	West Pacific?	successful	none	many reef spps ?
Eucheuma denticulatum	Honolulu Harbor, Kane'ohe Bay	from 10/70 to late 1976	Philippines	not successful	kappa carrageenan	unknown
Eucheuma isiforme	Kane'ohe Bay	1/74	Florida	No	iota carrageenan	none
Gracilaria epihippisora	Waikiki & Kane'ohe Bay	4/71 9/78	Big Island (Hawai'i)	marginal	agar	unknown
Gracilaria eucheumoides	Kane'ohe Bay	mid 1970's	Philippines	unknown	carrageenan	unknown
Gracilaria salicornia	Waikiki & Kane'ohe Bay	4/71 9/78	Big Island (Hawai'i)	highly successful	agar	many reef spp
Gracilaria tikvahiae	Kane'ohe Bay & Kahuku	mid 1970's	Florida	successful	carrageenan fresh produce	unknown
Gracilaria sp.	Honolulu Harbor	1971	Philippines	unknown	carrageenan	unknown
Hypnea musciformis	Kane'ohe Bay	1/74	Florida	highly successful	kappa carrageenan	many reef spp
Kappaphycus alvarezii	Honolulu Harbor & Kane'ohe Bay	9/74 to late1976	Philippines	successful	kappa carrageenan	unknown
Kappaphycus striatum	Honolulu Harbor & Kane'ohe Bay	8/70 to late1976	Pohnpei and Philippines	successful	kappa carrageenan	unknown
Lola lubrica	Makapu'u & Kahuku	1976	California	No	none	none
Macrocystis pyrifera	Makapu'u & Keahole Pt	1972 1980's	California	No	Abalone food ; alginates	none
Nemacystus decipiens	Waikiki	1950's	unknown	successful	none	unknown
Pilinella californica	Makapu'u Kahuku	1976	California	No	none	none
Porphyra sp.	O'ahu	unknown	Japan	unknown	nori	unknown
Wrangelia bicuspidata	Kane'ohe Bay	1974	unknown	successful	none	unknown

3.4.2 Algal Invasion Patterns

Along with biological characteristics of the seaweeds themselves, environmental conditions in the donor and recipient regions play a role in the establishment and spread of marine invasives (See Table 1.1.2-1). Where new habitat becomes available, introductions not only become established but can move to nearby regions. These areas can act as stepping stones to accelerate the spread of invasions. This was the mechanism for the introduction of the zebra mussel, *Dresseina polymorpha* into the Laurensian Great Lakes where it is not commercially exported (Carlton, 1996). Changes in the donor regions can also accelerate the spread of otherwise innocuous species. Nutrification, sedimentation, removal of herbivorous fishes and other anthropogenic impacts can initiate phase shifts that can trigger unprecedented growth of algal species. This in turn may increase the chances of transport outside the donor region as was the case with the clam, *Theora lubrica*. Pollution in the Inland Sea of Japan triggered a population explosion of this clam that was connected to its increase in San Francisco Bay. An interaction of a number of factors can result in inoculation and dispersal events (Johnstone, 1986). Changes in physical factors such as salinity, temperature, and water motion can create optimum conditions for invasion. These environmental fluctuations are occurring at unprecedented rates. Technological advances in shipping have further aggravated the problem. Larger vessels carrying more ballast water are traveling faster to more ports of call than in any previous time, continually increasing the chances of invasion.

Herbivory can be an important factor in the success of introduced algae. Many algae have developed defenses to reduce the effects of hervivorous fishes. These include spatial and temporal adaptations. Some seaweeds inhabit cracks and crevices that are difficult for grazers to reach. Others such as *Halimeda*, produce uncalcified young blades at night when herbivorous activity is at a minimum. Other algae have developed chemical defenses making them unpalatable to fishes. Secondary metabolites not only resist pathogens and fouling organisms but also have been shown to reduce predation (Faulkner, 1984). Morphological adaptations can also deter predators.

3.4.3 Growth Rates

Specific physical and oceanic conditions can play an important role in the distribution and abundance of invasive algal species. Water motion explained the most variability in distribution, abundance and productivity in invasive algal species in Kāne‘ohe Bay (Doty, 1971; Glenn, 1992; Rodgers and Cox, 1999). *Kappaphycus* thalli have thick branches, which have been shown to reduce diffusion of materials into the center of the thallus, therefore requiring greater water motion than alga with thinner thalli (Glenn, 1992). In field growth experiments by Glenn (1992) in Kāne‘ohe Bay, water motion was the only environmental factor consistently correlated with growth rates of *Kappaphycus alvarezii* and *K. striatum*. Maximum growth rates occurred at the highest rates of water motion (15 cm s^{-1}) with 81% to 98% of the variability attributed to water motion. Under ideal conditions, *Kappaphycus* sp. can double their size in 15 to 30 days or less (Ananza-Corrales et al., 1992). In the Main Hawaiian Islands, Russell (1983) found a year-round average growth rate of 5%. Many algal species have genetically and environmentally adapted to different water motion regimes.

Brazilian studies of *Hypnea musciformis* found an 87% recovery rate after harvest for its Kappa-carrageenan. Cultivation experiments determined a 15% growth rate per day (Faccini and Berchez, 2000).

3.4.4 Means of Dispersal

Other species are less restricted in their ecological requirements than *Kapaphycus* sp. *Acanthophora spicifera*, the most successful and widespread alien algae in the Main Hawaiian Islands, has become well established in a wide variety of habitats from sheltered bays to exposed coastlines occurring from the lower intertidal to the eulittoral zone. It spans a range of oceanic conditions, occurring in moderate to strong water motion and survives in a wide range of salinities. *A. spicifera* attaches to stable substratum such as basalt and carbonate platforms or large rocks or to shifting shells, sand or rubble, facilitating its spread. Once established, *A. spicifera* can spread rapidly throughout the NWHI chain as it has in the Main Hawaiian Islands. This species has been documented to attach to stationary buoys and ropes as well as to mobile boat hulls and floating objects that can act as vectors of spread to extend their distributions.

Vegetative fragmentation is an extremely effective means of propagation, which can result in widespread establishment. Algae can break into pieces from waves, predation or other means of disturbance. It was found that fragments as small as a few apical cells can regenerate to start new populations. Fragments of *Kappaphycus striatum* as small as 0.05 g were found to exhibit positive growth (Woo, 2000). Many species that exhibit this form of reproduction have successfully invaded new areas (Mshigeni, 1978; Kilar and McLachlan, 1986; Meinesz et al., 1993). In Hawai‘i, several invasive rhodophytes have spread extensively through vegetative fragmentation. Through successful ecological strategies such as vegetative fragmentation, *Acanthophora spicifera*, has become widely established on all the main Hawaiian Islands since its introduction in 1950.

3.4.5 Spread

There is growing concern about the impacts of invasive marine species on a global scale. In the United States alone, least 4,500 non-indigenous marine species have become established (U.S. Congressional Office of Technology Assessment, 1993), with severe ecological impacts incurred by at least fifteen percent of these (Ruiz et al., 1997). The rate of introduction has rapidly escalated in the last half of the century, initiating increasing research and management action.

