Regional Biosecurity Plan for Micronesia and Hawaii

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Marine Invasive Species Risk Assessment for the Commonwealth of the Northern Mariana Islands, Guam, Hawai'i, Palau, the Federated States of Micronesia, and the Republic of the Marshall Islands

Edited version of the original document

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Preface

This document presents a risk analysis for the marine systems of Micronesia, providing a framework and recommended actions to reduce the risks (probability of establishment, spread, and impacts) of invasions by non-native species in marine habitats.

The work presented in this document is primarily a synthesis and review of information available on the processes, spatial and temporal patterns, and existing management (regulations, guidelines and practices) for invasions by non-native marine species. Micronesia was the primary focus of this analysis, and information was also included from other regions, where relevant to understanding invasion dynamics and current (and emerging) management practices.

Most of the information presented in this document was obtained from extensive literature review, analysis of reports and documents, existing datasets (especially on ships and commerce), and interviews and correspondence with experts across a diverse range of topic areas. As conceived by the sponsoring agency, the project scope was constrained to what could be accomplished in one year of effort. Thus, the available time and resources were insufficient to complete any new major research effort, such as conducting field-based surveys to document existing biota in Micronesia or associated with vectors operating in the region. The resulting document indicates therefore what data and data gaps exist in this respect. An exception to this approach was an opportunistic field-based survey of a small number of supply ships in Guam, providing some preliminary data that begin to assess the extent and taxonomic diversity of marine organisms associated with the hulls (underwater surfaces).

It is important to recognize that the information presented in this report represents a snapshot in time. The work for this project began in late 2009, and most of the information collection and analyses were done in 2010. Unfortunately, due to delays in obtaining data for vessel traffic patterns (as discussed in Chapter 1), the final report was not completed until early 2012. While the authors attempted to include new information as it became available through February 2012, it also was not possible to accomplish this in a comprehensive way. Management of marine invasions is a very dynamic field that is undergoing rapid changes, and new policy changes emerged during the report drafting. For example, since this project began, new regulations have emerged for ballast water on a national level, for ballast water discharges by commercial ships operating in U.S. waters (including Guam). The U.S. Environmental Protection Agency published draft regulations (Federal Register, Volume 76, Number 236, December 8, 2011), and the U.S. Coast Guard published a final rule for ballast water treatment (Federal Register, Volume 77, Number 57, March 23, 2012). In fact, the latter rule did not become final until after this report was completed, and reference to it was added as a footnote in a revised version. Additional regulations are pending at state levels, as seen in California for management of biofouling organisms on commercial vessels operating in state waters (http://www.slc.ca.gov/spec_pub/mfd/ballast_water/Ballast_Water_Default.html).

Finally, we are greatly indebted to the many people who generously shared their time, expertise, insights, and information concerning the invasions, management, policy, culture, and history of Micronesia and Hawai’i. This project would not have been possible without the enormous assistance and advice provided from those who shared their knowledge (at regional, national, and local scales) in resource management, customs and quarantine, commercial and military maritime transportation, port operations, fisheries, aquaculture, recreation, tourism, conservation, policy, and marine species distributions and inventories. Large numbers of people, agencies, and organizations were involved in this regard from many different parts of Micronesia and elsewhere. Rather than attempt a comprehensive list and unintentionally omit some participants, we simply acknowledge the important information contributed to this report by many people throughout Micronesia and Hawai’i.

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PART I.

Overview: Introduction to the Report and Analysis of Marine Invasion Mechanisms and Management in Micronesia

Chapter 1: Introduction to the Report and Marine Biological Invasions

By Gregory M. Ruiz, Chela J. Zabin, and Paul W. Fofonoff

1.1 Purpose of the Report

Recognizing existing concerns about biological invasions, the U.S. Department of Defense (DoD) has requested development of a Biosecurity Plan for Micronesia to minimize the risk of introduction and spread of non-native species in the region. This plan is in response to the proposed relocation of Marine Corps, Navy and Army operations from Okinawa, Japan to Guam (hereafter referred to as the Buildup), as outlined in the Draft Environmental Impact Statement (DEIS; DoD 2009) and Final Environmental Statement (FEIS; DoD 2010) . Overall, the U.S. military originally anticipated the relocation to Guam of 24,713 military employees and dependents. This was expected to result in construction of ~3,000 buildings and major infrastructure improvements, including the creation of a new deep draft wharf that could accommodate a transient nuclear powered aircraft carrier. During the construction phase, the population of Guam was projected to (a) increase by 79,178 people at its peak, in order to provide the infrastructure and services in existing plans and (b) level off at 33,608 (including the military personnel and dependents). These estimates are subject to changes, and current plans are to lower the estimated size of the Buildup and extend the time of completion (U.S.-Japan Security Consultative Committee 2012). The increased demand for equipment (e.g., dredging equipment, silt curtains, etc.), vessels, construction materials, household goods, food, and other supplies regardless of the ultimate size and nature of the buildup will result in increases in commercial and military shipping and air traffic activity.

This increased flux could increase the risk of introduction and establishment of non- native species to Guam and, once established, increase their potential to spread to other parts of Micronesia. Currently there are connections between islands in the region via commercial shipping, military and private ship/boat traffic, and airline and helicopter traffic, which move goods and people. Spread within the region could be potentially further facilitated by the DoD’s plans to use Tinian in the Commonwealth of the Northern Marinas Islands (CNMI) for military operations, by more frequent military ship traffic to other locations within Micronesia, and by increased tourism by military personnel and dependents within Micronesia and Hawai’i.

For this reason, the DoD has called for a Risk Assessment and Biosecurity Plan, which is required as part of the FEIS and the Record of Decision for the Buildup. The Risk Assessment and Biosecurity Plan are intended to have two phases, as specified in the Statement of Work. The first phase uses a science-based analysis and assessment to characterize potential mechanisms and associated risks of non-native species transfers. The second phase develops a biosecurity plan that identifies best management practices (BMPs) and responses needed to reduce the likelihood and potential effects of new invasions by non-native species. While this effort focuses on Guam as the center of increased military activity, the DoD has specified that the Risk Assessment and Biosecurity Plan include analysis of the Micronesian region more broadly and also the linkages (opportunities for species transfers) between Micronesia and Hawai'i.

This document is intended to (a) outline risks of marine invasions to Guam and Micronesia, as well as those in Hawai'i associated with the Buildup, and (b) provide recommendations for practices that can reduce the likelihood of introductions, establishment, and spread of non-native marine species. Below, we provide a more detailed description of the process, structure, and content for this report.

1.2 Context, Timeline, and Limitations of the Report

The issue of biological invasions was largely absent from the DEIS , released by the DoD in November 2009, with an understanding that the current analysis (findings of the Risk Assessment and recommendations in the Biosecurity Plan) would be incorporated at a later date, as available. This project was initiated in September 2009, when funds became available to implement the analysis for coastal marine ecosystems.

In anticipation of a 2011 construction start date, especially for facilities at Apra Harbor in Guam, the DoD requested preliminary recommendations for BMPs prior to the completed Risk Assessment, focusing primarily on port facilities and operations in Guam. A set of draft BMPs were submitted to the DoD in March 2010 to serve as general guidelines while this RA and the overall MBP were completed. The recommendations contained in the current document build upon and refine those made in March 2010.

The findings and recommendations from this risk analysis support the regional biosecurity implementation plan. The U.S. Navy and University of Guam entered into a cooperative agreement in September of 2011, whereby the university has agreed to create a strategic implementation plan using this analysis, as well as those for freshwater plants, freshwater fishes, and terrestrial organisms (see above). Thus, the current report aims to highlight the current understanding about marine invasions, identify key data gaps, and recommend management strategies to include in the implementation plan, in order to reduce invasion risks to the region. However, this report does not identify the necessary resources, possible timeline, or the institutional framework and coordination required to fully implement and sustain an effective biosecurity program. These latter elements are inter- dependent upon each other, representing critical aspects of the implementation planning process.

Importantly, the time period specified by DoD in the Statement of Work limited the analysis to relying primarily on the collection and synthesis of existing data as available to us, through efforts to identify and obtain relevant information for Guam, the Commonwealth of the Northern Mariana Islands, Palau, the Federated States of Micronesia, the Republic of the Marshall Islands, and Hawai'i. It is evident that significant data gaps exist, and many of these are identified throughout the report in particular chapters, which discuss (a) the implications for risk assessment, (b) how these gaps are addressed within the analyses, and (c) approaches to address these gaps.

One of the conspicuous data gaps merits brief mention at the onset, because it is a core component to assessing invasion risk as outlined in the Statement of Work. Access to vessel movement data or hull information for U.S. Navy combatant ships was not provided, due to concerns about the sensitive nature of these data with respect to national security and potential public release. In consultation with DoD, we sought data on both U.S. Navy combatant and supply ships, in order to assess the current connectivity among global regions and the potential opportunity for transfer of non-native species by vessels. In the summer of 2011, we received data on the supply ships, and DoD requested that analyses proceed without data for the combatant ships. Consequently, U.S. Navy combatant ships arriving to Guam or elsewhere were not included in the risk assessment (see Chapter 5). In the absence of vessel movement data, there is no reliable way to constrain the potential ports visited (and non-native species contacted) by this classification of vessel, and the potential risk of invasions associated with combatants remain undefined in this analysis.

1.3 Structure and Rationale of the Report

The report is divided into three different parts, most with multiple chapters, to address different topics associated with marine invasions and biosecurity. Part I characterizes the current status and knowledge of human-mediated transfer mechanisms (vectors) for non-native marine species into Micronesia, summarizing available information on their operation, scope, and management (including regulations and practices) in four separate chapters. Part II (one chapter) provides an assessment of risks of marine invasions for Micronesia. Part III (one chapter) outlines a biosecurity plan, providing recommendations for specific management actions, strategies, and frameworks to minimize impacts of marine invasions for the jurisdictions covered by the Micronesia Biosecurity Plan (MBP).

This first introductory chapter (Chapter 1) provides a brief overview of the report and background information regarding the patterns and mechanisms of marine invasions across multiple geographic regions. This chapter also highlights the importance of particular vectors for the introduction of marine species, including especially (a) the movement of organisms associated with vessels and (b) trade of live organisms associated with aquaculture, restocking efforts, food, bait, and home aquaria.

A focus on vectors, as described in the introductory chapter, is used as a general framework for the organization of the report. This framework serves multiple purposes; first, focusing on vectors places primary attention on understanding and preventing unwanted species transfers in order to reduce the likelihood of invasions. A pre-border (prevention) approach to biosecurity is widely considered more desirable, effective, and predictable than post-border interventions, after species have arrived or established populations (Meyerson and Reaser 2002; Wittenberg and Cock 2005). This approach is also consistent with guidance for U.S. federal agencies (see Section 2.1). Second, guidelines and management strategies to advance pre-border biosecurity are organized primarily by vector, recognizing that this is the operational unit for both (a) invasion opportunities and (b) particular segments of industry, military, commercial, and public activities. Any pre-border strategy or policy must have an explicit vector-based component, whether for particular types of organisms or habitats, addressing the transfer mechanism(s) of concern. In short, this organizational framework will underscore vector management as a critical component of the biosecurity plan, aiming to reduce the risk (probability) of future invasions.

In Chapter 2, the report reviews current regulations, guidelines, and practices used to reduce marine invasions associated with vessels. Of particular relevance are practices for vessels arriving to Guam, other parts of Micronesia, and Hawai'i. We also consider the practices that are applied to vessels in other global regions, discussing the rapid changes that are now underway on an international scale. The analysis in Chapter 2 focuses on commercial and U.S. military vessels, including military supply vessels. Although recreational and fishing vessels also pose potential invasion risks, biosecurity guidelines and regulations are largely undeveloped for these vessels at the present time.

Chapter 3 reviews what is known about the current and projected future flux (number) of vessels arriving to Guam and Micronesia, as well as the magnitude of vessels moving between this region and Hawai'i. We focus particular attention on commercial and military vessels, evaluating what is known about the previous ports of call, since these are the potential source regions of species transfers. We also summarize available information across all types of vessels and other in-water structures and equipment which may transport organisms. In some cases, there are significant gaps in knowledge regarding vessels, in-water equipment, and various other equipment types. These information gaps are identified and discussed.

Live trade as a possible vector for non-native species introductions to Micronesia is addressed in Chapter 4, providing information available on (a) existing regulations and practices and (b) current activities, and (c) anticipated future activities.

A risk assessment for marine invasions associated with vessels is presented in Chapter 5. This uses information from several different areas, including: (a) a detailed analysis of shipping traffic for commercial and U.S. Navy vessels (specifically Navy supply ships, as data from combatant ships were not made available), indicating the connectivity to various geographic regions; and (b) a list of some of the non-native marine species known to occur in these various geographic source regions. These data are combined to assess the opportunity for transferring species with a known invasion history from areas of known occurrence, thereby posing some invasion risk to Guam, other jurisdictions of Micronesia, and Hawai'i. The analysis focuses solely on biofouling organisms, or those species that are known to occur as biofoulers on the hulls and underwater surfaces of vessels, and does not distinguish between biofoulers originating from tropical regions (which have a higher likelihood of establishment in Micronesia and Hawai'i) versus biofoulers from temperate and colder waters (which have a lower risk of establishment). Moreover, only species that have been reported thus far to be invasive were considered. A similar analysis of biofouling for other vessel types (i.e., fishing vessels, recreational vessels, and barges) was not undertaken; neither were environmental parameters accounted for in the risk assessments. Also omitted were analyses of other important vectors such as ballast water and the live trade. Such analyses were deemed to be not yet possible, due to lack of sufficient data on geographic sources and fluxes, as discussed in Chapter 3.

One of the challenges in conducting a risk assessment is to identify the potential hazards or impacts associated with invasions. As an extension of Chapter 5, a small pilot study was conducted to explore what is now known about values in Micronesia and possible implications for risk analyses. This is presented in Appendix B and begins to characterize the environment, economic, social and cultural core values that people in these locations hold and how they perceive that introduced species will affect these values.

Chapter 6 presents a biosecurity plan for Guam, Commonwealth of the Northern Mariana

Islands, Palau, the Federated States of Micronesia, the Republic of the Marshall Islands, and Hawai'i. Following a brief overview of existing regional plans and programs, this chapter outlines recommendations for management practices to (a) prevent new invasions as well as (b) detect and respond to such incursions that may occur. It is evident that there are currently many gaps in meeting these recommendations for marine biosecurity in the region. Thus, beyond the practices themselves, regional coordination and capacity are discussed and must be considered explicitly to implement various elements of the biosecurity plan.

1.4 Terminology for Non-Native Species

In general, we avoid the use of the term “invasive,” because in regards to tropical marine systems it is an imprecise term that is functionally difficult to define in a robust fashion. It is important to recognize that (a) the impacts, or potential impacts, of most non-native marine species have never been evaluated (e.g., Ruiz et al. 1999, 2011a; see also Chapter 5), and (b) such impacts can vary greatly in space and time. Thus, it is currently not possible with any confidence to divide non-native marine species into those that are “invasive” and those that are not, based on impact criteria. In the absence of data, a precautionary approach would assume that most non-native species have the potential to cause harm under some circumstances. For this report, use of the term “invasive” is restricted primarily to cases where specific negative effects are perceived or recognized, and “non-native” and “invasive” are used as synonyms.

Finally, following Carlton (1996), species that occur in a specific region are considered to fall into one of three categories: native, non-native, or cryptogenic. The latter are species of uncertain origin, reflecting a poor state of knowledge about taxonomic identity and/or biogeographic origin of an organism. A large number of species in a region may be cryptogenic, as is the case with many locations with limited historical data, such as tropical marine ecosystems (Paulay et al. 2002), but is also the case in well-studied estuaries like San Francisco Bay, California (Cohen and Carlton 1995).

1.5 Vectors as Drivers of Marine Invasions

Analyses of marine invasions have frequently been conducted to assess human-mediated transport mechanisms (vectors) responsible for marine invasions, based upon life history characteristics, the time of detection, and the operation of vectors in the relevant geographic regions and temporal context. This approach has been used to assess vector strength, or the relative contribution of different vectors to the number of observed invasions, over time in specific locations (Cohen and Carlton 1995; Ruiz and Carlton 2003; Hewitt et al. 2004).

Where available, analyses of vector strength indicate that most marine invasions are attributed to the unintentional transfer of organisms by vessels (Reise et al. 1999; Ruiz et al. 2000; Fofonoff et al. 2003; Hewitt et al. 2004). While vessels have been a dominant vector on a global scale, other transfer mechanisms can also be important sources for marine invasions in some locations. Among these, the movement of live organisms for food, bait, aquaculture, or aquaria has been a common source of invasions (Cohen and Carlton 1995; Chapman et al. 2003; Weigle et al. 2005; Hewitt et al. 2007; Ruiz et al.