Many alien species arrive in new areas but do not expand and persist (Mollison, 1986). Once a species settles and becomes naturalized to the surrounding environmental conditions there is possibility for expansion. Species may expand naturally or by anthropogenic means of transfer (Ribera, 1994). Once a species persists in new environments it has the potential to become invasive, competing with native species for resources such as space and nutrients.

Alien, invasives have already demonstrated the potential to spread rapidly throughout the Main Hawaiian Islands. *Kappaphycus* alvarezii was introduced on the shallow reef flat on Moku o lo‘e in 1974 and was not expected to spread. It was hypothesized that the lack of a sexual reproductive cycle would limit its spread. Based on its distribution in shallow waters, it was further suggested that its introduction onto the shallow reef flat would keep it contained since it was believed that *Kappaphycus* could not survive in the deeper waters surrounding the island. Its apparent inability to cross channels and deeper dredged reefs was thought to prevent its dispersal into new areas (Russell, 1981). Russell also concluded that *K. alvarezii* would not compete with native algal species since it had been documented to inhabit sandy grooves on the reef edge where native algal abundance was low. Eighteen years after the documentation of the distribution of *K. alvarezii* in 1978 (Russell, 1983), Rodgers and Cox (1999) assessed its rate of spread. It was documented to have spread throughout Kāne‘ohe Bay, extending its range 5.7 km from 1974 to 1996, with an estimated rate of spread of 260 m yr^{-1}. Although each invasive species responds differently to physical, biological, and environmental conditions in new habitat, Woo (2000) found that *Kappaphycus striatum* is not limited by environmental conditions but rather by dispersal, herbivory, and substrate availability.

Other introduced species have even higher rates of spread. The rate of spread varies with species and environmental conditions. The chlorophyte, *Caulerpa* *scalpelliformis* was documented to have spread 300 m yr^{-1} in Botany Bay, New South Wales (Davis et al., 1997). A few species have exhibited extremely rapid rates of spread. In the Mediterranean, *Caulerpa taxifolia*, a popular marine aquarium species due to its fast growth, was reported to have spread 53 km yr^{-1} (Meinesz et al., 1993) and displaced the native seagrass *Posidonia oceanica* (Ribera & Boudouresque, 1995). Similarly, Carlton and Scanlon (1985) estimated the rate of spread of *Codium fragile* to be 55 km yr^{-1}. The ability of these algae to spread rapidly is in large part due to the reproductive strategy, vegetative fragmentation. The aquaculture industry has made good use of this ability for seaweeds to grow rapidly (Glenn and Doty, 1990). Other successful invasives on O‘ahu have been documented to reproduce through fragmentation. These include the weedy species *Acanthophora spicifera* (Kilar and McLachlan, 1986), *Hypnea musciformis* (Russell and Balaz, 1992), and *Kappaphycus striatum* (Glenn and Doty, 1990). This ecological advantage over many native species allows them to increase their distribution and abundance rapidly.

The economic and ecological impact of species that become invasive can be great. In algae, some of the competitive strategies that make these weedy macrophytes so successful have been identified. They reproduce readily through vegetative fragmentation and have the ability to fragment easily and regrow rapidly. They can alter their photosynthetic performance to compete successfully in new areas. They can even change their morphologies to take advantage of specific nutrient conditions. Understanding these adaptive strategies can influence the approach management takes to preventing and predicting its introduction and spread.

It has already been documented that *Hypnea musciformis* has invaded the NWHI (Tenbruggencate, 2005). *Hypnea musciformis* has recently been reported from samples collected from the leeward side of Mokumanamana (Necker Island). These samples were collected from lobster traps deployed at depth of 30 to 90 meters. The first reports of this invasive alga in 2002 found very low quantities. Samples from subsequent years continued to include small amounts of this invasive alga. The most recent reports from 2005 samples found much higher quantities than any previous years. This verifies that *H. musciformis* has not only become established but is increasing in abundance. It has expanded its distribution from its last known point 350 miles northwest on the island of Kaua‘i. High biomass of this species has been correlated with areas with high levels of nutrients such as locations off Maui that are affected by agricultural runoff or sewage seepage. Possible contributions of nutrients to waters surrounding Mokumanamana include guano droppings from resident bird populations. The documentation of the spread of this invasive to the NWHI highlights the high probability of continued island hopping along the chain.

Most introduced species do not become established, yet those that do can upset marine biodiversity, change successional patterns, compete with native species, and alter habitat complexity. These few persistent invasives can have large ecological and economic impact. Most of these macrophytes can be easily identified in the field, aiding in monitoring and management efforts.

Although data on characteristics of alien macrophytes is sparse, there are certain life strategies that favor growth and spread of these invasives.

- The ability to reproduce easily through vegetative fragmentation
- The ability to adjust their photosynthetic capabilities in a wide range of light environments
- To ability to modify their morphologies to adapt to differing wave and nutrient regimes

It has been well documented that invasive algae can outcompete native species, reducing endemism (Woo, 2000). The possibility also exists for hybridization of non-native with native species.

Recent inventories show a high rate of error in some regions. Accurate records exist in very few places. Yet in response to worldwide algal invasions at an alarming rate, research on introduced algae has grown. In the Mediterranean, at least 60 invasive macrophytes have become widely established. Along the Atlantic coast of the United States, nearly 30 non-native algae have spread extensively and over 20 invasives have spread in New Zealand. Algal invasions have also been reported from Australia and Brazil (Ribera and Boudouresque, 1995). Here in Hawaiʻi, 19 non-indigenous species of algae have become established and are spreading throughout the state (Russell, 1992).

3.4.6 Ecological Consequences

Algal invasions can have an impact on biodiversity, community structure, species richness, competition, and genetic diversity. Diversity of species and species richness may initially increase following invasions with a consequent decrease in the number and abundance of native species. Community composition may be altered dramatically when the spread of an invasive alga reduces the heterogeneity of the environment by reducing endemic native species. On a cellular level, increases in gene flow and the success of particular genotypes can also alter genetic diversity. The difficulty in preventing invasions includes identifying possible algal candidates, regions they may invade and the rate of spread. Spatial and temporal variation prevents accurate predictions. Development of strategies to avoid introduction is critical. By the time an invasive has been reported, it has spread extensively. Once they have begun to advance it is extremely difficult to eradicate.

Descriptions of some species with the potential to spread to the Northwestern Hawaiian Islands Marine National Monument are included in the following sections, (*Hypnea musciformis* already spread to Necker Island):

3.4.7 *Hypnea musciformis*

Figure 3.4.7-1. *Hypnea musciformis*. **Photo by L. Preskitt**

Description

Hypnea musciformis can be found in clumps or intertwined cylindrical branches that become progressively thinner towards the tips. This highly branched species processes tendrils that attach easily to other species. The holdfasts are either extremely small or lacking. Its coloration ranges from red to yellowish brown in high light or nutrient poor regions. *Hypnea musciformis* is easily distinguished from other species in this genus including the native *Hypnea cervicornis* by broad, flattened hooks at the end of branches. It can be epiphytic, attaching easily to other algal species with hooked tendrils that twist around algal axes.