2011a). This intentional movement of organisms is often referred to as “live trade.” Marine invasions and spread of non-native species are also known to result from (a) movement of in-water structures, such as docks, (b) transfer of construction or restoration materials, such as sand and rock, and (c) construction of canals that connect water bodies, such as the Suez Canal and Kiel Canal (Gollasch et al. 2006).

Below, we provide a further description about movement of organisms by vessels and live trade. We highlight these two categories because they are dominant vectors for marine invasions, contributing strongly to the total number of documented invasions on regional and global scales (as above; see also Hewitt and Campbell 2010). However, we note that invasions from other vectors may have high ecological or economic impact, even if the total number of species invasions attributed to a particular vector is not great.

1.5.1 Introductions by Vessels

There are two dominant modes of transfer for marine species by vessels, excluding organisms shipped as cargo. Organisms commonly occur in the ballast materials of vessels and on hulls (and other underwater surfaces). A significant body of literature documents the occurrence of many taxonomic groups in ballast tanks and on hulls, across a wide variety of vessel types, underscoring the enormous potential for species transfer over great distances. For both ballast tanks and vessel hulls, the transfer of organisms is an unintended consequence of normal vessel operations, as discussed below. It is also evident that both modes of ship-mediated transfer have contributed strongly to invasions observed around the globe.

1.5.1.1 Ballast Water

Ballast is used by ships to maintain stability and trim. It is generally taken on in port before a ship’s departure. Prior to the 1900s, vessels used solid ballast (rocks and sand), but this has been replaced with ballast water, which may also contain sediments (Carlton 1985). A diverse array of marine organisms, from crabs and fish to bacteria and viruses, have waterborne life stages such as larvae (often microscopic) that are taken up in ballast in one region and discharged at subsequent ports of call, creating an efficient transfer mechanism for marine organisms (National Research Council 1996; 2011). For example, a single vessel can discharge > 50,000 metric tons of ballast water upon arrival, and recent estimates indicate vessels arriving from overseas to the continental U.S. alone discharge approximately 60 million metric tons of ballast water per year (Miller et al. 2011a). While there is considerable variation among vessels in the quantity of ballast discharge and its associated biota (National Research Council 2011), the cumulative effect of global ship traffic transfers large numbers of marine organisms throughout the world in ballast water, overcoming historical barriers to natural dispersal and allowing invasions to occur.

1.5.1.2 Biofouling.

Many marine organisms colonize hard substrata during part of their life cycle, including rock, coral, wood, metal, and many other materials. Vessels and maritime structures provide such substrata, which are utilized by a wide diversity of micro- and macro-organisms (Visscher 1927; Woods Hole Oceanographic Institution 1952; Haderlie 1984).

Many of these organisms live attached to the underwater surfaces of structures; these sessile species can include algae, barnacles, protists, oysters, mussels, coral, sponges, tunicates, bryozoans, and tube-building worms. In addition, mobile fauna such as snails, crabs, and fish can occupy (a) the structure created by attached species as well as (b) “niche areas” of the vessel (such as intakes and areas around propellers, rudders, and other in-water structures) that provide protection from high flow environments on the exposed hull surfaces. Some organisms, such as shipworms and particular isopods, burrow into wooden structures when available. Throughout this document, we refer to species associated with the underwater surfaces of vessels, whether mobile or sessile (fixed to a particular location) as “biofouling organisms.”

Movement of any in-water structure creates a potential opportunity to transfer associated biofouling organisms. Attached organisms can release gametes, larvae, or various types of spores upon arrival; some organisms may be able to spread via fragmentation; and mobile animals can simply crawl or swim away.

Despite existing hull husbandry practices to reduce undesirable effects of biofouling on vessel speed and performance (as described in Chapter 2), it is evident that extensive numbers of organisms are still transferred on vessels’ hulls, resulting in new invasions (Skerman 1960; Godwin 2004; Sylvester et al. 2011). Among vessel types there is a high degree of variation in the magnitude and diversity of associated biofouling organisms (Carlton and Hodder 1995; Ferreira et al. 2006; Davidson et al. 2008; Davidson et al. 2010). However, in contrast to ballast water usage, which is restricted to particular types of vessels, biofouling organisms can occur on any type of surface vessel (commercial, fishing, military, recreational, barge; see above), submarine (Voight et al 2012), or in-water structure. Another important distinction is that vessels are exposed continuously to colonization and release of biofouling organisms at each port of call, cumulatively through time between dry-dock and thorough cleaning, whereas ballast water uptake and discharge is much more episodic and limited in space and time (Miller et al. 2011a).

1.5.2 Introductions Resulting From Live Trade

The trade in live marine organisms and their release into the environment has historically been one of the top pathways for the introduction and establishment of non-native marine species. Live organisms are often moved intentionally among biogeographic regions for use as aquaculture species, bait, food, scientific research, and pets (aquaria). Importantly, live organisms are also moved unintentionally by humans, as a type of accidental “by-catch.” Such unintentional transfers can result when biota are associated with (a) target species that are moved for commercial purpose (as above) or (b) packing materials or processes used in transfer of live species and other goods (e.g. ice chests). These unintentional transfers include a remarkably diverse range of taxonomic groups, from free-living organisms (such as macro-invertebrates and fishes) to those that occur attached or within organisms (such as microorganisms, including parasites and pathogens).

It is evident that live trade has been a potent source of invasions in some regions (e.g. Cohen and Carlton 1995), but it also has received less attention than vessels as a source of marine invasions, especially in terms of the current magnitude and geographic variation in such species transfers. Moreover, while the transfer of species poses some risk of release and establishment, not all transfers result in release. For example, many organisms moved for consumption or for pets (aquaria) may not be released to the wild, although a subset of these are released or escape. Despite some uncertainty about various dimensions of live trade, past invasions have resulted from such species transfers, regardless of whether release is intended or not. Below, we provide further background information for selected components of live trade.

1.5.2.1 Aquaculture.

Among the unwanted consequences of importation of aquaculture species is the establishment of exotic pests, pathogens and predators (Culver and Kuris 2004; Moreno et al. 2006; McKindsey et al. 2007; Naylor et al. 2010) that become problematic for cultured and native species. Eldredge (1994) reviewed species introduced both intentionally and unintentionally to the Pacific Islands via aquaculture. From giant clam aquaculture alone, seven bacteria and bacterial diseases, four parasites, and three protozoans and protozoan diseases are known to have been introduced to various locations in Asia and the Pacific (Humphrey 1988). One of the best-known examples of an accidentally imported disease is shrimp virus IHHNV (infectious hypodermal and hematopoietic necrosis virus), which was accidentally introduced to Tahiti, Guam, and Hawai'i and causes stunted growth and mortality in shrimp. Aquaculture species themselves can become problematic if they escape from pens, tanks, and marine cages, or in the case of organisms planted directly into the environment, when they reproduce or spread out of control. For example, several algal species (including *Kappaphycus striatum*, *Gracilaria salicornia, and Hypnea musciformis*) were introduced to Hawai'ian waters for aquaculture purposes and have since become pest species, overgrowing coral, outcompeting native algae and ruining beaches for human enjoyment by washing up in huge drift piles (Preskitt et al. 2001; Smith et al. 2004; Nelson et al. 2009; Vermeij 2009).

Although many of the species transferred for marine culture are actively managed in pens or selected areas, stocking also occurs. This has been most common with fishes in low salinity habitats (see Cohen et al. 2005). For example, tilapia (*Oreochromis mossambicus*, *Oreochromis* hybrids, and *Tilapia zilli*, native to Africa,) were brought into the Micronesia region for aquaculture and mosquito-control purposes, have become established in the region, and have been the target of eradication efforts on Palau and Nauru (Nelson and Eldredge 1991; Nico and Walsh 2011). However, there are also examples of stocking to create marine invertebrate fisheries, such as the king crab introduction in Russia; this has created a large population of the introduced crab that is spreading in Scandinavia, creating some concerns about ecological and fisheries impacts (Jørgensen and Nilssen 2011). In the Pacific, there have been introductions of hatchery-raised giant clams (tridacnids) to many overharvested and non-native localities. These seeding efforts have sometimes been associated with the introductions of some diseases, parasites, and gastropod predators, most notably the predatory snail *Cymatium muricinum* (reviewed in Eldredge 1994). Since the 1920s, *Trochus niloticus* has also been brought in to many localities outside its native range (including the Marianas, Chuuk, Kosrae, Pohnpei) in order to create new fisheries for trochus shell (Eldredge 1994). More recently, the sandfish (*Holothuria scabra*) has been introduced to Kiribati from Fiji and to New Caledonia from Wallis.

1.5.2.2 Live Food Trade.

Marine organisms imported live for food can become established if they a) accidentally escape from holding tanks or pens or b) are "planted" in the environment, either for short-term use or to establish local populations. This is perhaps best illustrated by the massive transfer of oysters to California in the late 19th and early 20th centuries, from eastern North America and Asia (Carlton 1979; Miller et al. 2007). This resulted in the unintentional transfer of many other associated organisms, including a diverse range of taxonomic groups (e.g., bacteria, protists, crustaceans, gastropods, and bryozoans) that were present in and on the oysters, and over 80 non-native species established in California may have arrived by oyster importation (Ruiz et al. 2011b). Other examples of established non-native species associated with live food trade on the U.S. West Coast include several brackish water species (that use both freshwater and marine environments): the Chinese mitten crab (*Eriocheir sinensis*), the crayfish *Procambarus clarkii,* and the clam *Corbicula fluminea* (Cohen and Carlton 1995).

Transfers of organisms for food have resulted in introductions in other parts of the U.S. and globally. This is has been documented for some transfers of shellfish, including oysters, mussels, lobsters, and crabs (Wolff and Reise 2002; Chapman et al. 2003, Jørstad et al. 2007; Miller et al. 2007; Fofonoff et al. 2009). In addition, the recent arrival of the northern snakehead (*Channa argus*) to eastern North America is attributed to its importation for food and subsequent release (Orrel and Weigt 2005). It is noteworthy that snakehead fishes and mitten crabs, both attributed to live food trade as a mechanism of introduction, are now listed as "injurious wildlife" in the U.S. under the federal Lacey Act, prohibiting future importation and interstate movement (Thomas et al. 2009; Miller 2011).

1.5.2.3. Pet/Aquarium Trade.

The release of species associated with the aquarium trade represents a significant vector for introductions of non-native aquatic and marine organisms (Ruiz et al. 1997). In the mainland U.S., 150 species that have invaded natural ecosystems have been transferred via aquarium and ornamental culture trade (Padilla and Williams 2004). In some cases, release from aquaria is accidental (through public aquarium outflows, escapes from tanks/pens during storms, etc.), but in others, pets and plants are released into local waters by aquarists who no longer want them. In contrast to transfer via shipping in which organisms are released into only a few locations (mainly ports), aquarium plants and animals are widely distributed into homes and businesses, and thus potentially may be released into a wider distribution of natural habitats, including coral reef habitats (e.g., Semmens et al. 2004). Non-native species linked to the aquarium trade include intentionally traded species and species transported accidentally with these and aquarium components such as live rock (Bolton and Graham 2006; Minchin 2007; Duggan 2010). Generally speaking, organisms imported intentionally for the aquarium trade are often hardy species (i.e., able to withstand stress of transport and a relatively wide range of environmental conditions), and those that survive transport are hardy individuals, increasing the potential for survival upon release.

Two high-profile examples of marine invasions associated with the aquarium and pet trade are the alga *Caulerpa taxifolia* and the Indo-Pacific lionfish (*Pterois* spp.). The alga, which now carpets vast swaths of the Mediterranean Sea, out competes native algae and sea grasses, apparently causing major changes in habitat and food sources for many native organisms (Meinesz and Hesse 1991; Bellan-Santini et al. 1996). This species was also detected in California and was the focus of an intensive and successful eradication effort (Anderson 2005). *Caulerpa taxifolia* is also invasive in New South Wales, Australia, where control and eradication efforts are ongoing (Creese et al. 2004). The lionfish, a popular aquarium fish, is now established in the Caribbean and Western Atlantic, where it appears to be altering reef fish community structure through predation (Whitfield et al. 2002; Albins and Hixon. 2009).

1.5.2.4. Bait.

Imported bait, including algal packing materials and associated organisms, is often discarded into the environment, providing another transfer mechanism for marine introductions (Weigle et al. 2005). Available studies indicate a large volume (number) of bait shipments occur in some regions, and these shipments can include a diverse assemblage of associated non-target species (Passarelli et al. 2010; Haska et al. 2011). As with live food imports, associated organisms found in bait shipments range from macrofauna to microorganisms, including parasites and pathogens (Pernet et al. 2008; Haska et al. 2011). Moreover, several recent invasions may have resulted from bait transfers, such as colonization of western North America by the knotted wrack (*Ascophyllum nodosum*), the common periwinkle (*Littorina littorea*), and the green crab (*Carcinus maenas*), which originated from the North Atlantic coast (Miller et al. 2004).

1.5.2.5. Scientific Research.

Some marine organisms are imported for research and teaching purposes, presenting a potential opportunity for release of non-native species to local environments. While this can occur, relatively few invasions have been attributed to this mechanism in existing analyses for multiple global regions (Cohen and Carlton 1995; Hewitt et al. 1999; Fofonoff et al. 2009; Minchin and Gollasch 2002; Siguan 2002).

1.6 Distribution of Marine Invasions across Habitat Types

In marine ecosystems, most known invasions are reported from within protected bays and estuaries, with relatively few non-native species documented along exposed coasts or in deep water (Carlton 1979; Ruiz et al. 1997; Wasson et al. 2005; Preisler et al. 2009). While this does not imply that offshore waters are immune to invasions, the observed pattern indicates that bays are hotspots for invasion. This is likely driven, at least in part, by (a) the relatively high concentration of shipping and other activities that deliver organisms to port systems as centers of human commerce and (b) the relatively prolonged time periods that vessels spend stationary in ports.

Within bays and estuaries, a large proportion of non-native species is associated with artificial hard substrata, such as pilings, docks, and seawalls (Cohen and Carlton 1995; Wasson et al. 2005; Glasby et al. 2007; Ruiz et al. 2009). It is not clear what factors generate this pattern. It is thought that the presence of artificial substrata may facilitate establishment of non-native populations, providing a beachhead for colonization and possible spread to surrounding areas. One implication of this is that construction in ports and harbors (which usually include use or creation of man-made structures such as pilings and walls) may increase the probability of invasions, independent of propagule supply.

Despite this general pattern of association with artificial substrata and protected waters, marine invasions do indeed occur on natural substrata (e.g., rock, cobble, and reefs) and in outer coastal waters. This is illustrated by *Didemnum vexillum*, a colonial tunicate that has covered extensive offshore areas of seafloor in the Georges Bank of eastern North America (Bullard et al. 2007; Valentine et al. 2007). Additional examples are also documented in tropical ecosystems such as Hawai'i (see Section 1.7.1). Thus, it is not surprising to see that outer coastal waters are susceptible to invasions, even at considerable depths, given a supply of non-native organisms with suitable characteristics.

1.7 Geographical Patterns of Marine Invasions

Invasions have occurred commonly in coastal marine habitats during recent time. Hundreds of non-native marine species are known to be established in many well-studied regions throughout the world, such as Australia (Hewitt and Campbell 2010), the Mediterranean Sea (Galil 2009), the continental U.S. (Ruiz et al. 2000; 2011a), and Hawai'i (Carlton and Eldredge 2009). It is clear that some non-native marine species are having significant ecological, economic, and human-health impacts (Carlton 2001). Importantly, a comprehensive estimate of marine invasion impacts is not available for any global region, because (a) many invasions are undetected (Carlton 1996; Ruiz et al. 2000) and (b) effects of most invasions have not been studied and remain difficult to predict (Ruiz et al. 1999; 2011b).

For marine ecosystems, most of the invasions to date have been detected in temperate latitudes, compared to polar or tropical regions (Hewitt 2002; Ruiz and Hewitt 2009; Ruiz et al. 2009). A similar pattern has been reported for some taxonomic groups in terrestrial habitats, where the number of established non-native species increases from high to subtropical latitudes followed by a precipitous decline in the tropics (Sax 2001). This pattern may reflect historical differences across latitudes in (a) the amount of research on biological invasions, (b) understanding of species biogeography and (c) the level of organism transfer, or propagule supply. Although not well quantified, the level of research and economic activity (trade and transportation which transfers organisms) is concentrated at mid-latitudes. In addition, it is also possible that tropical and polar regions are relatively more resistant to invasions, due to either environmental or biological conditions.

Despite the dominance of information about temperate invasions, it is evident that marine invasions do occur in tropical marine systems. This is illustrated by the introduction and rapid spread of the lionfish in the Caribbean basin (Guerrero et al. 2008; United States Geological Survey 2011). Lionfish, native to the Indo-Pacific, have invaded the U.S. coast from Florida to Rhode Island, and several Caribbean locations. These aggressive predators have reduced the abundance of native fishes on coral reefs (Albins and Hixon 2009) and mangrove habitats (Barbour et al. 2010) and are the target of management efforts. Yet, to date, few studies have begun to explore the extent to which tropical marine invasions are occurring relative to those in mid-latitudes. Hawai'i is exceptional in this regard, and some background data also exist in Guam, as outlined below.

1.7.1 Marine Invasions in Hawai'i

Carlton and Eldredge (2009) compiled a comprehensive monograph of introduced and cryptogenic marine species from the Hawai'ian Islands, which includes species of protists, fungi, invertebrates, fish, algae, and flowering plants. They reviewed 490 species, including (a) 301 species considered to be established non-natives and (b) 117 species classified as established cryptogenic species (of uncertain biogeographic origin). The remaining 72 species were non-native but either not established or not known to be established.

Crustaceans, insects, mollusks, and ascidians were among the most speciose taxonomic groups in this analysis. Indo-Pacific species comprised the largest portion at 46%; Western Atlantic species represented 22% and species from the Eastern Pacific made up 7%. The origin of 34% was unknown, but most likely was Indo-West Pacific or Western Atlantic.

For these documented invasions in Hawai'i, 70% were classified as introductions attributable to shipping (including either ballast water or biofouling, or both), and 15% were attributed to intentional and accidental releases. Only 11 species were considered introduced prior to 1900. Over 290 species are thought to have been introduced in the early 20th century, although many may have been transported earlier. Intentional releases occurred during two phases: (a) between 1895 and 1939, when 10 species were introduced, and (b) between 1950 and 1974, when 17 species were released. Intentional introductions appear to have ceased after 1974. Overall, the greatest number of introductions was detected in the mid-20th century and more recently, through numerous harbor and shoreline surveys and collections.

Remarkably, of the 301 introduced species considered, only six have been studied for impacts at the community or ecosystem level. Some of the major studies have been carried out on the snapper *Lutjanus kasmira* (ta'ape), the sponge *Mycale grandis*, the barnacle *Chthamalus proteus*, the octocoral *Carijoa riisei* (snowflake coral), and the algae *Kappaphycus* sp. and *Acanthophora spicifera*. The Caribbean mangrove *Rhizophora mangle* has become a particularly conspicuous species that is undergoing rapid spread in Hawai'i.

Among reported impacts in Hawai'i, several non-native species of marine algae, introduced for aquaculture purposes, are now overgrowing coral reefs and crowding out native algae (e.g., Smith et al. 2004; Vermeij et al. 2009; Carlton and Eldredge 2009); the non-native octocoral *Carijoa riseii* threatens the black coral fishery down to depths of 120 m (Grigg 2003); an Australian sponge, *Mycale grandis,* overgrows and kills corals (Coles and Bolick 2007); community structure of native reef fishes is likely affected by *Cephalopholis argus,* an introduced piscivorous grouper (Dierking et al. 2009); competition for shelter with the introduced snapper *Lutjanus kasmira* may make native goatfish more vulnerable to predation (Shumacher and Parrish 2005); and non-native tilapia are considered a serious threat to native aquatic plants (K. Peyton, University of Hawai'i, personal communication 2009).

A handful of these species have become the target of management efforts, including hand removal by volunteers, a massive pier wrapping project in a Maui harbor, the use of a "super sucker" which can be used to vacuum algae off the reef (The Nature Conservancy

2012), and experimental-scale biological control, but eradication has not yet been successful. Costs for marine invasive-species management in Hawai'i exceed millions of U.S. dollars (A. Montgomery, Hawai'i Department of Land and Natural Resources, personal communication).

1.7.2 Marine Invasions in Guam and Micronesia

Humans have transported many marine organisms to Guam and other parts of Micronesia over time. Some non-native species have successfully colonized and are documented for the region, but the full extent of marine invasions is much more difficult to determine as no comprehensive study of the marine invasive species of Micronesia currently exists.

Micronesia as a whole lies within the planet's greatest region of marine biodiversity, the coral reef region of the Indo-West Pacific (Vermeij 1978; Paulay 2003; Kingsford et al. 2009). The natural marine habitats of Micronesia are extremely diverse, ranging from the rocky shores of volcanic islands to coral reefs, mangroves, estuaries of small rivers, the lagoons of atolls, and many other habitats. In addition, many new habitats have been created by human activities, especially with the addition of artificial structures to create ports and harbors.

For Micronesia, the biota associated with many of these habitats has not been well characterized, especially given the high diversity and areal extent of the region. A recent series of surveys documented 5,640 species from the Mariana Islands, including some non-indigenous species (Paulay et al. 2002; Paulay 2003). However, even where surveys exist, recognizing introduced species is a major challenge in the face of this high native diversity and the relatively recent onset of marine biological studies in relation to the long history of human activity in the region.

A variety of criteria are used for recognition of non-native species including: (1) lack of previous known occurrence in a region, (2) recent range expansion, (3) association with likely vectors of introduction, (4) association with known invaders, (5) strong association with artificial substrata or human-disturbed habitats, (6) restricted local distribution, (7) disjunctive global distribution, (8) poor adaptation for long-range natural dispersal, and (9) exotic evolutionary origin (Chapman and Carlton 1994). The high diversity of the region means that many native species remain to be discovered, so that criteria 1 and 2 are difficult to apply. Micronesia is close enough to a major region of biodiversity that Criterion 7 is more difficult to apply than in such isolated island regions as Hawai'i or New Zealand.

Many marine organisms known to occur in Guam and other islands are widely distributed in both the Atlantic and Pacific oceans, but have not previously been treated as introductions anywhere. Some of these are probably undiscovered introductions, others represent species complexes, and others may be organisms which have not diverged enough to become distinct species since the closure of the ocean basins (Vermeij 1978; Lambert 2002; Lessios 2008). Criterion 5 may be a stronger indicator of native status, but native species may also show similar traits, for example some native species with fossil records on Guam are restricted to Apra Harbor, and frequently occur on artificial substrata.

Using a combination of the above criteria, Paulay et al. (2002) identified 21 non-native marine species as established in Guam waters and an additional 21 non-native species as recorded for the area but not known to have established populations. In a review of available recent literature, using similar methods, 33 non-native marine species that are considered to be established in Micronesia as a whole can be readily identified, including nine species in Palau, 25 in Guam, five in the Commonwealth of the Northern Marianas Islands (CNMI), five in the Federated States of Micronesia (FSM), one in Kiribati, and six in the Republic of the Marshall Islands (RMI). An additional 23 non-native marine species have been reported for the region, but to date it is not known whether or not these species have established populations. A more recent and comprehensive analysis is presented in Chapter 5, reporting the occurrence of additional non-native species in Micronesia.

These documented non-native species occurrences represent gross underestimates of the number of invasions in Micronesia, for several reasons. First, many important groups of organisms, including copepods, amphipods, isopods, mysids, marine insects, and bryozoans have not been well studied in Micronesia. In the Hawai'ian Islands, where these taxa have been better-studied, these five groups alone contained 68 non-native species (Carlton and Eldredge 2009). Second, the biota for many regions of Micronesia has simply not been sampled. Third, where surveys exist for particular groups and locations, these are not comprehensive inventories of all species present but instead an analysis of a subset of the total species pool. The combination of high biodiversity and limited taxonomic effort means that much of the biota in the region is unidentified. Moreover, the difficult taxonomy and biogeography of many of the identified species means that a large fraction of the biota deserves cryptogenic status, and can neither be designated as native or introduced (Carlton 1996; Paulay et al. 2002).

The known established marine invaders in Guam and elsewhere in Micronesia are dominated by sessile organisms that occur on hard substrata (18 of 25 species for Guam and 25 of 33 for all of Micronesia). Cnidarians (six hydrozoans, one anemone) and tunicates (nine species) are the most numerous non-native taxa in Micronesia. Motile taxa are represented by the crab *Metopograpsus oceanicus*, two gastropods (*Trochus niloticus* and *Tathirella iredalei*), and five fish species. All of the fishes identified in the present review are capable of inhabiting freshwater and marine (or at least brackish) habitats (this, however, does not include three species of non-native marine fishes reported from Apra Harbor by Smith et al. 2009). The majority of non-native marine species in Micronesia (18 of 33) are species of uncertain geographic origin, but very broad ranges in multiple oceans, with cryptogenic ranges in the Atlantic, Indian, and Pacific Oceans. At least 20 of the 33 species introduced to Micronesia have also been introduced to the Hawai'ian Islands (Carlton and Eldredge 2009).

Most of the detected non-native species for Micronesia (16 of 33 species) are attributed to ship biofouling as a possible vector, but seven of these species (including hydrozoans and barnacles) have planktonic life stages and could have been transported either by fouling or ballast water. One notable fouling introduction was the hydroid *Eudendrium carneum*, native to the Western Atlantic, and introduced to Palau in July 1997 when a floating bridge was brought to Palau from Guangzhou City, China (Shine et al. 2003). Three species were introduced by fisheries activities -- the mother-of-pearl snail (*Trochus niloticus*, also referred to in the region as the topsnail) and the peacock bass (*Cichla ocellaris*) were deliberately stocked (Maciolek 1984; Smith 1987; Eldredge 1994; Lever 1996), while the parasitic snail *Tathrella iredalei* was introduced with giant clams (*Tridacna* sp.) via aquaculture (Eldredge 1994). The western mosquitofish (*Gambusia affinis*) was widely stocked in freshwater and brackish water for mosquito control on many islands (Krumholz 1948; Maciolek 1984; Lever 1996). The tilapias *Oreochromis mossambicus (*Mozambique tilapia and hybrids) and redbelly tilapia (*Tilapia zilli*) were both stocked in Guam reservoirs for control of aquatic weeds, but *O. mossambicus* was also widely introduced to many islands for aquaculture and as bait for tuna (Maciolek 1980; Lever 1996). It is unclear how the sailfin molly (*Poecilia latipinna*) was introduced to Guam; it may have been an aquarium release, intended for insect biocontrol, or as a baitfish (Maciolek 1984; Lever 1996).

The 23 additional non-native species that are documented without established populations add to our knowledge of the vectors which are active in the region. Perhaps most instructive is analysis of a floating dry-dock, the *Machinist*, which was towed from Hawai'i to Guam, having been positioned in the Philippines prior to its existence in Hawai'i. At the start of its voyage, 113 species were identified on its hull, and at least 42 species were identified soon after arrival in Apra Harbor. At least 12 species were considered definite introductions to Guam. However, many of these organisms survived the voyage in poor condition, so their ability to colonize Guam waters is uncertain (Paulay et al. 2002). At least two species of fishes (*Neopomacentrus violascens* and *Omobranchus elongatus*), each represented by single specimens, were found associated with ship hulls in Apra Harbor (Eldredge 1994; Paulay et al. 2002). These could have been transported in ballast water, in sea-chests (openings on the outer hulls of vessels for water intake), or on slow-moving structures such as dry-docks.

At least 12 marine species have been introduced for aquaculture, of which 10 have failed to survive or reproduce, or are apparently confined to aquaculture facilities. Four species of shrimp are, or have been cultured on Guam, starting in 1978. One of these, the catadromous *Macrobrachium rosenbergii*, escaped into rivers on Guam when dams burst during a typhoon in 1992, but its establishment in the wild is unknown and does not appear to have been studied (Eldredge 1994). Three species of edible oysters (the Pacific oyster, *Crassostrea gigas*; the spiny rock oyster, *Sacccostrea echinata*; and the Philippines rock oyster, *Sacccostrea mordax*) have been stocked in Guam and Palau, but failed to reproduce (Eldredge 1994). In the 1930s, Japanese pearl companies stocked waters in the Marshall Islands, Palau, and Christmas Island, Kiribati, with the non-native pearl oysters *Pinctada fucata martensi* and *P. maxima*, but these operations were abandoned during World War II, and the oysters are not known to have become established (Eldredge 1994). A notable freshwater introduction, the chevron snakehead (*Channa striata*), escaped from fish farms in the 1970s, and is established in the Ajayan River drainage on Guam. Attempts at eradication are underway (Nico and Walsh 2011).

In summary, the available data demonstrate that marine invasions are occurring in Micronesia associated with the known transport mechanisms that are driving invasions throughout the world. Most invasions reported for Micronesia to date are known from Guam and have been associated with shipping. However, it is critically important to recognize that the extent of marine invasions to the region (a) has not been estimated formally or quantitatively and (b) is certain to far exceed the documented number of non-native species to date, as with many other regions (Cohen and Carlton 1995; Carlton and Eldredge 2009). The ecological, economic, and social impacts of marine invasions are not well-known in Micronesia, in part because so few invaders have been identified, and in part because the known non-native species have not been carefully studied (for further discussion see Shine et al. 2003; Marino et al. 2008; Appendix A).

Chapter 2: Overview of Current Regulations, Guidelines, and Practices Related to Ship-Mediated Marine Bioinvasions

By Chela.J. Zabin, Gregory M. Ruiz, Gail V. Ashton, and Ian C. Davidson

2.1 Introduction

Historically, ships have played a dominant role in the transfer of non-native marine species, leading to biological invasions throughout the world, as outlined in Chapter 1. Although the issue of marine invasions has received significant attention in recent time, the rate of reported invasions has increased in the past few decades, and this increase has been driven largely by shipping (Cohen and Carlton 1998; Hewitt et al. 2004; Ruiz et al. 2000; 2011b). In response, numerous regulations, agreements, and guidelines have emerged to reduce the likelihood of species invasions at national, regional and international levels (see recent review by Hewitt et al. 2009a). It is important to also note that these existing frameworks are undergoing rapid changes, which aim to further limit the transfer of organisms.

In general, and within the specific context of the Buildup, U.S. Executive Order 13112 on Invasive Species (signed by President Clinton in 1999) directs U.S. federal agencies to: "… not authorize, fund, or carry out actions that it believes are likely to cause or promote the introduction or spread of invasive species in the United States or elsewhere unless, pursuant to guidelines that it has prescribed, the agency has determined and made public its determination that the benefits of such actions clearly outweigh the potential harm caused by invasive species; and that all feasible and prudent measures to minimize risk of harm will be taken in conjunction with the actions."

The Executive Order applies to all activities of federal agencies and also establishes the U.S. National Invasive Species Council (NISC), to coordinate actions to prevent and control non-native species throughout the U.S. federal government. Toward this end, NISC has developed a National Invasive Species Management Plan and implemented a formal framework of interagency and advisory meetings to limit the extent and impact of biological invasions.

In addition to the overarching framework outlined in Executive Order 13112 for the U.S., there are also some specific regulations and guidelines to limit species transfers by ships (including ballast water and hull biofouling) , but to date these guidelines are either not comprehensive or are not currently established (such as the IMO hull fouling guidelines). These guidelines exist primarily at national and international levels. It is also noteworthy that different requirements and practices exist for commercial versus military vessels.

This chapter provides a review of current regulations, guidelines, and practices for management of ballast water and hull biofouling. We focus on commercial and military vessels, examining differences in the way in which ballast water and biofouling are managed for these vessel types. Throughout, we consider these management practices in the explicit context of Guam, the Commonwealth of the Northern Mariana Islands, Palau, the Federated States of Micronesia, and the Republic of the Marshall Islands.

2.2 Ballast Water

2.2.1 Regulations and Guidelines

2.2.1.1 Commercial Vessels.

At a national level, U.S. federal regulations exist currently for ballast water management and discharge by commercial vessels arriving to U.S. ports. The federal regulations governing ballast discharge in the U.S. were issued by the USCG (United States Coast Guard 2004), and more recently by the EPA (United States Environmental Protection Agency 2008; see National Research Council 2011 for review). At the present time, the regulations by these two agencies are similar. Both require commercial vessels arriving to U.S. ports from beyond the exclusive economic zone (EEZ) to treat ballast water of coastal origin (i.e., taken up within 200 nautical miles (nmi) of shore) prior to discharge in U.S. waters. In general, discharging vessels arriving from overseas are required to treat their ballast water by (a) use of open ocean ballast water exchange (i.e., flushing out tanks in open ocean, > 200 nmi from shore) or (b) an alternative technology that is approved for use (of which there currently are none). In addition, the EPA regulations also apply to some coastwise (domestic) vessel traffic along the western U.S.