It can be found on hard bottom substrate or attached to rocks, coral, or shells. It can also commonly be found attached to other macrophytes including *Sargassum* spp., *Ulva fasciata* and another invasive, *Acanthophora spicifera*.

History

The invasive algae, *Hypnea musciformis* was intentionally introduced from Florida to Kāne‘ohe Bay, Hawai‘i in 1974. Following a three-year lag, it expanded its range to several reefs within the bay. It subsequently spread rapidly to intertidal zones spreading to Waikīkī in 1980 and continuing to extend its range to include most of O‘ahu by 1982 (Abbott, 1987). The original intention was to market it as a product in the carageenen trade. Although the project was subsequently abandoned and it was presumed that this species would die out, it has spread prolifically to most of the main islands. It was first recorded in Pā‘ia on the island of Maui in 1987. More recent observations determined that in the winter on both windward and leeward Maui beaches, *H. musciformis* is responsible for two-thirds of the drift algal biomass. These nuisance blooms can result in large drifting mats that can result in over 20,000 lbs. of algae washing up weekly. The rotting algae on the beaches have reduced property values and occupancy reductions in

Kihei, Maui resulted in losses of over $20 million dollars (HCRI, 2002). Clean-up efforts have also cost taxpayers thousands of dollars.

Current Distribution

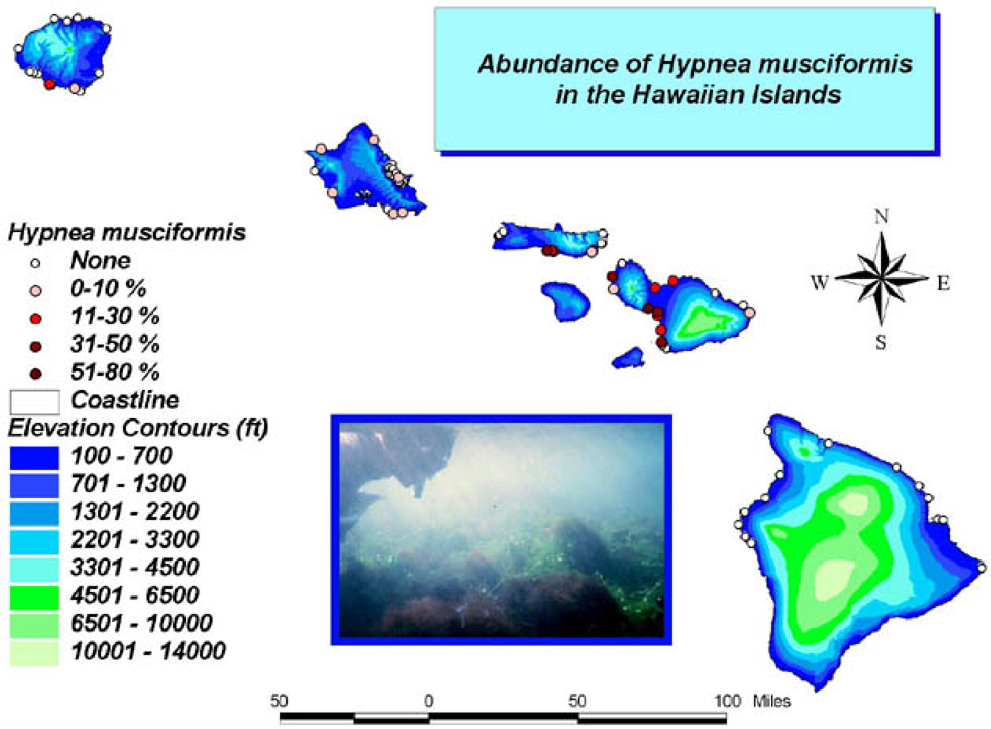

Figure 3.4.7-2. Data from www.botany.hawaii.edu/GradStud/smith, used with permission.

Hypnea musciformis is distributed throughout most of the world. In Hawai‘i, it is one of the few invasive algal species whose range has been followed since its initial introduction. It is currently reported to have extended its range to all of the main Hawaiian Islands with the exception of the island of Hawai‘i and Kaho‘olawe. It has recently spread to Mokumanamana (Necker Island) possibly through island hopping or transport by the commercial lobster fisheries traps.

Ecology

This species possess traits favorable over native species. It has a high growth rate, propagates effectively, exhibits morphological plasticity, resists herbivory, is an effective epiphyte, and has high surface to volume ratios (Carpenter, 1990). Growth rates in field studies in Kāne‘ohe Bay recorded 10-12% day^{-1} increases (Russell, 1992). Earlier field studies found even higher growth rates from 20% day^{-1} (Dawes, 1987) to 50% day^{-1} (Humm and Kreuzer, 1975). These may be underestimated due to the difficulty in determining growth rates in situ due to loss by fragmentation and predation.

Figure 3.4.7-3. Mokumanamana (Necker Island), Northwestern Hawaiian Islands. Photo Credit: M. Costa

Typical of many macrophytes, *H. musciformis* reproduces both sexually and asexually. Through vegetative reproduction it is highly successful in all size classes, especially the smallest pieces. Fragmentation studies have shown that the tiny hooks left behind after physical disturbance can increase up to 200% in a less than a week (Smith et al., 2002). Currents disperse the drift algae removed by high wave action to new locations.

Along with another invasive algae, *Acanthophora spicifera, H. musciformis* is a prominent food source of the endangered green sea turtle, *Chelonia mydas*.

Threats

Spreading rapidly through reproductive fragmentation and prolific spore development, *H. musciformis* has become one of the most prevalent species in the shallow reef environment. Russell (1992) demonstrated a competitive dominance of this weedy species over the native macroalgae *Laurencia nidifica* and *Hypnea cervicornis*.

3.4.8. *Avrainvillea amadelpha*

Figure 3.4.8-1. *Avrainvillea amadelpha*. **Photo Credit: L. Preskitt**

Description

A. amadelpha is comprised of one to four small, thin wedge-shaped blades. Plants do not normally exceed 4 cm in width and 3 cm in height. Its short stature is due to horizontal growth from the basal region rather than upward expansion from the blades. The surface of each blade has a velvety texture. Although the color of this alga is a green to greenish gray, it often appears brown due to fine silts which can get trapped and lightly cover blades or aggregations of blades. Other macroalgae is often found attached to more established plants.

History

Although the mechanism of introduction is unknown, the most recent of the described invasive algae in the Main Hawaiian Islands, *Avrainvillea amadelpha* is hypothesized to have arrived after 1981. The possible origin of this introduction includes the Mauritius, Tuamotus, Fiji, or the Philippines. It was first identified on O'ahu's leeward coast. It has spread rapidly along O'ahu's south shore where it currently inhabits similar communities as *Acanthophora spicifera*. Its recent extension of its range to the island of Kaua'i confirms its ability for interisland dispersal.