Under the USCG regulations, commercial vessels (whether arriving from a foreign or a domestic port) are also required to submit a detailed report to the USCG on the origin, treatment, and volume of discharges. These reports are submitted for each arrival event to evaluate compliance and changes in ballast water management over time. Vessels out of compliance with regulations are subject to criminal prosecution and financial penalty (United States Coast Guard 2004).

The aim of current U.S. federal regulations is to reduce the concentration of coastal organisms delivered in discharged ballast water that pose a risk of invasion to subsequent ports of call and coastal waters of the U.S. During ballast water exchange, coastal organisms are replaced with oceanic organisms. In general, it is considered unlikely for coastal organisms to survive in the open ocean (or to reach coastal habitats if discharged at sea), or for oceanic organisms to colonize coastal regions, due to their respective habitat requirements. While ballast water exchange provides a significant reduction of coastal organisms delivered in ballast water (Minton et al. 2005; Ruiz and Reid 2009; Bailey et al. 2011), some residual coastal organisms are still present following this treatment, and, critically, there are logistical constraints that prohibit its application for some routes and conditions (Miller et al. 2011a). For these reasons, there is significant momentum to replace ballast water exchange with treatment technologies, which (a) can be used on most vessels and routes and (b) achieve lower concentrations of organisms in ballast discharge than possible with ballast water exchange (National Research Council 2011).

New regulations are now being advanced by U.S. federal agencies for ballast water to meet specific discharge standards which are lower than organism concentrations often achieved by ballast water exchange. This is reflected in a Notice of Proposed Rulemaking (United States Coast Guard 2009) issued by USCG, which is required to regulate ballast water under the Nonindigenous Aquatic Nuisance Species Prevention and Control Act of 1990 (updated by the National Invasive Species Act of 1996). This rule has just cleared administrative review, and a Final Rule is scheduled for publication in March 2012; this is expected to result in new requirements (regulations), but the specific details and timetable are not yet available publicly. Similar regulations to require specific discharge standards are also under consideration at the EPA (United States Environmental Protection Agency 2011), which is required to regulate ballast water discharge under the Clean Water Act of 1972 (see National Research Council 2011 for review of recent requirement to regulate ballast water under this law).

Requirements for ballast water treatment are also being advanced at the international level by the International Maritime Organization (IMO). The International Convention for the Control and Management of Ships' Ballast Water and Sediments was adopted in 2004, establishing ballast water management requirements for commercial shipping on a global scale. The IMO convention will slowly phase out ballast water exchange, replacing it with treatment technologies to achieve specific discharge standards (International Maritime Organization 2004). The IMO discharge standards are the same ones that have recently been proposed by USCG[1] and the EPA.

The IMO Convention is awaiting ratification and is not yet in force. The Convention requires ratification by at least 30 countries accounting for 35% of the world's merchant shipping. As of February 2012, it had been approved by 33 countries that represent 26% of the global fleet (International Maritime Organization 2012).

Although not directly relevant to Micronesia, it is also perhaps useful to note that several individual state regulations exist for ballast water discharge in the U.S. (e.g. California, Oregon, Washington and Michigan; see National Research Council 2011 for

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[1] The Final Rule was issued by USCG and published in the Federal Register after completion of this report. For specific details see: Standards for living organisms in ships' ballast water discharged into U.S. waters, Federal Register, Volume 77, Number 57, March 23, 2012[1]

discussion). These state regulations do not replace federal regulations, but instead impose additional requirements on commercial vessels. In some cases, the state regulations result in more stringent discharge standards and have created additional requirements for treatment of coastwise vessel traffic among U.S. ports. Some of these state requirements are also written into (included) in current, existing federal regulations from the EPA.

In considering the geographic scope of this report, USCG and EPA regulations apply to commercial vessels arriving to Guam, Commonwealth of Northern Mariana Islands (CNMI), and Hawai'i. Thus, vessels arriving to each of these jurisdictions are presently required to either (a) retain ballast water, (b) undergo open ocean ballast exchange (at 200 nmi from shore), or (c) use an alternative ballast water treatment technology that is approved by USCG. As noted above, the requirements for ballast water treatment are likely to change to concentration-based discharge standards, which are pending at both the U.S. federal and international levels.

For the rest of Micronesia, there are no other countrywide or regional regulations that specifically address ballast water management and discharge by commercial operators. On a local scale, ballast water discharge is not allowed within 12 nmi of the Port of Saipan, per port regulations (Commonwealth Ports Authority Regulations Private Use of Harbor Property and Facilities 3.26b). In Palau, although there are no regulations specifically addressing ballast water, it is thought that discharges can be regulated as non- point discharge under the Environmental Protection Act 24 PNC. In several other parts of Micronesia, officials suggested that agencies regulating water quality already may have the legal authority to control deballasting. Moreover, it was widely recognized throughout Micronesia that the pending IMO standards would apply to arriving vessels, when they come into force. Palau, the FSM and the RMI each have pending biosecurity bills that would, among many other topics, address ballast water management.

One aspect not currently being considered in the management of ballast water in the region is the proximity of the Mariana Islands to the West Mariana Ridge (WMR). While none of the volcanic peaks of the WMR quite reach sea level, 11 summits have depths of less than 500 m, of which three seamounts (including Stingray Shoal) are 16 m or less in depth (Gardner 2010). The WMR is well within the 200 nmi allowable zone for ballast water exchange. Of equally great concern are a number of shallow banks west of Guam and the Marianas that are only about ~22 nmi or less from the main island chain. These shoals are potential landing sites for invasive species flushed from ballast. As such, "open ocean" ballast water discharge is not the ideal solution for the Marianas, and alternative technologies should be explored.

2.2.1.2 U.S. Navy Vessels

Although military vessels are exempted from the above regulations, there are separate requirements that exist for the U.S. Navy. Specifically, when U.S. Navy ships take on ballast water within 3 nmi of shore (or in areas that are potentially polluted), they are instructed to exchange ballast water outside the 12 nmi zone from shore before next entry (Section 22-10.3.1, Environmental and Natural Resources Manual 2007; OPNAVINST 5090.1C, updated July 18 2011). U.S. Navy ships are instructed to pump out and twice fill tanks with clean seawater outside the 12 nmi mark, and to do this exchange even when deballasting has happened before exiting the 3 nmi mark (or polluted waters) to remove any contaminated residual ballast water. The ships' engineers are instructed to record in ships' engineering logs such ballasting and ballast exchange, including the location and amount of water taken on (Section 22-10.3.2, Environmental and Natural Resources Manual 2007).

Based on current policy, two key differences exist in regulations for U.S. Navy vessels compared to commercial vessels. First, for U.S. Navy vessels, the required distance from shore for source of ballast water (3 nmi) or ballast water exchange (12 nmi) is much less than that for commercial ships (200 nmi). Second, we are not aware of a reporting requirement or analysis for U.S. Navy vessels, in which compliance with these requirements has been evaluated (see Section 2.2.2). In addition, we note that regulations for commercial vessels are rapidly moving toward a requirement for alternative treatment technologies with specific discharge standards, and we are not aware of similar efforts to develop such requirements for U.S. Navy vessels.

By having ballast water sources (including ballast water exchange) closer to shore, the likelihood of transfer of coastal organisms by U.S. Navy vessels to a suitable habitat is increased per unit ballast water volume relative to commercial vessels that conduct exchange in the open ocean (see Chapter 3 for comparison of traffic and ballast discharge between these vessel types). With increasing proximity to any particular shore, the concentration of coastal organisms is expected to increase, and the probability that organisms can reach coastal habitats by currents should also increase. For both attributes, the specific decay functions with distance from shore will vary geographically and temporally. Nonetheless, it is certain that coastal organisms occur in many regions at 3- 12 nmi from shore. It is partly for this reason that greater distances were required for ballast water exchange by commercial vessels (Brickman 2006; Miller et al. 2011a). Moreover, there is evidence that ballast water exchange closer to shore does entrain coastal organisms, which can be discharged at subsequent ports of call (Endresen et al. 2004; Cordell et al. 2009; Simkanin et al. 2009).

It is worth reiterating that the 12 nmi stipulated by the U.S. Navy for ballast water exchange may lead to ballast water being flushed in close proximity to shallow shoals only 22 nmi from the main island arc of the Marianas, as well as to the West Marianas Ridge approximately 100 nmi from the islands. These shoals and seamounts could become areas for alien coastal species to settle and invade.

A recent study aboard U.S. Navy supply vessels (oilers) along the eastern U.S. found a high efficacy for ballast water exchange, when conducted properly (Ruiz and Smith 2011). Experimental tests found that double ballast water exchange removed 99% of the original water and up to 99% of selected coastal organisms, compared to untreated control tanks on the same vessels. While comparable or better than similar tests on commercial vessels (Ruiz et al. 2005; Bailey et al. 2011), it also appears that concomitant entrainment of new coastal organisms occurred with this nearshore ballast water exchange, as perhaps expected (see above discussion). Thus, ships that undergo nearshore ballast water exchange can have residual coastal organisms from a previous source (albeit with severely reduced concentrations compared to pre-exchange conditions) as well as additional coastal organisms that are entrained during the nearshore exchange process.

Based on available information for both commercial and U.S. Navy vessels (Minton et al. 2005; Holm et al. 2005; Levings et al. 2004; Cordell et al. 2009; Ruiz and Smith 2011), it is apparent that the current ballast water management practices on the Navy vessels will often not allow them to meet the concentration-based discharge standards for zooplankton that are being advanced for commercial vessels by the U.S. and IMO (see above). These new standards are more stringent than ballast water exchange, at least for zooplankton concentrations (Minton et al. 2005), requiring fewer than 10 organisms (≥50 microns in size) per cubic meter. Importantly, this standard applies to total concentrations and does not distinguish between coastal and oceanic organisms. Thus, even if all coastal organisms could be replaced by the process of ballast water exchange (which does not occur), the entrainment of new organisms from nearshore or oceanic waters would frequently cause exchanged ballast water to exceed discharge standards.

Although the U.S. Navy is exempted from the discharge standards now being proposed for commercial vessels by the USCG, EPA, and IMO, all military vessels do fall under the jurisdiction for Section 312(n) of the Clean Water Act, which requires establishment of Uniform National Discharge Standards (UNDS). More specifically, Section 312(n) of the Clean Water Act requires the DoD and EPA to determine which discharges from military vessels require control and to set standards for environmental protection. While ballast water was identified previously as a discharge that required control by UNDS (United States Environmental Protection Agency 1999), no specific guidance or standard has been provided to date for this discharge.

Another area of concern is the risk of invasive species being transported to Micronesia and Hawai'i by foreign military vessels of partnering countries (e.g., Singapore, Philippines, Japan, Australia, etc.) that will arrive in the area to partake of training and joint exercises with the U.S. military. The routes and anticipated frequency of such foreign military vessel visits, as well as the ballast water guidelines these vessels are expected to follow, will need to be clarified.

2.2.1.3 Military Sealift Command Vessels

Supply vessels for the U.S. Navy operate under the Military Sealift Command (MSC). Some supply vessels are owned and operated by the MSC, representing a subset of U.S. Navy-owned vessels. However, additional supply vessels are privately owned or operated, under contract to the MSC. This latter group is distinctly different from other commercial vessels, which may transport cargo but are not under MSC orders.

Vessels that are owned or operated by the MSC are governed by the same environmental instruction as U.S. Navy vessels. However, ships that are operated by civilians under contract to the MSC are not subject to the Navy's regulations and are thus not obligated to carry out any of the Navy guidelines for environmental stewardship. It appears regulations for commercial vessels would apply in the latter case, but it is not clear (a) the extent to which these vessels operate with this understanding and (b) what management practices are used routinely on these vessels (see below for additional details).

2.2.1.4 Other Military Vessels

Vessels operated by the U.S. military (including Army, Navy, Marine Corps, Air Force, MSC, and USCG) are all exempt from U.S. regulations that exist for commercial vessels, as outlined above. While ballast water on all military vessels falls under the jurisdiction of UNDS, no ballast discharge standards have been advanced under UNDS to date for these vessels (United States Environmental Protection Agency 1999). Aside from the ballast management requirements in place for U.S. Navy vessels (above), we were unable to identify similar policies or requirements for other branches of the military or for military vessels of other countries when operating in U.S. waters.

2.2.2 Current Practices, Operating Procedures and Compliance

<u>2.2.2.1 Commercial Vessels</u>

A considerable amount of information is available on ballast water management for commercial vessels arriving to U.S. ports, because the USCG has established a reporting and analysis mechanism through the National Ballast Information Clearinghouse (NBIC). As noted above, commercial vessels are required to submit a report on ballast water management and discharge upon arrival to U.S. ports, and these data are used by NBIC to characterize status and trends in ballast water compliance and management (for more detail see http://invasions.si.edu/nbic/).

For the two-year period 2006-2007, NBIC received over 200,000 ballast water reporting forms that were submitted by ships' personnel or agents for arriving vessels (Miller et al. 2011b). Using an independent data set, it was estimated that 83.5% of overseas arrivals and 77.8% of coastwise arrivals (from another domestic port in the contiguous U.S.) were in compliance with the reporting requirements that exist. Most (76.9%) of these commercial arrivals reported no ballast water discharge. The remainder reported a cumulative discharge of >390 million metric tons of ballast water over the two-year period, including 111 million tons from overseas sources and 280 million tons from domestic sources. For the overseas ballast water, 81.7% of the total volume had reportedly undergone some type of treatment (ballast water exchange) prior to discharge, whereas 18.3% was not treated before release into U.S. waters. Under current USCG regulations, a similar requirement for treatment of ballast water from domestic sources (by coastwise traffic) does not exist; however, recent regulations by the EPA, and also those for a subset of States, do require ballast water treatment for some domestic sources (United States Environmental Protection Agency 2008; National Research Council 2011).

Miller et al. (2011b) estimated that ballast water reports were submitted by 62.6% of overseas arrivals to Guam and 73.7% to Hawai'i for 2006-2007. These compliance rates were below the national average (83.5%). A recent examination of NBIC reporting data, for the five-year period of 2005-2009, suggested that reporting compliance for arrivals to Guam and Hawai'i remains at approximately this level (http://invasions.si.edu/nbic/). For this five-year period, overseas arrivals reported discharge of 358,496 metric tons of ballast water to Guam, and an estimated 15.5% of this volume was reported to be untreated (i.e., did not undergo ballast water exchange). This represents a minimum estimate, given the low reporting compliance for Guam, which does not include roughly one third of the commercial vessel arrivals (see Chapter 3 for additional information on ballast water movement within Micronesia, and between Micronesia and Hawai'i).

Overall, Guam and Hawai'i have a relatively low number of vessel arrivals, representing 0.9% and 2.5% of the total vessel traffic reported for the entire U.S. in 2005-2006 (Miller et al. 2011b). Moreover, these regions accounted for an even lower percentage of the total reported volume of ballast discharge, reflecting the fact that these regions are net importers, with the exception of some transshipping operations. Commercial ships tend to arrive loaded with cargo and leave with less than they came with. Thus, the need for deballasting is likely to be lower in the region than in many other port locations; instead, Hawai'i and Micronesia are likely net exporters of ballast water (Godwin and Eldredge 2001). Despite the low relative volumes, ballast water discharges into these regions create opportunities for species transfer, and ballast uptake in these regions increases the probability of spread both within and outside of each region.

Much less information is available about ballast water management in other parts of Micronesia. In most locations in the region, management officials told us they depended on ships and shipping agents to be aware of existing regulations and to follow them. However, we note that few regulations exist currently. In the FSM, legal code allows for the inspection of ballast by agricultural quarantine inspectors (FSM Code, Title 22, 410); in most locations, it appears that environmental protection or environmental quality agencies also have the authority to regulate ballast water. As far as we were able to determine, none of the jurisdictions in the region check the records of arriving vessels to evaluate the extent of ballast water management and discharge.

While IMO discharge standards appear likely to come into force in the near future, requiring ballast water management throughout Micronesia, understanding the current and future ballast water practices will require increased capacity. Outside of the ballast- water reporting program described above for the U.S. jurisdictions, based on extensive interviews and correspondence with port officials throughout Micronesia, it appears there are no programs with such a focus in the region. Thus, evaluating ballast management in Micronesia would require personnel and training, which are not currently available. Further, it is noteworthy that existing programs throughout the world have primarily served to compile self-reported data from ships' personnel, with little effort to implement tests that verify whether ballast water exchange was conducted properly (but see Noble et al. 2010), which would require some additional development and training.

2.2.2.2 Military Vessels

In contrast to commercial vessels operating in Guam and other U.S. waters, relatively little information is accessible to evaluate current practices for U.S. military vessels, which are not required to submit reports to the USCG. While the U.S. Navy has a specific requirement to conduct ballast water exchange and record ballast water management in the ships' engineering logs, as noted above (Section 22-10.3.1, Environmental and Natural Resources Manual 2007; OPNAVINST 5090.1C), we are unaware of any effort to synthesize, analyze, or evaluate data on implementation of the Navy's ballast water management program. Instead, it is our understanding that existing data remain distributed across individual ships' logs and are not readily accessible. As a result, it appears there are no summary statistics available to characterize (a) the extent of compliance with OPNAVINST 5090.1C, (b) locations of ballast water sources, exchange and discharge, or

(c) volumes of ballast water discharged to Micronesia, Hawai'i, or other locations.

A small amount of information is available on supply vessels that operate under the MSC; because some of these vessels submitted ballast water data to the USCG through NBIC (see above for description). From 2005 to 2009, 77 MSC arrivals to Guam reported to NBIC, representing < 20% of the total estimated arrivals to Guam for this period (for commercial and MSC vessels combined; see Chapter 3). These MSC vessels reported

7,408 metric tons of ballast water discharged in Guam, and 15.2% of the total volume had not been treated by ballast water exchange. This accounts for 2% of the cumulative ballast water discharge reported to NBIC for Guam during this time period, and the percentage of untreated discharge is similar to that reported for commercial vessels to Guam (15.5%). However, with such a low proportion of the MSC arrivals included, it is premature to draw any conclusions about the relative contribution or nature of ballast water management by MSC vessels. Equally important, the volume of ballast discharge is not a good proxy for concentration of organisms or the probability of invasion (see National Research Council 2011 for discussion of this issue).

Beyond such records for MSC vessels, no other information was available to us to evaluate ballast water management and discharge of other Navy or other military vessels arriving to Micronesia or Hawai'i.

Some U.S. Navy vessels, such as surface combatants, have compensated fuel stowage systems, which are also subject to Navy regulation (Section 22-10.3.3, Environmental and Natural Resources Manual 2007). These regulations require vessels to record seawater intake occurring in potentially polluted areas or within 3 nmi of shore during routine internal fuel transfer for propulsion plant operation (but do not require ballast water exchange). Most fuel operations are reported to occur away from ports, possibly restricting uptake and transfer of coastal organisms. However, we have no access to information on the location of operations, volumes of water involved, or biota (types and concentrations) associated with this water arriving to Guam or any other region.

In addition, amphibious vessels are instructed to wash down any amphibious vehicles they are recovering (as well as anchors, anchor chains, and other shipboard equipment) and to dispose of wash water 12 nmi outside of the next operating area. This is outlined in Section 22-10.3.4 of the Environmental and Natural Resources Manual (2007). We have no information on the frequency or locations of this activity, or the biota that may be associated.

2.3 Biofouling

2.3.1 Regulations and Guidelines

2.3.1.1 Commercial Vessels

Biofouling is probably the most important vector of invasive species introductions. Biofoulers may account for up to 55% of marine pests globally, while in Australia over 60% of the known introduced species have most likely arrived as biofouling (Hewitt and

Campbell 2010). Despite this, the requirements surrounding biofouling on vessels are less advanced with respect to biosecurity than those for ballast water discharges. Existing requirements that apply to hull husbandry are motivated primarily by international vessel classification societies for insurance purposes (Takata et al. 2006), operational performance, and efficiency of the vessel, instead of prevention of species transfers and biological invasions. There are currently no international requirements that aim specifically to manage biofouling and associated invasion risks by commercial, military, or recreational vessels. Nor are there such requirements specific to Guam or the rest of Micronesia. However, the IMO has recently agreed to guidelines for biofouling with this goal (see below), and regulations are advancing for several specific regions around the globe.

For the U.S., existing requirements for hull husbandry focus on safety and operations. The USCG requires most large commercial vessels that operate in U.S. waters to be inspected at least 2 times every 5 years, with 3 years as the maximum interval between inspections. Newer vessels can qualify for underwater inspections under certain circumstances under the USCG regulations, and other vessel types are exempt. Although it appears that the USCG may have the authority to regulate the extent of biofouling as well (Hewitt et al. 2009a), this has not resulted in any specific regulations or requirements to date. None of the countries or states in the Micronesian region has additional regulations or guidelines for the management of biofouling.

In contrast, several regional or state regulations are emerging that seek to limit biofouling transfers and the likelihood of invasions. Strict regulations exist for vessels applying for permits to enter (as opposed to passing through) the Papahanaumokuakea National Monument, Northwestern Hawai'ian Islands (Papahanaumokuakea Marine National Monument Best Management Practices No. 011, 2009), whereby the vessels must meet specific standards indicating clean hulls. However, these regulations do not apply to vessels transiting through the monument nor do they apply to other areas of Hawai'i. In addition, the State of California is in the process of enacting regulations for control of biofouling on commercial vessels arriving to ports within the state (http://www.slc.ca.gov/Spec_Pub/MFD/Ballast_Water/Laws_Regulations.html).

On a global basis, several countries already have voluntary guidelines for management and have developed very detailed recommended management practices. For example, New Zealand has released draft regulations requiring all vessels entering territorial water to be free of biofouling (Ministry of Agriculture and Forestry 2010).[2] Australia has released draft antifouling and in-water cleaning guidelines for all vessels and other moveable structures in aquatic environments (Department of Agriculture, Fisheries and Forestry 2011), and was, at the time of this report, accepting public comment on whether to adopt voluntary or mandatory regulations[3]. Most recently, the IMO has adopted guidelines for management practices to reduce invasion risk associated with biofouling of commercial vessels (International Marine Organization 2010).

2.3.1.2 Military Vessels

For U.S. Navy vessels, there is an established schedule for inspection, and the level (both type and extent) of biofouling is used to determine the need for cleaning, dry-docking and application of coatings (Naval Ships Technical Manual (NSTM) 2006). The NSTM Chapter 081 lists criteria for frequency of hull inspection and in-water cleaning (i.e., removal of biofouling organisms), including a fouling rating system on which to base maintenance, information on tools to clean hulls underwater, a decision tree for other actions based on coating condition and rust, and limited information on underwater paint systems for U.S. Navy ships.

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[2] New Zealand was slated to release mandatory regulations for commercial and recreational vessels in 2012, but had not done so at press time. Further information on these regulations and enforcement is available at http://www.biosecurity.govt.nz/enter/ships.

[3] Further information on Australia’s biofouling regulations is available at http://www.daff.gov.au/animal-plant-health/pests-diseases-weeds/marine-pests/biofouling

As specified in NSTM 081, cleanings of ablative coatings (paints that work by slowly eroding, exposing new layers of anti-fouling compounds at the surface) are not done until 24 to 36 months after application, as the anti-fouling paint is expected to work well until then. Underwater paintings and coatings are expected to require no cleaning during the first year or two of service. Following this initial high-performing period, hulls may be cleaned as often as required to maintain fouling below acceptable levels. Acceptable is defined as: not above a one-knot speed penalty at shaft revolutions per minute (rpm) for standard sea-speed, not over a fuel usage penalty of 5% to attain standard sea-speed, or not to exceed fouling rating limits outlined in NSTM 081. Though heavy fouling and hard calcareous fouling in particular is to be avoided, full hull in-water cleanings are not expected to occur more frequently than every six months, even with tired coatings in high fouling bioregions. At present, dry-dock intervals for U.S. Navy ships range between five and twelve years, the upper limit far exceeding that for commercial vessels.

Beyond the hull itself, specific underwater fixtures require the use of specialized husbandry protocols, as outlined in NSTM 081. Vessels intended for "silence" (submarines) have specialized hull husbandry protocols intended to maintain that feature. This may include sheathing of certain features while in port. On all ships, sonar equipment, propulsion equipment in general (including bow-thrusters and emergency propulsion units), and the bow area receive priority attention, and may be cleaned much more frequently than the entire hull. Propellers, which are not painted with anti-fouling paints, foul more quickly than painted areas. In general, these are expected to be cleaned quarterly, although practices vary depending on operations. The NSTM also mentions that sea-chests commonly require hand tools for cleaning.

The UNDS, established under the Clean Water Act of 1996, has identified hull coating leachate and underwater ship (hull) husbandry as discharges requiring control for DoD vessels (United States Environmental Protection Agency 1999). Reports that characterize the nature of these discharges indicate that there is the potential for transport of non- native species associated with the hulls of vessels and also vessel cleaning, but the reports did not identify analyses that characterized the transfer of organisms on DoD vessels or the associated biosecurity risks (http://unds.bah.com/Nod/uwshphub.pdf;).

The U.S. Navy has sustained a long-term program that records data and maintains information on the extent and type of biofouling organisms present on Navy vessels, following protocols outlined in NSTM 081. Based on interviews with U.S. Navy personnel, it is our understanding that a routine schedule of in-water inspections and associated data (for biofouling) are maintained for all Navy-owned vessels. Existing analyses of these data to examine the potential for non-native species transfers with the U.S. Navy vessels could not be found.

Vessels that are privately owned and operated under the MSC appear to not be subject to similar requirements for inspections, records, and maintenance as outlined above for U.S. Navy-owned vessels. Navy personnel indicated that most such vessels under contract to MSC do not follow the U.S. Navy protocols for biofouling and operate instead under guidelines for commercial vessels, as discussed above.

Aside from the Navy, it is not clear if any specific regulations, requirements, or policies may exist for biofouling associated with other types of U.S. military vessels. Inquiries to DoD and associated research did not identify any existing policy in this regard.

2.3.1.3 Other Vessels and In-Water Structures

Any in-water structure or platform such as a floating dry-dock that is allowed to accumulate marine organisms has the potential to transfer non-native species when moved to another location. Although most recent efforts to evaluate and prevent marine invasion outcomes have focused on large vessels, small recreational craft and other in- water structures (such as drilling rigs and dry-docks; see below) can be potent sources of invasions. Indeed, even if these represent low frequency arrivals to a region, they can be sources of high-density inocula, especially because they may have high port residence times, slow travel speeds, and highly variable maintenance practices (see Section 2.3.2 for discussion).

For example, transportation of a decommissioned vessel (e.g., for scrap metal breaking or an artificial reef) may transfer large biofouling assemblages because the vessels have often been laid-up in port for long periods of time with little to no hull husbandry and are then towed slowly to another destination. These two attributes allow for extensive colonization of the outer hull by organisms and facilitate transfer and survival under low sheer forces (Davidson et al. 2008). A similar situation exists for floating dry-docks, mobile drilling platforms, floating docks, pontoons, navigation buoys, and fish aggregating devices (FADs), which operate often with high residence times and slow transport speeds. Indeed, although the literature on stochastic and high-density biofouling transfer events is limited, there are examples of such vessels and structures arriving to Hawai'i and Guam (Doty 1961; Brock et al. 1999; deFelice 1999; Godwin and Eldredge 2001). Floating FADs have also occasionally arrived at Saipan and Tinian waters within the past decade, concomitant with the increased use of that fishing technology in the Central and Western Pacific region.

Considering this more broadly, the transfer of any in-water material has some probability of transferring associated organisms, if present. Although this section focuses attention on vessels as a transfer mechanism for biofouling organisms, the same concept applies to the transfer of other materials as well, including port infrastructure (caissons, seawalls, rip-rap materials, sand), construction equipment (dredges and barges), scuba diving gear, and other equipment. This broader range of transfer mechanisms is outside the scope of the current chapter but will be revisited in the Biosecurity Plan (Chapter 6).

To our knowledge, there are currently no regulations or guidelines in Micronesia that address biofouling and invasion risks associated with the movement of these types of vessels, structures, and platforms, however both the FSM and RMI are in the process of developing biosecurity bills that will address these issues. Inquiries to DoD and review of available documents did not identify any such regulations or guidelines.

2.3.2 Current Practices, Operating Procedures and Compliance

2.3.2.1 Commercial Vessels

There are strong incentives to reduce biofouling on vessels, as it reduces streamlining of vessels and thus increases the drag, resulting in higher fuel consumption and longer transit times. Fouling on propellers, rudders and intake pipes can also interfere with functionality. To reduce biofouling, vessels are cleaned in dry-dock, often at set time intervals, and antifouling or foul-release coatings (paints) are applied to prevent the settlement or accumulation of marine organisms on boat hulls. Painted surfaces are also cleaned in water to remove biofouling organisms that accumulate between dry- docking intervals.

Several factors are known to influence the extent and species richness of fouling communities on underwater surfaces of ships, including age and type of coatings, route, speed, and frequency of operation (including port residence times). New vessels tend to have relatively low biofouling levels, due to several attributes, such as (a) complete coating of underwater surfaces with intact paint surfaces, (b) relatively high performance of new coatings, and (c) a paint type that is selected to be appropriate for the intended function (route and tempo) of the vessel, which can change over the approximate 30-year lifespan of the vessel. In general, the performance of coatings to prevent biofouling deteriorates with age, requiring routine cleaning and reapplication (Visscher 1927; Haderlie 1984; Schultz et al. 2011).

Controlling for other factors, short residence times in port and fast traveling speeds reduce the likelihood of an extensive fouling community on the exposed hull surfaces (Coutts and Taylor 2004; Davidson et al. 2009; Floerl and Coutts 2009; Sylvester and MacIsaac 2009). Floerl and Coutts (2009) also noted the "potential ramifications on the human-mediated spread of non-native marine species from commercial vessels being moored stationary for extended period of time due to the economic crisis. Vessels which visit a diverse or extreme range of environments (e.g., freshwater of the Panama Canal, warm water tropical ports, freshwater and cold water high-latitude ports), exceeding environmental tolerances of many biofouling organisms, are likely to be less prone to biofouling accumulation than vessels which remain within a narrow environmental range (Visscher 1927; Skerman 1960; Coutts and Taylor 2004, Davidson et al 2006). In addition, "niche" areas, or those protected from laminar flow (i.e., crevices), appear to be more susceptible to hull fouling (Coutts and Taylor 2004; Davidson et al. 2009). Thus, a vessel with low surface complexity will likely be cleaner than a vessel with complex and numerous niche areas, independent of other influences on hull fouling.

Many, if not most, anti-fouling coatings (which operate to reduce settlement of organisms) and foul-release coatings (which operate to prevent permanent adhesion, and therefore accumulation of organisms, under sheer forces) are engineered to work best when vessels are underway (Lewis 2002b). Thus, vessels that are seldom used, slow moving or poorly maintained are at high risk of being fouled. In general, vessels that are laid-up or spend long residence times in port can accumulate extensive biofouling, relative to vessels that are in continuous service or operate with shorter port residence times. Moreover, increased residence time in ports also causes niche areas, such as intakes and rudders (which are protected from shear forces while the vessel is underway), to be highly vulnerable to fouling, even on otherwise well-maintained vessels.

Since most existing guidelines and practices to reduce biofouling are aimed at maintaining the operational safety and cost efficiency of vessels, and are not driven by reducing invasion risk, there has been little incentive to address biofouling for (a) niche areas that do not increase drag, (b) slow-moving vessels, and (c) vessels that remain stationary for long periods of time. Yet, from a biosecurity perspective, high biofouling levels in niche areas (even though a small overall proportion of underwater surface area of a ship) are thought to pose significant invasion risks. For similar reasons, the transfer of biofouling communities on vessels that are slow-moving or that have had long residence times, even if rare events, is of considerable concern.

These gaps in current biofouling management practices are now the focus of guidelines and requirements, which are still taking shape around the world. Some programs are including (a) requirements for in-water hull inspections and consistently maintained reports (logs) on hull biofouling, and, (b) specific standards on permissible levels of biofouling for operations (California State Lands Commission 2011; Department of Agriculture, Fisheries and Forestry 2011; Ministry of Agriculture and Forestry 2010).

At the current time, there are no specific requirements to manage or report biofouling associated with commercial vessels operating in Micronesia, beyond those discussed in Section 2.3.1.1 (however, regulations should be forthcoming for FSM and RMI, upon approval of their biosecurity bills). While there is considerable literature on biofouling on vessels operating throughout the world (as above), relatively little information applies to Micronesia specifically. However, Section 2.3.3 provides new data on biofouling surveys conducted during this project.