Current Distribution

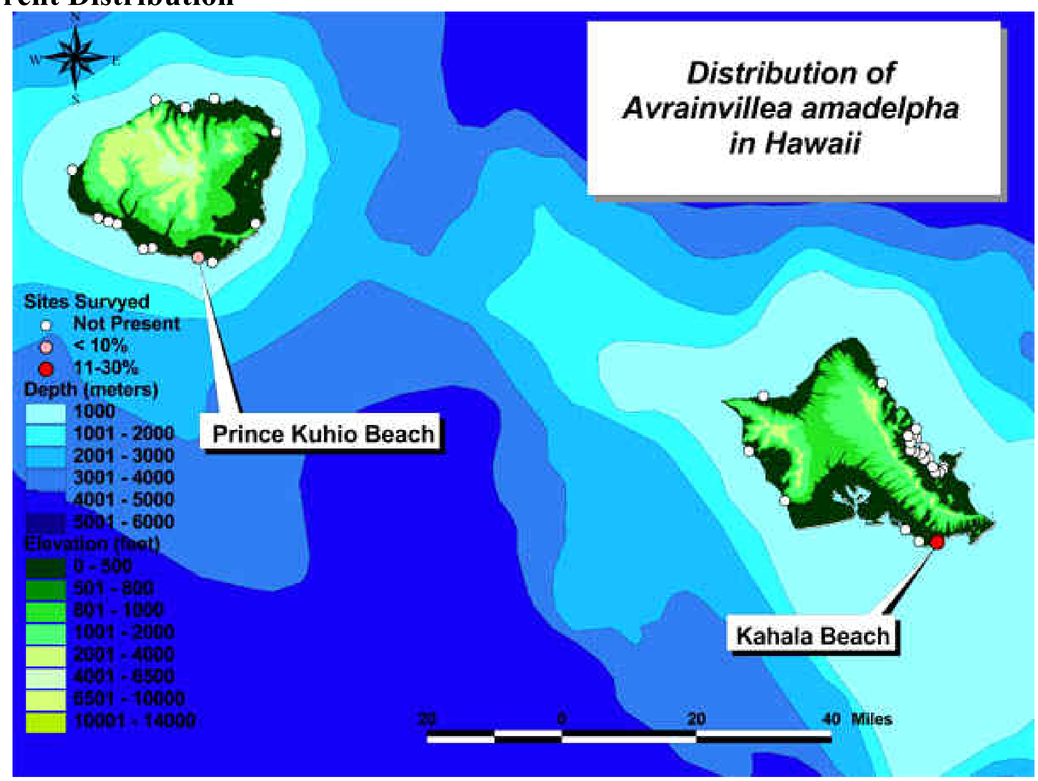

Figure 3.4.8-2. Data from: www.botany.hawaii.edu/GradStud/smith, used with permission

Invasive algae surveys conducted in 1999 and 2000 by the University of Hawai'i's Botany Dept. show the distribution of *A. amadelpha* to include the islands of O'ahu and Kaua'i. Although it primarily inhabits shallow coastal waters, it has been collected from 14m depths off Waikīkī. It can thrive in sandy or rubbly areas. On the island of O'ahu, its range extends from Kahe Point to Diamond Head. It has similarly been reported from Kaua'i's south shore. This may be of some concern to the NWHI since it is capable of interisland dispersal whether through natural mechanisms such as currents or through anthropogenic vectors including ship traffic. With its spread occurring in a northwesterly direction, the possibility of island-hopping exists.

Threats

Given the current rate of spread of *A. amadelpha*, the threat of dispersal to new areas is highly probable. In areas where it has become established, it covers a wide expanse of substrate, eventually acting as substrate for attachment of other algae. Competition with native species has already been described. Overgrowth of *Halophila hawaiiana*, a significant native seagrass has occurred in large sandy regions. *H. hawaiiana* is a relatively rare seagrass found in the subtidal environment. The roots of this important species traps and holds sediment. Within these meadows a rich community of organisms are supported. A variety of sessile and mobile invertebrate species take advantage of the food and shelter provided. Fishes also utilize these seagrass beds. In addition, they provide a significant portion of the endangered green sea turtle's (*Chelonia mydas*) diet. *A. amadelpha* may also be competing with *Halimeda* spp., a calcified chlorophyte that contributes to sand production. Loss of habitat may influence certain fisheries.

3.4.9 *Kappaphycus* and *Eucheuma* spp.

Figure 3.4.9-1. *Kappaphycus*. **Photo by K. Rodgers**

Description

Kappaphycus alvarezii has been referred to as the "licorice algae" due to its ropy appearance and rubbery texture. It is easily distinguished by its large branches, often extending over 6 feet in length with a diameter of up to an inch, making it one of the largest species of seaweed. It varies in coloration from yellow to green to golden brown. The morphological plasticity and lack of sexually mature adults of species within the *Kappaphycus* and *Eucheuma* genus make differentiation difficult.

History

The genus *Kappaphycus* and *Eucheuma* occur naturally throughout the Indo-Pacific although the most commonly cultured species are from the Philippines. Thus far, species from these two genus have been introduced to 32 countries for aquaculture purposes with a current annual value of $270 million (Ask and Azanza, 2002). Several *Kappaphycus* and *Eucheuma* species were intentionally introduced from Florida and the Philippines to Honolulu Harbor and Kāneʻohe Bay in the early 1970's for experimental aquaculture studies, to assess the feasibility of producing kappa-carrageenan, used for medicinal purposes and as a thickener for many foods. These included *K. striatum, K. alvarezii, E. denticulatum,* and *E. isiforme*. Three of these four species became highly successful, extending their distributions and increasing their abundance. The exception was *E. isiforme*, which has not been reported since shortly following its introduction into Kāneʻohe Bay in 1974.

Kappaphycus alvarezii (formally described as *Eucheuma striatum*) was initially introduced into Honolulu Harbor on Oʻahu's south shore in September 1974. It was later transplanted to Moku o loʻe (Coconut Island) on the northwest reef in late 1976 (Russell, 1992). It was again transplanted to several other locations within Kāneʻohe Bay.

Glenn and Doty (1990) conducted research on growth, photosynthesis, and respiration, while Russell (1981) documented the introduction and establishment of *K. alvarezii* in a doctoral dissertation with subsequent ecological studies.