2.3.2.2 Military Vessels

All U.S. Navy vessels operating in Micronesia and elsewhere in the world are expected to have regular in-water inspections for extent and type of biofouling coverage, as specified in the NSTM 2006 and discussed previously (see Section 2.3.1.2). According to U.S. Navy personnel, most of the records (including data and photographs collected during inspections) are maintained by the U.S. Navy, and these can be especially useful for analysis of biofouling associated with these vessels (see Bendick et al. 2010; Schultz et al. 2011). Based on interviews with U.S. Navy personnel and literature searches, we were unable to identify such analysis to examine biosecurity issues associated with these vessels (see also Section 2.3.1.2).

We were not given access to these records and therefore were unable to assess either (a) the hull maintenance and cleaning schedules for U.S. Navy vessels arriving to the Micronesia region or Hawai'i or (b) the extent and diversity of biofouling organisms associated with such Navy vessels. There are at least three steps that would be needed to examine these records. First, we would need to know the name (or other unique identifier) of Navy vessels arriving to or visiting Micronesia or Hawai'i, in order to examine the associated inspections records. This request was denied, due to concerns about national security. Second, we would need to access the records themselves. While this can clearly be done (see Bendick et al. 2010), it is also our understanding that many records are not readily available or in electronic format, requiring considerable effort (the third step).

In-water cleaning occurs in Apra Harbor, as outlined in NSTM 081 protocols, according to U.S. Navy personnel. A commercial dry-dock on Guam services MSC vessels, and U.S. Navy vessels are also sometimes dry-docked here for emergency repairs. Further details on the frequency or particular methods surrounding each aspect above were not available to us.

While existing protocols and schedules for hull biofouling management clearly apply to the surface combatants, there is some uncertainty about their application to supply vessels, barges, floating dry-docks, lighters, small craft or auxiliaries associated with U.S. Navy activities. We have discussed earlier this issue with respect to those MSC vessels that are privately owned and under contract. Other vessels with limited (local) operating distances also may not receive the same attention as surface combatants, with respect to biofouling inspection and maintenance, however we have no data on this to evaluate implementation or performance of existing protocols.

2.3.3 Survey of Biofouling on Commercial and MSC Vessels in Guam

We surveyed six MSC vessels and eight commercial vessels that were docked in Apra Harbor in summer and fall 2010. For each vessel, information concerning the hull maintenance history and voyage characteristics was collected using a questionnaire that was completed by a member of the crew. Questions included date of last dry-dock or delivery of the vessel, regular service route/destinations visited in the previous year, average speed of the vessel, and average in-port duration.

In-water surveys were conducted using SCUBA to access biofouling communities on hull surfaces and niche areas on one side (non-dock side) of each vessel. The following areas were targeted during the surveys: bulbous bow, bow thruster, bow hull surface areas, bilge keel, mid-ship hull surface areas, rudder, propeller, propeller-strut, and stern hull surface areas. In-water survey duration was approximately 60 minutes. This time was divided between the target areas described and other niche areas were sampled as encountered during the survey

Digital photographs were taken of all fouling communities encountered to assess the extent of fouling. Where fouling was present, the total abundance of attached macro-invertebrates was estimated to the nearest order of magnitude for each of the targeted survey areas; as only a portion of each vessel was surveyed, this represented a minimum estimate of abundance and also provided a standard measure for comparison across vessels. In addition, samples of invertebrates were collected and examined to assess the diversity (composition) of the biofouling community. Samples of the attached invertebrates were dislodged carefully and collected in zipped bags. A sample of each organism that appeared morphologically distinct was collected to provide an estimate of species diversity (richness) on the vessel. On return to the lab, each sample was inspected under a microscope and described using taxonomic characteristics (dead specimens were not included in this assessment).

As a coarse measure, morpho-taxa (or organisms that appeared to be different species based on morphology) were used as a conservative estimate of the total number of species.

Many species are cryptic and difficult to differentiate without in-depth (morphological and molecular) analyses and taxonomic expertise, which exceeded the scope of the current project. Furthermore, the analysis focused only on large (>1mm) invertebrates and did not include smaller organisms and algae that were present. Thus, pragmatically, morpho-taxa were used to provide a quick, first assessment for our analysis and data presentation here. Although algae are an important component for biofouling communities, these were excluded from this initial assessment, because none of the biologists involved had sufficient taxonomic expertise for this group.

2.3.3.1 Vessel Histories.

All vessels sampled had been either delivered new or dry-docked within the past four years (Table 2.1). Three of the MSC vessels were nearing the end of this dry-docking period, which suggests that they could go into dry-dock in the very near future; according to interviews, most were planning to maximize the five-year window before going into dry-dock again. Five of the commercial vessels sampled were also towards the end of this expected service window, however these vessels were all new builds (generally subsequent antifouling paint applications deteriorate more quickly) and were recently inspected by underwater survey.

Based on interviews, a stark contrast existed between MSC and commercial vessels in terms of both in-port duration and average speed (Table 2.1). Commercial vessels spent minimum time in port (less than one day) and moved quickly between locations (14-21 knots, with the exception of Comm 8 which is a locally-operating vessel on a slower schedule). However, MSC vessels spent up to and sometimes over four weeks in a single location, and did not move quickly between locations (<14 knots). Several of the MSC vessels spent >60% of their time in one location (Guam for these vessels) and tended to stay within the central Pacific region, with occasional trips further afield (Table 2.1). Commercial vessels operated on a regular route, either between the East-Central and West-Pacific (Comm 1-4), Central and West-Pacific (Comm 5-7) or in a very small area around Guam (Comm 8).

Table 2.1 Vessel characteristics from questionnaires of vessel crew. Characters considered indicative of potential for heavy fouling are highlighted in grey.

Vessel	Dry-dock (DD)/ New build (NB)	Duration in Port	Average Speed (knots)	MSC Program/ typical round-trip duration	Destinations in past 12 months/ regular route for commercial vessels
MSC 1	DD 2007	2 wks	8-14	NFAF	Pacific: SW-NW-Central
MSC 2	DD 2007	65%	14	NFAF	North Pacific: Central-West, 65% time in Guam
MSC 3*	DD 2008	3-4 wks	10-14	NFAF	Pacific: SW-NW-Central, 70% time stationary
MSC 4	DD 2010	3-4 wks	12-14	PP	Gulf of Mexico-Panama-California-Central Pacific [normally stay within 7th Fleet]
MSC 5	DD 2007	1 wk	13	NFAF	Pacific: SW-NW-Central
MSC 6	DD 2009	3-4 wks	12	PP	Gulf of Mexico-Panama-California-Central Pacific [normally stay within 7th Fleet]
Comm 1	NB 2007	6-12 hrs	21	35 days	North Pacific: East-Central-West
Comm 2	NB 2007	6-12 hrs	21	35 days	North Pacific: East-Central-West
Comm 3	NB 2007	6-12 hrs	21	35 days	North Pacific: East-Central-West
Comm 4	NB 2007	6-12 hrs	21	35 days	North Pacific: East-Central-West
Comm 5	NB 2007	6-12 hrs	14	21 days	North Pacific: Central-West
Comm 6	DD 2008	6-12 hrs	15	21 days	North Pacific: Central-West
Comm 7	DD 2009	6-12 hrs	14	28 days	North Pacific: Central-West
Comm 8	DD 2008	2-3 days	unknown	7 days	Local vessel, stays within 150 miles of Guam

NFAF- Naval Fleet Auxiliary Force

PP- Prepositioning Program

7th Fleet encompasses the Asia-Pacific region from the Kuril Islands to the north to Antartica to the south, from the International Date Line to the 68th meridian.

***-MSC 3 was scheduled to be taken out of service in December 2010 and thus may not have been maintained to 'normal' standards.**

2.3.3.2 Extent of biofouling.

Biofouling was detected on all 14 vessels sampled in Guam. Twelve of the vessels had greater than 10,000 organisms across various submerged locations, indicating dense aggregations of biofouling (Figures 2.1 and 2.2). The remaining two vessels had abundances of invertebrates on the order of 1,000s of organisms (Comm 1 and Comm 2). There was a distinction between MSC ships and commercial ships: MSC vessels tended to have biofouling that was at least one order of magnitude higher than commercial vessels.

Figure 2.1. Biofouling organisms on vessels arriving to Guam. Left: High percent cover of fouling organisms below the rudder. Right: Sessile species such as sponges, tunicates and hydroids, growing on a grate provide habitat for mobile species.

For hull surfaces, biofouling tended to be most abundant at stern areas compared to bow and mid-ship areas among all vessels, and hull biofouling was far more extensive on MSC ships compared to commercial vessels (Figure 2.2). The higher biofouling at stern areas of most ships is a general feature of vessel biofouling because stern hull surfaces tend to have greater protection from laminar water movement which allows greater retention of biofouling organisms. The higher levels of fouling on MSC vessels was probably due (at least in part) to operational differences among the two ship types, especially port durations (time spent stationary) and average speeds, which are expected to increase biofouling accumulation (see Section 2.3.2 for discussion).

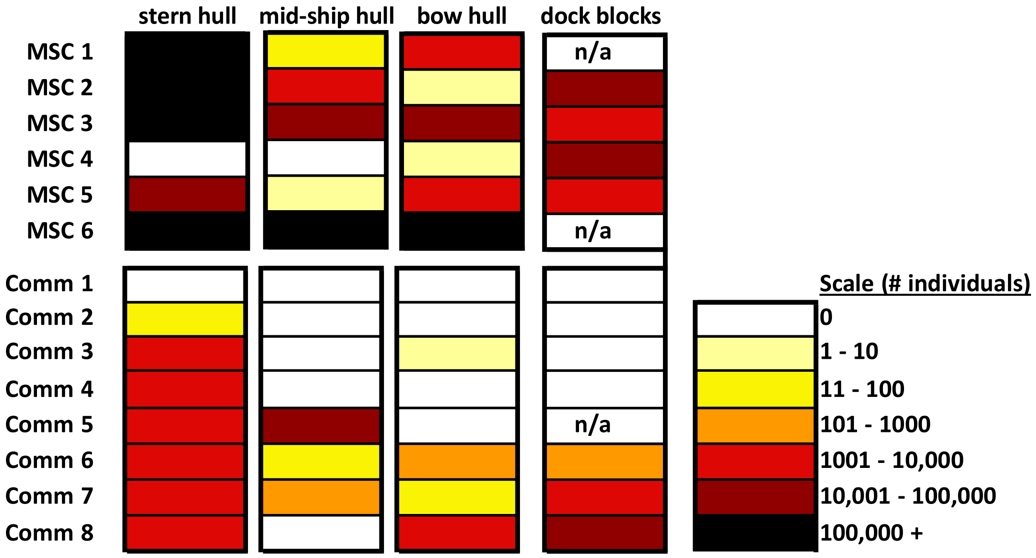
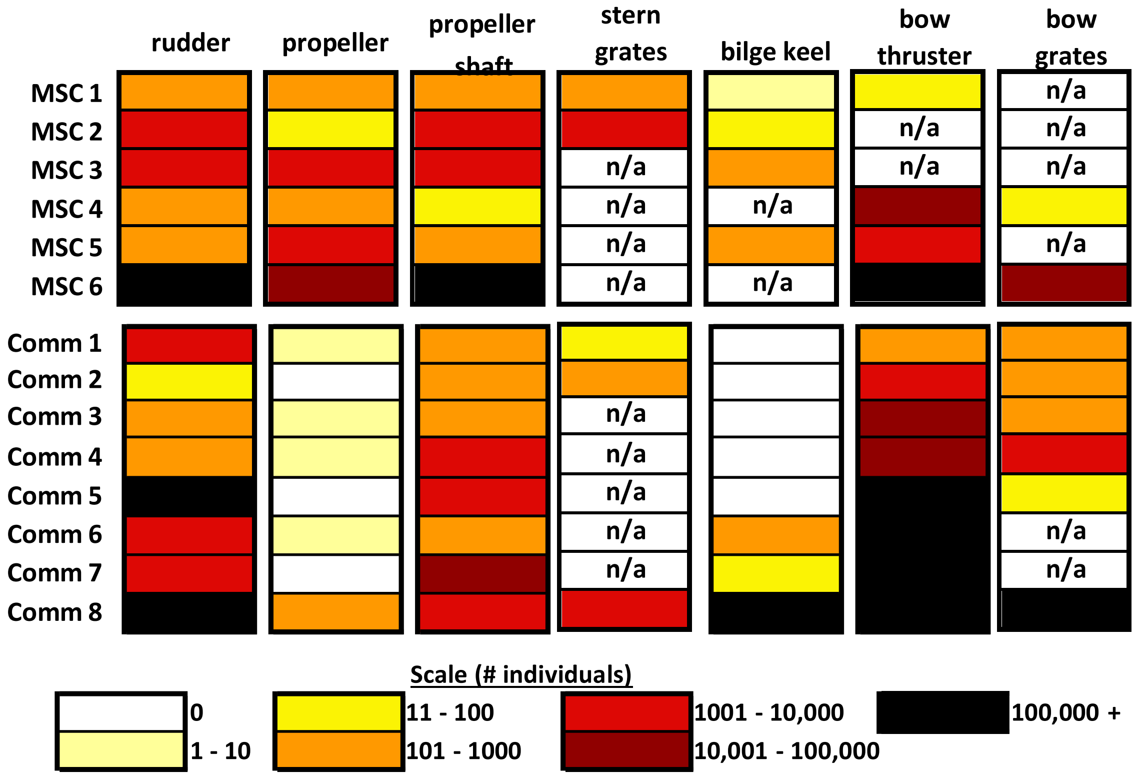


Figure 2.2. Biofouling extent on hull surfaces of 14 ships sampled in Guam. The scale of biofouling extent is color-coded to correspond with orders-of-magnitude abundances of macro-invertebrates detected for the portion of each vessel surveyed (see text). Biofouling was generally higher on stern surfaces than bow surfaces across all vessels and higher on MSC vessels (darker boxes) compared to commercial vessels.

The vessel with most fouling on hull surfaces (MSC 6) had hundreds of thousands of invertebrates at stern, midship and bow areas. This was a preposition ship, with long port residence times, but it was transient, moving among regions as distant as the Gulf of Mexico, California, and Micronesia (Table 2.1).

Four commercial vessels (Comm 1, 2, 3, and 4) had little or no biofouling on bow, midship and dock block surfaces. The major operational difference between these commercial vessels and others was that their voyage routes include trans-oceanic trips to the U.S. Pacific coast. All other commercial vessels had voyage routes within the Central- NW Pacific region.

Biofouling abundance on non-hull surfaces (vessel appendages and grates) was highly variable (Figure 2.3). The pattern of higher biofouling on MSC compared to commercial ships was most notable on propeller surfaces; most commercial vessels had zero or <10 organisms while all military ships had an order-of-magnitude higher abundance. One MSC vessel had more than 10,000 organisms on its propeller, which is unusually high for an in-service vessel. By contrast, bow thruster areas had similar high levels of fouling for both types of ship (commercial and military). Moreover, bow thrusters had the highest extent of fouling compared to other niche areas, and a majority of ships had tens to hundreds of thousands of invertebrates on thruster grates and within the thruster tube. Rudders also tended to have substantial numbers of fouling invertebrates associated with their surfaces, edges and articulations. The abundance of organisms detected on rudders was of a similar range between commercial and military vessels.



	rudder	propeller	propeller shaft	stern grates	bilge keel	bow thruster	bow grates
MSC 1	🟧	🟧	🟧	🟧	🟡	🟨	n/a
MSC 2	🟥	🟨	🟥	🟥	🟨	n/a	n/a
MSC 3	🟥	🟥	🟥	n/a	🟧	n/a	n/a
MSC 4	🟧	🟧	🟨	n/a	n/a	🟫	🟨
MSC 5	🟧	🟥	🟧	n/a	🟧	🟥	n/a
MSC 6	⬛	🟫	⬛	n/a	n/a	⬛	🟫
Comm 1	🟥	🟡	🟧	🟨	⬜	🟧	🟧
Comm 2	🟨	⬜	🟧	🟧	⬜	🟥	🟧
Comm 3	🟧	🟡	🟧	n/a	⬜	🟫	🟧
Comm 4	🟧	🟡	🟥	n/a	⬜	🟫	🟥
Comm 5	⬛	⬜	🟥	n/a	⬜	⬛	🟨
Comm 6	🟥	🟡	🟧	n/a	🟧	⬛	n/a
Comm 7	🟥	⬜	🟫	n/a	🟨	⬛	n/a
Comm 8	⬛	🟧	🟥	🟥	⬛	⬛	⬛

Scale (# individuals)

⬜ 0
🟡 1 - 10
🟨 11 - 100
🟧 101 - 1000
🟥 1001 - 10,000
🟫 10,001 - 100,000
⬛ 100,000 +

Figure 2.3. Biofouling extent on hull appendages or niche areas of 14 ships sampled in Guam. The scale of biofouling extent is the same as Figure 2.2, with white and black corresponding to zero and hundreds of thousands of organisms, respectively. Ships are listed down the side while niche area locations are listed across the top.

2.3.3.3 Biofouling composition.

The diversity of fouling organisms on both commercial and MSC vessels was high compared to previous studies (e.g., Davidson et al. 2009; Figure 2.4). Bryozoans, bivalves, tunicates and tubeworms were the most diverse groups on MSC vessels, while barnacles and bivalves were richest on commercial vessels. Various forms of algae were also encountered on all vessels, but the taxonomic diversities were not analyzed (as noted above).

The average number of morpho-taxa of invertebrates collected from MSC vessels (30) was slightly higher than for commercial vessels (27). It is noteworthy that this estimated species number was higher on both vessel types than that found in previous studies, using similar methods, on the west coast of North America (Davidson et al. 2009). MSC vessels 3, 4 and 6 each had above-average taxonomic diversities: these were the vessels which spend the most time in-port (3-4 weeks at a time). MSC vessels 4 and 6 were also both in the Prepositioning Program and generally stayed within a closer range of Guam than vessels in the Naval Fleet Auxiliary Force. Of the commercial vessels, vessels 5 and 8 had the highest numbers of morpho-taxa, which can be explained by the long duration since dry-docking for vessel 5 and narrow operating range and longer in-port duration for vessel 8.

The results also show that there was a wide variability in species diversity even when vessel histories were very similar. Commercial vessels 1-4 were operated by the same company and had very similar histories, yet the number of sessile morpho-taxa varied between 17 and 28 for these four vessels. Although not included in estimates of biofouling cover (Figures 2.2 and 2.3), which focused on sessile and sedentary invertebrates, a number of mobile species were found on the vessels, including crustaceans and mollusks (Figure 2.4), despite most of them being sampled soon after the vessel docked.

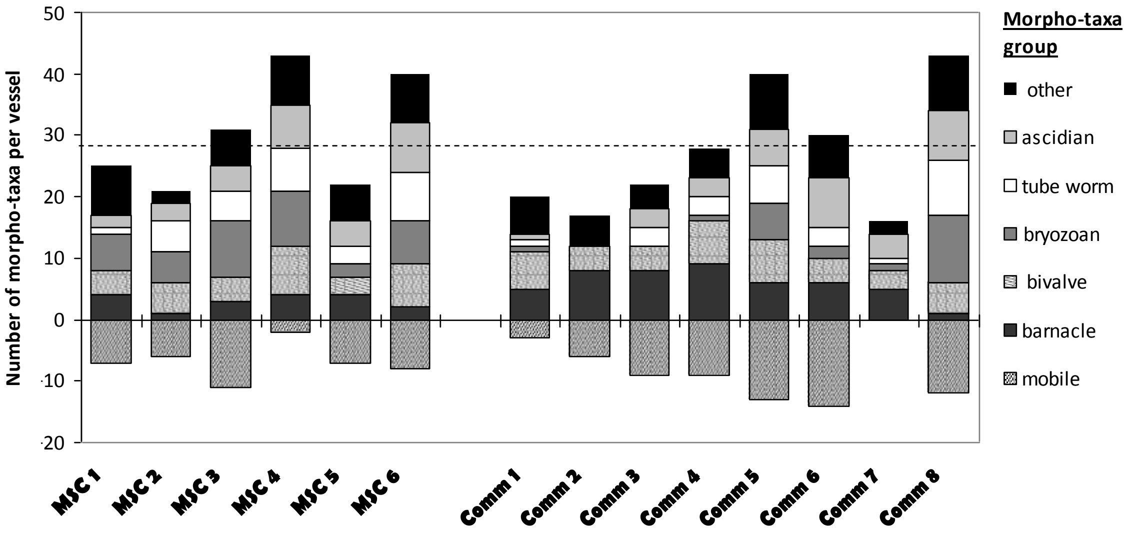


Figure 2.4. Diversity of morpho-taxa found on all surfaces of each vessel sampled during 2010. Vessels on the left are MSC and vessels on the right in the shaded portion are commercial vessels. Sessile species are accumulated above the x-axis (with the dashed line showing the mean value of 28.42 across all vessels) with mobile species shown separately below the x-axis.

2.3.3.4 Inferences for Hull-Mediated Transfers of Organisms to Guam, Hawai'i , and Micronesia.

It is evident that substantial numbers of organisms are currently associated with MSC and commercial vessels that arrive to Guam. Despite a relatively small sample size of vessels, the 2010 surveys indicated that both abundance and diversity (species number) on these Guam arrivals was often high relative to similar analyses of commercial vessels in other regions (Coutts and Taylor 2004; Davidson et al. 2009; Sylvester and MacIsaac 2009). It is also important to emphasize that these were minimum estimates for abundance and diversity, because (a) only a portion of each vessel was surveyed, (b) the analysis focused only on macro-invertebrates, excluding algae and other smaller organisms that were present, and (c) the use of morpho-taxa can only detect species with conspicuously different morphological characteristics. Further study of existing samples would certainly reveal higher taxonomic diversity (species number). Nonetheless, the current coarse-grained analysis provides a clear indication that transport of biofouling organisms to and from Guam is relatively high for these vessels on a per-capita basis.

While multiple factors may contribute to the accumulation of biofouling communities on vessels, vessel speed and port residence time probably explain (at least in part) why such dense and diverse communities occurred on many Guam arrivals (see Section 2.3.2 for discussion of mechanisms). Vessel speeds were slower for these arrivals, and port residence times longer, compared to many biofouling studies on vessels in other regions (e.g. Gollasch 2002; Davidson et al. 2009; Sylvester et al. 2011). In addition, it is also the case that most studies of vessel biofouling have occurred in temperate latitudes (Pyefinch 1950; Skerman 1960; Gollasch 2002; Sylvester et al. 2011; Godwin 2004 is an exception), and it is possible that the rates of biofouling accumulation or survival (persistence) are greater for either tropical systems or the specific routes represented. Perhaps important in this regard is that many of the surveyed vessels operate within tropical waters, and sometimes within a narrow range of ports, providing stable environmental conditions (i.e., temperatures and salinities) compared to some routes. The available data are presently insufficient to test the relative contribution of these (and other mechanisms) to the observed patterns.

While the identity and biogeography of the organisms has not yet been determined in the current analysis, it is unlikely that all fouling species encountered are native to Guam. Instead, simply based on voyage histories, the assemblages may include species that are non-native to Guam and other regions of Micronesia, and some of these species may not yet be present (established as self-sustaining populations or invasions) in the region. Further evaluation is required for these particular ship-biofouling samples, but also for the background communities in ports and harbors of Micronesia (see Chapter 6), in order to obtain robust estimates of non-native species richness on vessels and the proportion of novel species that have not yet colonized Guam or Micronesia.

2.4 Conclusions

2.4.1 Ballast Water

While ballast water management practices are advancing on a global scale to limit non-native species transfers by this vector, there are some conspicuous gaps for Micronesia and Hawai'i, including the following:

- On a broad scale, management requirements do not exist at the present time for ballast water discharged in many ports and coastal areas throughout Micronesia.

- While this will change if and when the IMO international regulations eventually come into force, most countries in Micronesia do not currently have a program or specific plan to assess compliance with these requirements.

- While the U.S. Navy has established requirements for ballast water exchange, there is uncertainty about whether these requirements apply to vessels operated under MSC; if not, and these are considered commercial vessels, a large fraction of MSC vessels that arrive to Guam appear currently to be out of compliance with USCG federal regulations.

- It is not evident whether any policies or requirements exist for DoD vessels operated by other branches of the military. Although these vessels fall under the

> UNDS process, no ballast water guidelines or discharge standards have been issued under this program to date.

The U.S. Navy was quick to adopt requirements for ballast water management, which were contemporary with those implemented for commercial vessels, but there are some substantive differences between these programs. First, U.S. Navy vessels are allowed to conduct ballast water exchange much nearer to shore (3-12 nmi versus 200 nmi), which increases the likelihood of non-native coastal species transfers. Second, we are unaware of any program by the U.S. Navy to evaluate compliance with this requirement in Guam, Hawai'i, or elsewhere in the world. Third, it appears that ballast management of the commercial fleet is poised now to transition from ballast water exchange to more stringent, concentration-based discharge standards, but we are unaware of a similar transition plan for U.S. Navy vessels.

We recognize that ballast discharge volumes in Guam and Hawai'i by U.S. Navy vessels are likely to be relatively small, whether considering cumulative or per-capita volumes, but the current treatment requirements may be less protective than those for commercial vessels. As discussed above, treatment efficacy will depend on location of ballast management and other factors. Importantly, the data required for this assessment were not available to us, and it appears such an assessment has not been made.

2.4.2 Biofouling

The available data suggest that per-capita transport of biofouling organisms to Guam by commercial and MSC vessels is relatively high, creating significant opportunities to transfer species. While the current analysis has focused on arrivals to Guam, it is critical to recognize that all of these vessels have visited other regions. Thus, they may simultaneously be a source of new introductions to Guam and other ports of call, including those in Hawai'i and elsewhere in Micronesia. Moreover, native and non-native species present in Guam (a regional hub) can colonize vessels and be transferred sequentially to other ports, in a hub-and-spoke model of dispersal (see Carlton 1995). Chapter 3 further illustrates the degree of connectivity between Guam and other ports in Micronesia and Hawai'i.

It is also apparent that the management practices outlined in NSTM 081 for hull husbandry (see Section 2.3.1) are not applied to all MSC vessels, given the extent of biofouling observed on several vessels. This is perhaps not unexpected for vessels that are relatively stationary (such as preposition ships) or slow-moving supply ships, where the penalty in time and fuel are not major considerations for additional maintenance.

Obviously, the current data cannot be extrapolated to other types of U.S. Navy vessels (e.g., surface combatants), where the frequency of operations and speed differ substantially. Although the Navy conducts routine in-water surveys, as discussed previously, these data were not available for us to evaluate the extent and composition of biofouling for vessels visiting Guam. Importantly, the surveys are used primarily to sustain vessel performance, and we are unaware of an analysis of these data by the U.S. Navy to assess the opportunity for non-native species transfers to Guam or elsewhere.

Although the window of opportunity is open for hull-mediated transfers of non-native species by MSC and commercial vessels that visit Guam, it should be noted that these vessels may not be out of compliance with current regulations. It is presently unclear whether those outlined in NSTM 081 are intended to apply to all MSC vessels (i.e., privately owned or operated vessels under contract to the U.S. Navy), and husbandry requirements for commercial vessels are still largely undeveloped with respect to biosecurity (see Section 2.3.1). In addition, we are unaware of any requirements for husbandry of vessels and equipment used by DoD contractors, or for movement of decommissioned vessels by DoD; barges may be of particular concern in this regard for Micronesia, because of (a) their long residency periods and slow speeds, as discussed previously, and (b) a likely increase in barge traffic during the Buildup on Guam (see Chapter 3). Thus, the lack of a well-defined, consistent, and effective approach to hull husbandry (to limit species transfers) represents a clear gap in biosecurity, given the importance and dominant role of hull biofouling as a vector for introductions of marine species throughout the world (Chapter 1).

Chapter 3: Current and Predicted Vessel Flux and Related Activities

By Gregory M. Ruiz, Chela J. Zabin, and Mark Minton

While Chapter 2 reviewed current management practices for vessels operating in the region of interest for this report (Micronesia and Hawai'i), Chapter 3 summarizes what is known about the magnitude of vessel movements (flux) and vessel-related activities for these areas. The predominant focus is on military and commercial vessels, examining (a) the number of arrivals and (b) the direct linkage to other geographic regions. This approach provides one measure of connectivity among port systems, and the potential for movement of organisms associated with vessels. In addition to consideration of military and commercial vessels, this chapter also summarizes information for other types of vessels and vessel-related activities with relevance to species introductions.

Some of the same data presented here are used for a more detailed analysis and risk assessment for biofouling organisms, which combines vessel movement and non-native species information, in Chapter 5. The current chapter is intended to provide a broad overview of vessel movement patterns, describing both sources and constraints of available information. In this sense, Chapter 3 provides important background information and sets the stage for the subsequent analyses.

While this report attempts to consider both past activities and possible future shifts across vessel-related vectors, associated with the Buildup (construction) phase and post-Buildup phase in Guam, it is important to recognize that the latter are extrapolations as provided in previous reports. For example, projections of increased vessel traffic (arrivals) exist for Guam, both during and after Buildup. While such an increase appears inevitable for both military and commercial traffic, there is some uncertainty about the rate and magnitude of increase. Moreover, there is likely to be high uncertainty about geographic source(s) of vessel traffic for both military and commercial vessels, which will respond to dynamic strategic and financial interests respectively.

Finally, while a distinction is made throughout this chapter between military and commercial activities, it is also recognized that the magnitude of commercial activities (during and after Buildup on Guam) will be affected by the increased military activity and associated personnel. This indirect effect or feedback is inevitable, given the significant size of the military presence in Guam.

3.1 U.S. Military Vessels

There are many different types of U.S. military vessels that currently visit Guam. The following vessel types are home ported or regularly visit the DoD port in Inner Apra Harbor (Department of Defense 2009, 2010):

U.S. Navy (COMNAVMARIANAS)
SSNs/Sub Tender
Logistics Prepositioned Ships
MSC Combat Stores Ships
Maritime Prepositioning Ships
MSC Ammo Ships
H60s

USCG
225’ Buoy Tender (responsible for Guam, most of the Marianas, and Kwajalein)
110’ Patrol Boat
25’ Response Boat

Several additional U.S. Navy vessels will be home ported in Guam following the Buildup. These include: High Speed Vessels (HSVs) and a Littoral Combat Ship (LCS).

In addition to the home-ported vessels, the DoD port in Guam serves 12-14 ammunitions ships in the region, with 275 total days per year of use at its Kilo Wharf. Kilo Wharf appears to be near capacity, as Fleet and MSC vessels have been turned away due to lack of space at the wharf (Department of Defense 2009; see Volume 2).

Military vessel arrivals to Guam occur generally at the DoD port, or Naval Base Guam, which is distinct from the commercial Port of Guam. Although adjacent to each other in Apra Harbor, the military and commercial ports function largely as separate entities from the operations and record-keeping perspective.

The U.S. Navy reported 143 ship arrivals into the DoD port in 2008; 268 were reported in 2009, and 271 in the first 10 months of 2010 (Table 3.1). For 2009, the only year for which we were able to obtain data, the DoD port in Okinawa reported 175 visits of MSC traffic, and 85 days of warship traffic.

Additional vessel traffic data were provided for MSC vessels (and are presented in Section 3.3), but for the all other vessel types we have no further information on (a) the frequency with which vessels have visited Naval Base Guam, (b) their residence time in port, or (c) their specific transit histories (routes and ports of call). Although such data exist for U.S. Navy surface combatants and other vessels, these data were considered sensitive information and were not available to us.

The DoD provided lists of typical last ports of call for some of the vessel types arriving to Guam (Table 3.2). It is clear that military vessels arriving to Guam visit many ports throughout Asia and the Pacific Islands region as well as some ports in the Middle East (the latter not shown in Table 3.2). However, it is important to note that this is not a full list of vessel histories and ports visited; also excluded are any data on the frequency of port visits. Without such comprehensive data, it was not possible to evaluate the relative importance (weighting) of different ports, or the degree of connectivity to Guam for the U.S. Navy ships. Such data were only available for vessels operated under MSC, allowing for an analysis of a portion of the military ship traffic, the military supply ships.

Table 3.1 Number of ship arrivals by type reported by Naval Base Guam for Inner Apra Harbor.

Ship type	2008	2009	2010 (10 months)
CVN (aircraft carrier)	3	0	0
SSGN (nuclear-powered cruise missile submarine)	0	16	7
SSN (nuclear-powered fast attack submarine)	12	51	41
AS (submarine tender)	1	4	0
CG (guided missile cruiser)	5	3	1
DDG (guided missile destroyer)	14	23	12
FFG (guided missile frigate)	0	3	7
LCC (amphibious command ship)	0	1	7
Amphibious craft	3	5	4
Foreign	11	9	0
Research	0	7	8
NOAA	0	1	5
MSC	40	80	87
Commercial tankers	0	8	13
USCG	54	57	79
Totals	**143**	**268**	**271**

Military ship traffic and personnel are expected to increase as a result of the Buildup, which will also affect commercial traffic (see later sections). Based on recent interviews, the U.S. Navy projects only a modest increase in military ship traffic in Guam post- Buildup. The Navy estimates that approximately (a) 600 vessel movements per year (which includes arrivals, departures, and berth changes) are expected post-Buildup and (b) 65% of these vessel movements are expected to be transient vessels, for which Naval Base Guam is not the home port.