Current Distribution

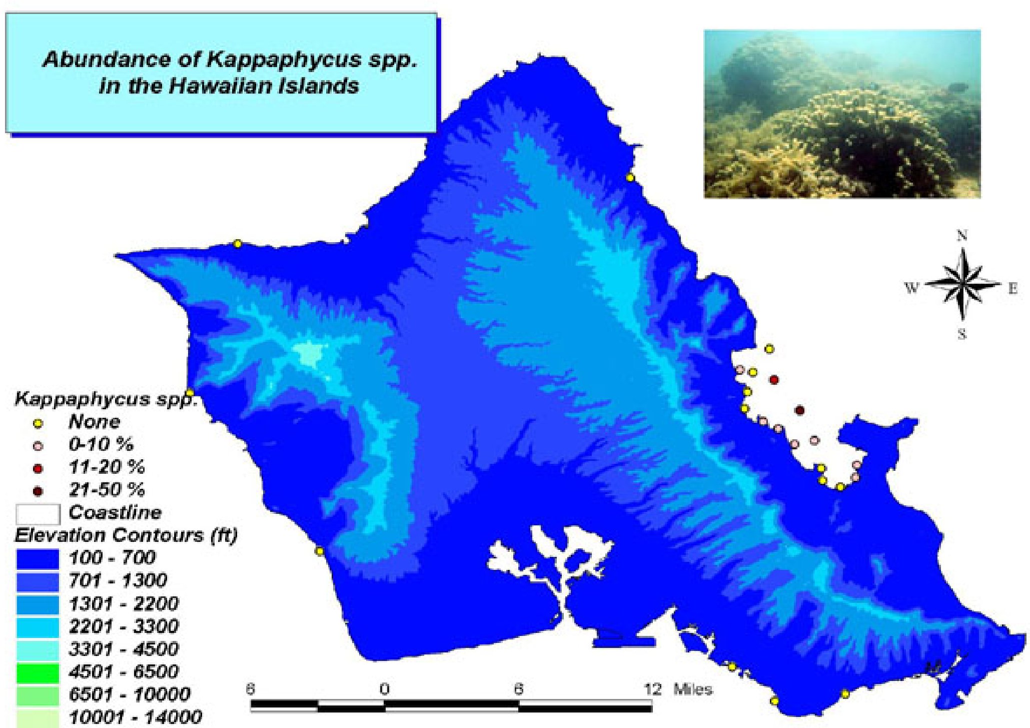

Figure 3.4.9-2. Data from: www.botany.hawaii.edu/GradStud/smith, used with permission

K. alvarezii also transplanted to Moku o lo'e (Coconut Island) in Kāne'ohe Bay in 1974 has since become highly successful, spreading as far as Kualoa at the far north end of the Bay. Although its distribution has expanded to include the whole bay, it is found in highest abundance on the fringing reef and patch reefs in the south and central sectors.

Ecology

Kappaphycus spp. can spread rapidly through fragmentation, growing from even the smallest pieces. In recent years, extensive scientific and community efforts have been undertaken to control its distribution and limit its abundance.

Threats

Invasive marine algae have displaced native algal species throughout the world. In temperate marine regions, *Caulerpa taxifolia, Codium fragile tomentosoides, Grateloupa turuturu, Sargassum muticum,* and *Undaria pinnatifida* have spread rapidly to invade new territories. In the tropics, the most well-documented case of displacement of natives is the *Kappaphycus* spp. from Hawai'i. It has demonstrated the potential to successfully invade new territory (Rodgers and Cox 1999, Conklin and Smith 2005) and its ability to compete directly with native species has been documented (Woo 2000). By 1996, eighteen years after its original introduction on Moku o lo'e, *Kappaphycus* spp. had spread nearly 6 km from the point of its origin to the northwest sector of Kāne'ohe Bay (Rodgers and Cox 1999). Subsequent surveys in 2003 found *Kappaphycus* spp. had not only continued its progression but has invaded new territory (Conklin and Smith 2005). This further extension of its distribution reflects an additional 3 km spread from 1996 to 2003, a nine-year period. Thus, in the 25 years since its arrival, it has spread 9 km. An additional concern is the abundance of *Kappaphycus* spp. near the channels where currents can potentially carry fragments outside the bay. It was also documented that *Kappaphycus* spp. has invaded new habitats (Conklin and Smith 2005). Once restricted to the outer margins of reef flats it has extended its geographic range to include the reef slopes.

The documented ability of *Kappaphycus* spp. to invade new territory and overgrow and kill native species has become a serious concern as has the results of recent research demonstrating its rapid re-growth following removal (Conklin and Smith 2005). Experimental plots on three different habitat types show extensive growth rates after only two months. A year following manual removal of all *Kappaphycus* spp. from plots, it averaged 62% cover. Residual tissue left at attachment points are responsible for this re-growth. These microscopic cells are impossible to manually remove. This can pose a problem in control and eradication efforts. An extensive program has been underway to control the spread of *Kappaphycus* spp. outside Kāne'ohe Bay. Research projects to link its ecology with methods of control are diverse. These include studies focusing on competition with native species, re-growth studies, effectiveness of biocontrol agents, and herbivorous fish preference tests.

These studies aid in understanding the ecology of *Kappaphycus* spp. and evaluating the possible measures of control. A manual removal attempt utilizing a modified dredge and suction is currently being tested as a joint effort between the University of Hawai'i, the Nature Conservancy, and the Division of Aquatic Resources. Manual removal had previously been demonstrated to be ineffective in preventing re-growth. Woo (2000) found *Kappaphycus* spp. to spread rapidly from only a few apical cells not even visible to the human eye. Conklin and Smith (2005) have documented substantial re-growth after removal from experimental plots.

Research involving the role of herbivorous fishes in controlling invasive species is disappointing. *Kappaphycus* spp. is not a preferred algae and is not being grazed heavily by fishes frequenting the bay (Stimson et al. 2001). An herbivorous invertebrate has however shown some promise in biocontrol of *Kappaphycus* spp. Unlike the local fishes, the sea urchin, *Tripneustes gratilla* appears to prefer this invasive algae over native species. Studies using experimental enclosures found a substantial decrease in *Kappaphycus* spp. although no increase in coral cover was observed (Conklin and Smith 2005). *T. gratilla* occurs in low abundance in Kāne'ohe Bay and would have to be brought into the bay in large numbers to effectively control the *Kappaphycus* populations. The negative effects of biocontrol agents in terrestrial environments are well documented. Their wide-ranging effects are usually irreversible, creating more problems than they solve. Biocontrol as a method of introducing a species in an attempt to control a destructive species can have devastating effects. There can be synergistic effects with other species and non-target effects can results. Host switching may occur when the targeted species becomes limiting. The host may expand their range since they are self-propagating and self-dispersing. Competition with native species can arise. A common carnivorous snail introduced to control the African snail populations and the Indian mongoose as a biocontrol for rats are just two examples of failed attempts at controlling invasive species. Introduced in 1955, the biocontrol agent *Euglandina rosea* drastically reduced the remaining endangered *Achatinelline* tree snails populations. The mongoose, *Herpestes auropunctatus* was similarly introduced as a biocontrol for rats on the sugar plantations in 1883 from Jamaica. It has since reduced bird populations through predation on eggs and hampered efforts to reintroduce the endemic nene goose, *Nesochen sandvicensis*, back to its native environment. In addition to reduction and competition with native species it has assisted in the spread of other introductions such as the guava (*Psidium* spp.) (Stone and Loope 1987). Although biocontrol agents have not been widely used in the marine environment, effects of marine introductions have been well-documented. The introduced snapper, *Lutjanus kasmira* carries an internal parasite that may spread to native fishes and may also displace deeper water snappers. Even introducing native species into areas with low abundances such as is suggested with *T. gratilla*, can dramatically alter the ecosystem.

Other suggested methods of controlling invasive species that have proven effective elsewhere include insitu killing using salt, copper sulfate, and chlorine (Thibaut and Meinesz 2002). Experiments would have to be replicated in Hawaiian environments to include *Kappaphycus* spp. If these chemicals prove to be effective in the control of *Kappaphycus* spp. it is still highly likely that they may inflict serious damage on adjacent native species.

Phase shifts from coral to algal dominated reefs have been associated with loss of biodiversity, reduction in value, and the erosion of reef structure. The spread of *Kappaphycus* spp. to other areas in the MHI is highly probable. As a possible NWHI invader, steps can be taken to slow its expansion beyond its present distribution and prevent its accidental import outside the MHI.

3.4.10 *Acanthophora spicifera*

Figuure 3.4.10-1 . *Acanthophora spicifera*. **Photo by J Smith**

Description

Acanthophora spicifera is a Rhodophyte or red algae. Its coloration varies with exposure to sunlight, from yellow in shallow waters exposed to bright light, to green, red or dark brown in areas with lower irradiation. The distinctive solid, cylindrical, spiny branches can grow up to a foot high. The short main branches are hook-like and brittle, fragmenting easily in high water motion. Its large holdfast is irregularly shaped to attach to hard substrate. Branch morphology can change under varying conditions. Under low wave energy conditions, it can reach greater heights. Kilar and McLachlan (1986) found that *A. spicifera* in Panama reached only about one-third the height in heavily wave influenced fore-reefs as those residing in low energy back reef areas.

History

Believed to have arrived accidentally from Guam to either Pearl Harbor or Waikīkī, this highly successful species has spread throughout the state since its arrival in the 1950's.

Current Distribution

Acanthophora spicifera is widely distributed throughout tropical and subtropical regions in tidal and subtidal zones (Kilar and McLachlan, 1986). It is typically found in shallow reef flats between 1-8 m although has been reported to depths of 22 m in Florida, the Virgin Islands and Puerto Rico. In Hawai'i, *A. spicifera* can be found on all main islands particularly in shallow intertidal zones and has been reported as one of the most abundant rhodopyhtes occurring on reef flats (Jokiel and Morrissey, 1986). It can be found on a diversity of substrate type. It is particularly abundant on hard bottom substrate, attached as an epiphyte on other algae or unattached as drift algae.

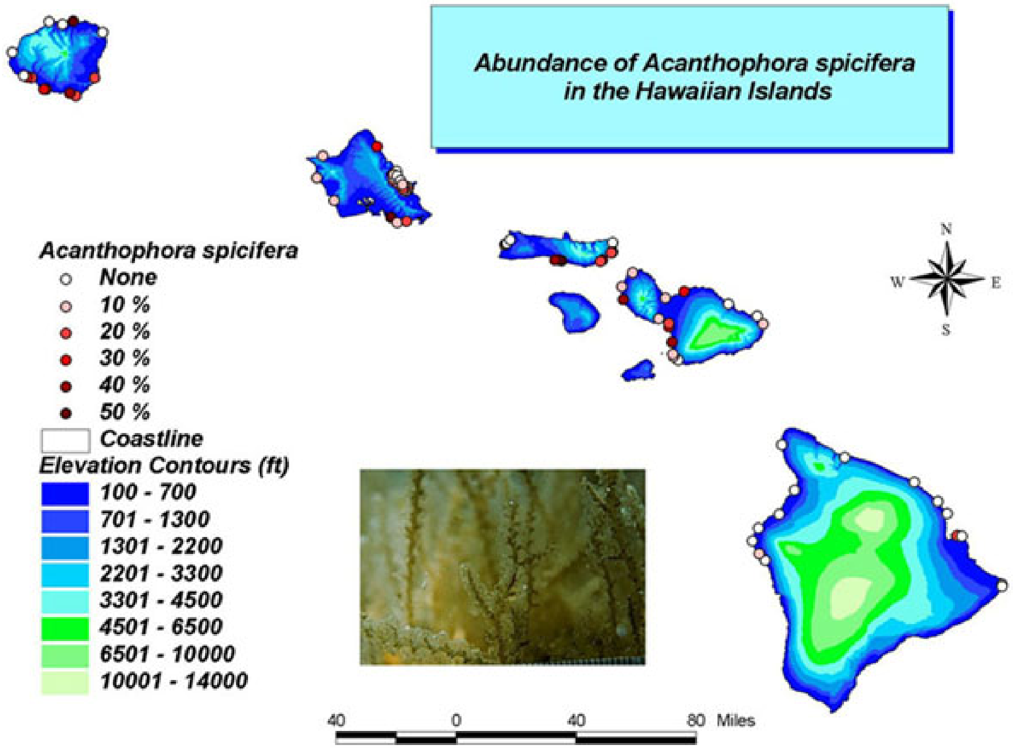

Figure 3.4.10-2. Data from: www.botany.hawaii.edu/GradStud/smith, used with permission

Ecology

Typical of most macrophytes, *A. spicifera* exhibits both sexual and asexual reproductive strategies. Sexual tetrasporaphytes were found to be extremely common on reef flats in Panama but dropped dramatically from 80% to 5% of the plants during prolonged periods of tidal immersion (Kilar and McLachlan 1986). Asexually, fragmentation accounts for most of the standing crop. High wave energy will fragment algae and local currents distribute them to adjacent areas. Fragments can securely attach to substrate in about two days. Its morphology is ideal for recruitment into new areas due to its hook-like branches that can snag on rocks, corals, or other species of algae.

Distributed throughout the tropics and subtropics, its temperature range is quite broad and has also been found to tolerate levels of salinity both higher and lower than ambient. It cannot survive repeated exposure to air (Russell 1992). However, its survival rate increases when it co-occurs with other species. This beneficial co-existence is due to the tolerance of the other algal species to wave energy and their retention of water to prevent desiccation.

The major predators on *A. spicifera* are reef fishes and the green sea turtle, *Chelonia mydas*. Russell and Balaz (1992) found in examining stomach contents that over 20% of their diet is comprised of *A. spicifera*.

Threats
Branches often break off easily and grow rapidly into extensive free-floating mats or attach to several species of native seaweeds. Competition with native algae was demonstrated by Russell and Balaz (1992).

4.0 MANAGEMENT OPTIONS

4.1 Prevention

In the aquatic environment it is considered unrealistic in most cases to be able to eradicate a non-indigenous species once it has become established. The best strategy is to minimize the likelihood of initial introduction through prevention and outreach efforts. The most common approach for prevention is to target individual species that are potentially invasive to an area. This is a method proven to be effective in terrestrial systems, however, a more comprehensive approach in aquatic environments is to identify major pathways that can expose habitats to non-indigenous species and determine ways to control their potential effects. These pathways have been identified in earlier sections. There are many pathways that can transport non-indigenous species to aquatic systems and a variety of management tools and treatment options aimed at prevention. In contrast to historic introductions, present introductions are seldom intentional. Measures to avoid unintentional introductions must now be addressed. Education and legislation can help control introductions associated with maritime shipping, live seafood and bait shipments, aquaculture, shipments of commercial and institutional aquarium species, the activities of education and research institutions and marine debris transport. The major vectors that can impact the Northwestern Hawaiian Islands Marine National Monument are covered in the following sections.

4.1.1 Ballast Water

Ballast water treatment and management can decrease inadvertent introductions associated with this vector. Several treatments have been suggested to treat ballast water. These include filtration, mechanical agitation, salinity alteration, exposure to radiation, microwaves, heat, removal of oxygen, construction of facilities to supply treated water, and facilities to discharge water into (Carlton et al. 1995). Several of these methods have been successfully employed. Using the heat from the engines to raise the temperature of the ballast water resulted in the mortality of all zooplankton and partial mortality of phytoplankton (Rigby et al. 1999). The use of nitrogen to remove oxygen to prevent ballast tank corrosion has also proved to be successful in eliminating most of the marine organisms (Tamburru et al. 2002). Another deoxygenating technique using a vacuum had similar results (Gordon and Horeth 2001). Presently, the most widespread method is the exchange of ballast water before arrival to a destination. This is the method that is in widespread use due to its inclusion in administrative rules on the national and international scene (see section 4.2).

4.1.2 Sediments

The measures taken to minimize the transport of organisms by sediments associated with maritime activities are varied. 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 due to 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 (International Maritime Organization, 1998) and state that it should be disposed of in land-based facilities or in open ocean environments. Sediments associated with deck surfaces and closed spaces such as anchor chain lockers and bait wells are easier to manage. These areas associated with sediment accumulation can easily be surveyed and the material eliminated by physical removal before departure from source ports to the Northwestern Hawaiian Islands Marine National Monument.

A synopsis of preventative measures to minimize transport of non-indigenous species by ballast water and sediments from source ports to the Northwestern Hawaiian Islands Marine National Monument are as follows (Based on Godwin and Eldredge 2001):

- Ballast water exchange in water deeper than 2000 m should be performed to flush out any surviving organisms taken in at ports, if pre-intake measures are not in place.
- Pre-intake measures such as filtration, ultraviolet treatment, sonic treatment, or other measures that exist should be implemented.
- Do not take in water from global hotspots where organisms that may be a threat to the environment exist, such as from areas that are experiencing toxic algal blooms or waterborne disease outbreaks.
- Do not take in ballast water at night since a more diverse assemblage of organisms may be present.
- Avoid areas with high sedimentation or shallow waters, poor water quality, or regions near sewage discharge.
- Post-intake extermination of organisms with biodegradable chemicals, heat, or electrical treatment should be conducted.
- Clean ballast tanks regularly and dispose of sediments properly.
- Inspect deck surfaces and enclosed voids for sediment accumulations and remove and dispose of properly.

4.1.3 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. 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 create 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 non-indigenous species 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.

A synopsis of high risk vessel platforms is as follows:

1. Towed vessel platforms: this category includes a variety of platforms towed by tug boats such as cargo and crane barges, drilling platforms, and pontoon bridges. The tug boats for this and the second category would also be included as high priority vessels.
2. Floating Drydocks: a category of large towed vessel platforms that can change ownership quite frequently and are subsequently moved throughout the oceans of the world. Purchasing and transporting floating dry docks to new locations is a cheaper alternative to constructing new shipyard facilities.
3. Stochastic Events: a general category that puts focus on arrivals that are not part of the regular suite of vessel arrivals to a port system. Examples would be unscheduled arrivals for medical and mechanical emergencies, salvaged vessels, and decommissioned military vessels. Personal craft from overseas locations are also included in this category due to the fact that arrivals are quite unpredictable. The exception would be regularly scheduled sailing races that use Hawaiʻi as a stop-over or finish point.

In order to prevent transfer of introduced species by vessel hull fouling the inspection of all vessels planning to enter the Northwestern Hawaiian Islands Marine National Monument is imperative and should include all surfaces at and below the waterline. This requires some specialized training and needs to be done by specialists. Levels of fouling vary and this makes the level of compliance variable. Fouling ranges from concentrations in discrete locations to uniform coverage. Discrete levels of fouling can be dealt with easily but uniform coverage requires a labor intensive and costly procedure performed by commercial diving companies. Potential operators/owners of vessels operating in the Northwestern Hawaiian Islands Marine National Monument should be made aware of this cost so that it can be figured into contract proposals. Public and private sector vessels that will be operating regularly in the Northwestern Hawaiian Islands Marine National Monument should adopt the following approaches to safeguard against non-indigenous species transport:

- Frequent underwater visual or video inspections
- Proper maintenance
- Regular cleanings at shipyards
- Sea chest and piping time-released biocides

4.1.4 Other Sources

Marine debris has been shown to have the ability to transport non-indigenous species to the Northwestern Hawaiian Islands Marine National Monument. Modes of transport such as derelict fishing nets are problematic to manage but the impact of other anthropogenic debris, such as Fish Aggregating Devices (FAD) deployed by the State of Hawaiʻi, can be minimized. Increased attention to the care and maintenance of FAD's will minimize the likelihood of them drifting into the Northwestern Hawaiian Islands Marine National Monument.

The increase in focused research in the Northwestern Hawaiian Islands Marine National Monument has created a situation in which more vessel traffic and extractive activities are influencing a variety of habitats. A suite of potential non-indigenous species vectors associated with research activities related to small boat and diving operations need to be considered. The large vessel platforms are included under the guidelines of other maritime traffic but the small boats launched from them need to be considered as well. Before loading onto the transport vessel, a full survey of outboard motor apparatus and bilges for live organisms, sediments and propagules should be completed. Appropriate cleaning with freshwater should be required in all cases. Dive gear, instrument arrays and other equipment should also be subjected to inspection and freshwater rinsing before being loaded for transport to the Northwestern Hawaiian Islands Marine National Monument.

Many other vectors associated with fisheries and conservation activities exist and a brief synoptic list of measures to minimize inadvertent exposure of the Northwestern Hawaiian Islands Marine National Monument to aquatic non-indigenous species is as follows:

- No aquaculture or small scale rearing of algae, invertebrates or fish
- No intentional introductions for any purpose
- No disposal of bait or seafood
- Sanitation of live wells and fishing gear prior to entry
- No release of any organism collected on another island
- Proper storage and disposal of marine debris
- No sand or soil transport

- Inspection and cleaning of marine construction material

4.2 Legislation and Administrative Rules

U.S. Federal Government Management Efforts

Due to the impacts of AIS documented in the United States , Congress passed the Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA). The NANPCA legislation created mandatory ballast water management guidelines that applied only to the Great Lakes. A reauthorization of NANPCA in 1996 created the National Invasive Species Act of 1996 (NISA), which expanded the legislation to cover all U.S. ports. Under NISA, the U.S. Coast Guard (USCG) developed voluntary ballast water management guidelines and mandatory ballast water management reporting and record keeping. NISA required the USCG to submit a report to Congress to evaluate the effectiveness of the voluntary ballast water management program. This report was submitted in June 2002 and concluded that compliance was too low to allow for an accurate assessment and proposed regulations that would make the voluntary guidelines mandatory. The proposed mandatory guidelines would require all vessels equipped with ballast water tanks entering U.S. waters after operating beyond the Exclusive Economic Zone (EEZ) to use one of the following approaches:

- Complete exchange of ballast water intended for discharge in U.S. waters. This exchange must take place no less than 200 nautical miles from any shore.
- Retain ballast water on board the vessel
- Prior to entry into U.S waters, use an environmentally sound ballast water management method that has been approved by the USCG
- Discharge ballast water to an approved reception facility

This legislation covers ballast water only and has no provisions for dealing with sediments or hull fouling, although they are mentioned as issues for the future.

Presently, the NISA 1996 legislation is being reauthorized as the National Aquatic Invasive Species Act 2005 (NAISA). This is expanded legislation that seeks to provide tools and coordination to manage AIS threats more broadly. The NAISA legislation will implement a framework for an effective AIS management program. The components of this framework will be coordinated between all levels of government in partnership with private sector stakeholders.

State of Hawai‘i Aquatic Invasive Species Management Effort

In 2003 the development of administrative rules dealing with the vectors of ballast water and ballast sediments were drafted by the State of Hawaii and pending rules for hull fouling are in development. The administrative rules for ballast water and ballast sediments were based on a rules and regulations from the International Maritime Organization resolution A.868(20) within MEPC 47, and State of California Assembly Bill 703. The rules were developed, reviewed and agreed upon by a multiple stakeholder task force.

In the Session Laws of Hawai‘i 2000, the Legislature established Act 134, which subsequently became Chapter 187A-31, Hawai‘i Revised Statues (HRS), titled Alien

Aquatic Organisms. Chapter 187A-31, HRS, designated the Department of Land and Natural Resources (DLNR) as the lead agency for preventing the introductions and carrying out the eradication of alien aquatic organisms through the regulation of ballast water discharges and hull fouling. It also gives DLNR the authority to establish an interagency task force to address concerns relating to alien aquatic organisms and adopt administrative rules, including penalties, to carry out the intent of this law.

The administrative rules for ballast water mirror the rules generated by the USCG for mandatory ballast water management and reporting. In the case of ballast sediments all vessels (including vessels at dry dock) are required to dispose of ballast sediment in a proper manner. Ballast sediment is defined as any settling particulate matter (organic or inorganic) that is found inside a ballast tank.

In 2003 a research project funded by the Hawai‘i Coral Reef Initiative Research Program focused on the initial efforts for hull fouling management for Hawai‘i. The focus of the effort was to develop an information framework that provides a baseline to support the development of management strategies for hull fouling introductions. A baseline risk assessment strategy based on priority vessel types was put together to guide the DLNR in preliminary decision-making. The vessels that received the highest priority were towed platforms, floating drydocks, and unscheduled arrivals of salvaged vessels, decommissioned military vessels, and private boats from overseas locations. Presently, the DLNR is pursuing funding to support efforts to expand the information as a tool for minimizing the introduction of marine AIS by hull fouling of commercial and private vessels. Although designed for the MHI, a similar approach for the NWHI could be developed.

4.3 Limitations and Information Needs

Before a prevention plan can be formulated it is imperative to know which species are involved, and their distribution and abundance. One of the main problems in taxonomic identification of introduced species in the NWHI is that a full assessment of species has not been completed. New species continue to be described. Although great strides have recently been made in describing new species, there are still few comprehensive surveys to determine endemic status. Descriptive taxonomic studies are crucial to understanding which species are native to a particular locale. The description of taxonomic groups is often biased by the size of the organism. For example, perhaps the most widespread organism in the marine environment, the nematode has been poorly described relative to mollusks or fishes. This size dependent information is highly correlated with commercial and recreational interests. To add to this problem, there has been a steady decline in the number of taxonomists (Winston and Metzger 1998). This shift away from systematics to cellular and molecular studies may hinder the description of marine organisms (Wilson 1989).

The lack of species distributions and abundance and an incomplete taxonomic database make identification of invasive species difficult. In order to determine if a species is introduced, baseline abundance and distribution data is necessary. The origin of many species is unknown and reported as cryptogenic.

4.4 Eradication

Only two attempts at eradication of a potentially invasive species have been reported in the literature. A mussel, *Mytilopsis* sp. was eliminated from Darwin Harbor in Australia Bax et al. 2002). Four marinas were quarantined and treated with sodium hypochlorite and copper sulfite and all boat hulls were cleaned. This was possible because the marinas were isolated from other waters by a set of double locking gates. Follow-up monitoring verified the success of the project.

The second success story involved the polychete, *Terebrasabella hetrouncintata* in Cayucos, California. Introduced with a shipment of South African abalone, it spread to an intertidal area near the mariculture facility. A two-fold eradication plan was initiated preventing further spread by placing screens over effluent pipes and eliminating its native host, the Black turban shell, *Tegula funebralis* (Culver and Kuris 2000).

These two successes were only possible because of the small spatial scale and early detection of the invasive species. Regrettably, this is the exception in the vast majority of cases. This is why extensive monitoring must be initiated to detect these aliens in the colonization phase before they have the time and opportunity to spread. Yet, monitoring large areas is not often feasible due to the time and expense involved.

Historically, most attempts at eradication of invasive species have not been successful as reported earlier. Physical or chemical removal can be very costly. Attempts to remove invasive Japanese sea stars (*Asterias amurensis*) from Tasmania were unsuccessful. The Asian mussels (*Mytilopsis* sp.) cost Australians millions of dollars to eradicate from a small artificial marina.

If an introduction is identified early before it has had a chance to spread and become invasive, it is possible to control or even eradicate it. Rapid response to incipient invasives is essential. Monitoring efforts and widespread assessment in the Northwestern Hawaiian Islands Marine National Monument may have the ability to identify

- Similar environment to the source of the invasive species
- Recently disturbed environment
- Low natural diversity
- Absence of predators of the invasive species
- No similar native species
- Simple food-web
- Anthropogenic disturbance

To implement a rapid response would require a core team composed of members that not only represent specialists familiar with disturbances but also include individuals from the variety of jurisdictions represented in the Northwestern Hawaiian Islands Marine National Monument.

Since it is difficult to predict which species may become invasive, identification of the habitats that may foster these species is often used (Williams and Meffe, 1999). Some of the characteristics of these habitats where introduced species are likely to invade can aid in minimizing the likelihood of introductions.

Recent scientific data has increased our knowledge and awareness that has amplified the focus on these invasive introductions. Through education and effective management strategies, the threat of invasion can be drastically reduced. In order to preserve and continue the legacy of the Northwestern Hawaiian Islands Marine National Monument it is imperative to take the necessary steps to protect its native biota from these non-indigenous species threats.

5.0 LITERATURE CITED

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