The U.S. Navy is proposing changes to Apra Harbor which would provide berthing capacity for an aircraft carrier. The carrier is expected to visit Guam three to four times a year, staying approximately three weeks each visit, up to a maximum of 63 cumulative days each year (Department of Defense 2010). Munitions operations that involve vessels are also projected to increase by 40 visit days to 315 per year (Department of Defense 2010).

Table 3.2 Typical last ports of call for vessels arriving to Naval Base Guam by vessel type. These are examples of ports visited but are not comprehensive, and vessels do visit additional ports.

Vessel type	Last ports of call
ACT	Philippines, Korea
ACTL (Assault troop carrier)	Kwajalein
AGOR (Oceanographic research)	Taiwan
AOR (Replenishment)	Philippines, Korea, Wake Island
ARS (salvage ship)	Saipan
AS (sub tender)	Saipan, Philippines, Hong Kong
CG (guided missile cruiser)	Japan, Philippines, Hawai'i, Korea, Malaysia
CV/CVN (aircraft carrier)	Japan, Philippines, Korea
DD/DDG (destroyers)	Australia, Japan, Philippines, Hawai'i, Korea, Thailand, Singapore
FFG (guided missile frigate)	Australia, Japan, Philippines, Hawai'i, Singapore, Palau
SSN (nuclear-powered fast attack submarine)	Saipan, Japan, Philippines

Plans for the Buildup include (a) relocation of Marine Corps assets and troops from Okinawa and (b) training exercises on the island of Tinian that involve the deployment of amphibious vehicles from Guam. Aside from what is outlined generally in the DEIS (Department of Defense 2009), we were not able to determine which, if any, specific in-water assets and vessels will be relocated from Okinawa.

With respect to training exercises on Tinian, amphibious task force visits, typically three weeks in duration, are expected to increase from two to four a year. The composition of the amphibious fleet varies with the mission, but may be up to 15 total vessels, typically including three ships carrying personnel, equipment, and the amphibious vehicles, and an escort of four surface combatant ships. Anti-submarine and strike force surface and subsurface vessels may also be included. In addition to these transient ships, the expanded harbor would house 12 AAVs (amphibious assault vehicles), two rigid hull inflatable boats and eight combat rubber raiding craft.

Of the transient ships associated with the amphibious task force, according to the FEIS (Department of Defense 2010), this fleet might travel to Guam from either Okinawa or California before deployment to Tinian, or travel directly to Tinian. More detailed information is not available for the future traffic patterns associated with the additional aircraft carrier, amphibious group, or other vessels associated with Naval Base Guam.

Aside from routine supply and training operations based in Guam and Tinian, such forecasts are undoubtedly difficult (if not impossible), given the shifting background of geopolitical and strategic interests.

3.2 Commercial Cargo Vessels

Guam and Hawai'i are major shipping hubs for commercial vessel traffic in Micronesia (Figure 3.1). Most commercial cargo entering Micronesia from the east or west goes to Guam (see also Section 3.3). Commercial cargo comes to Guam via three major trade routes: U.S. West Coast, Asia, and other foreign ports, and via transshipments within Micronesia.

Most trade routes from the U.S. Mainland to Guam also include Hawai'i. As indicated in Figure 3.1, all regular U.S. West Coast shipping lines to Micronesia stop in Hawai'i before continuing to Guam and west to Asia, returning directly back to the U.S. Mainland. In addition to these major shipping lines, Hawai'i also receives some commercial vessel traffic directly from Micronesia and the surrounding region (Godwin and Eldredge 2001).

Although most commercial vessels arriving to the region come to Guam, movement of cargo by vessels also creates connectivity throughout Micronesia, making it possible for species that occur (or colonize) in Guam to be transferred to other locations. Commercial inter-regional shipping currently follows various routes, and examples include:

1. Guam, Ebeye (RMI), Kwajalein (RMI), Majuro (RMI), Kosrae, Pohnpei (FSM), Chuuk (FSM), Guam
2. Guam, Saipan (CNMI), Yap (FSM), Koror (Palau)
3. Guam, Chuuk, Pohnpei, Kosrae, Guam
4. Guam, Saipan, Rota/Tinian (CNMI)

Although the magnitude of intra-regional transport is not great for commercial vessels, it is highly regular, as indicated here for 2009-2010. Kosrae, Pohnpei and Chuuk received usually two visits a month from Matson vessels traveling on a circuit between FSM and Guam. Port times appear to be extremely short, just a few hours in each location. Kosrae is also connected to Guam via (a) Kyowa Lines, which arrived on about a one-month interval, with some overnight stays, and (b) a fuel tanker, which arrives on a two-month interval. Regular commercial ship traffic to Chuuk also comes from Asian ports: the state received Kyowa vessels, at a rate of about two per month, from the Far East, and a fuel tanker once a month from variable locations including Guam, Majuro, Singapore, and the Solomon Islands. Yap was less directly connected to Guam, with Matson vessels coming from Palau two times a month, and one to two visits per month from Kyowa Lines coming from Hong Kong and Japan. FSM states are further connected by a government run passenger and cargo vessel based in Pohnpei (four to five times per year to Kosrae from Pohnpei) and by federal patrol boats.

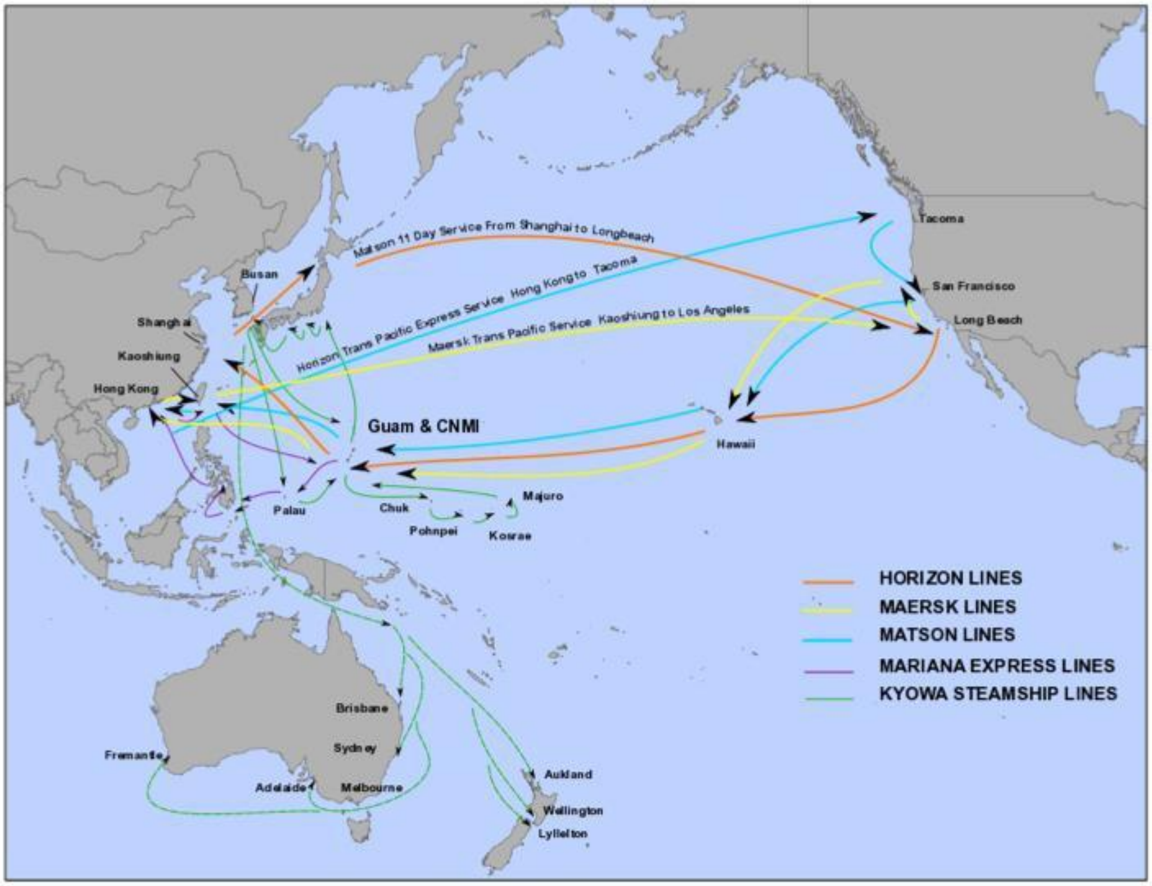


Figure 3.1. Recent commercial ship traffic routes in the region (from FEIS, Chapter 2, Figure 14.1-2; Department of Defense 2010). It is worth noting that not all jurisdictions nor ship routes appear in this image.

From a relative perspective, commercial traffic to most regions of Micronesia includes a strong linkage to Guam. For example, about 80% of the commercial ships arriving in Palau have stopped in Guam during 2009-2010. Palau also receives ships coming directly from Australia and various Asian ports, including oil tankers arriving once a month from Indonesia and the Philippines. A barge travels regularly between Palau and Yap, indicating a further level of intra-regional connectedness, independent of Guam.

The relative magnitude of commercial vessel traffic and connectivity is examined in greater detail in the next section (Section 3.3), based on past data, but future changes in traffic patterns are challenging to predict. In recent years, the number of commercial ships of all types calling at the Port of Guam has declined (PB International 2008). Commercial cargo ships (container ships and break-bulk/roll-on, roll-off (RoRo)/bulk) declined from 445 visits in FY 2003 to 353 in FY 2009 (Figure 3.2). However, the volume and nature of commercial ship traffic and perhaps routes will be affected by the Guam Buildup, and these effects are likely to differ during the Buildup and post-Buildup phases.

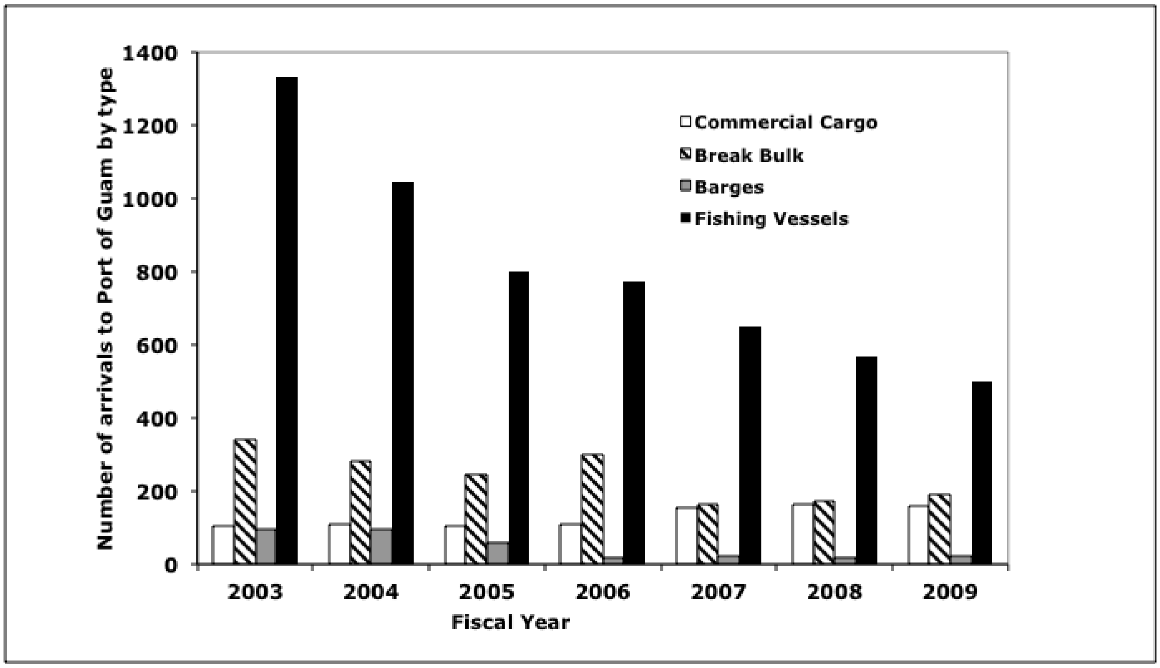


Figure 3.2. Number of commercial ship visits by vessel type to the Port of Guam per fiscal year. Data provided by the Port of Guam.

Guam cannot supply sufficient materials or labor for the construction phase. Thus, imports of construction materials, equipment, and supplies are expected to increase rapidly as the Buildup proceeds. Although information about the source of construction materials was not available, approximately 50% of the materials are expected to come from Asia (PB International 2008), but the sources are also likely to be strongly affected by market prices and other forces, which are dynamic. Thus, shipping imports associated with construction are likely to differ (both in geographic source and quantity) from historical patterns.

In addition to construction materials, the Buildup phase will require a significant and temporary increase in civilian workforce. Imports of household goods, food, and other commodities will increase to support those working on the Buildup. The source(s) of the temporary workforce will affect the geographic origin of shipped goods. While household goods may move along established shipping routes, demand for particular types of goods may shift according to geographic origins and customs of the workforce, having potential consequences for the trade of live organisms associated with food and pets (see Chapter 4 for further discussion).

Published projections for commercial shipping through 2018 predict a peak in the number of commercial container ship arrivals at 269 visits to Guam in 2015 (Table 3.3), during peak construction, slightly more than double the average number for 2003-2009 (see Department of Defense, 2009, Volume 4). An estimated 532 arrivals for break-bulk and RoRo ships are predicted during peak construction, slightly less than double the average annual number for 2003-2009. An additional 150 vessel trips by tugboats (tugs) and scows are anticipated over an eight to 18 month period during peak construction, compared to previous baseline traffic.

Across these vessel types, total additional commercial ship visits could increase by as much as 537 in a peak year, driven by the large pulse in construction materials and equipment delivered by break-bulk and RoRo vessels.

In the post-Buildup phase, following the pulse of construction and associated personnel, the number of commercial ship arrivals is expected to form a new baseline that is above recent (2009-2010) pre-Buildup levels. This overall increase in shipping reflects an increase in demand for goods, related to a projected increase in population size.

Table 3.3. Projected changes in number of commercial ship arrivals to the Port of Guam by vessel type. Data from FEIS (Department of Defense 2010; Volume 2, Tables 14.2-2 and 14.2-3-3).

Year	Container ships	Break-bulk/RoRo Ships	Total
2011	211	450	661
2012	244	532	776
2013	252	519	771
2014	258	507	765
2015	269	262	531
2016	255	199	454
2017	215	204	419
2018	207	206	413

From 2006-2009, barge traffic has been relatively infrequent at the Port of Guam, with 20 or fewer barges calling at the port each year (Figure 3.2). As recently as 2004, however, barge traffic had been significantly higher, with more than 100 such vessels arriving in port. Projections for barge traffic are not available in port documents, but it is reasonable to assume that the number of these vessels will increase along with other commercial ships during the Buildup.

Outside of Guam, with the possible exception of Saipan, it appears that other locations in Micronesia are not anticipating an increase in commercial shipping as a direct result of the Buildup, based on meetings and discussions with local management agency personnel. In Saipan, port officials have been approached by shipping concerns inquiring whether the port could accommodate vessels, should there be a back-up in unloading cargo to Guam during the Buildup. While it appears that Majuro hopes to increase its transshipping business in the near future, making better use of an underutilized container yard, we were unable to identify a specific plan for this activity in association with the Buildup.

3.3 Regional Comparison of Vessel Traffic and Geographic Connectivity

While previous documents on the Guam Buildup have focused some attention on the possible effects of shipping traffic to individual locations, and especially Guam (as above), it is of particular importance from a biosecurity perspective to also consider overall regional traffic patterns and connectivity. The first two sections (Sections 3.1 and 3.2) describe some of the linkages that exist among ports, in terms of vessels that move from one port to another, creating opportunities for species transfers to occur. Here, we expand upon this treatment and formally evaluate (a) the number of vessel arrivals to ports in Micronesia by vessel type, (b) the number of vessel visits to each country in Micronesia, (c) the last port of call (LPOC) and next port of call (NPOC) for vessels arriving to Micronesia, (d) the flux (number) of vessels that move among paired ports in Micronesia (and in both directions between Micronesia and Hawai'i) and (e) the reported ballast water discharge volumes for vessels arriving to Guam and also those moving from Guam to other regions of the U.S.

This regional analysis focuses primarily on commercial and MSC vessels, for which sufficient data could be obtained; the necessary data for similar analysis of other U.S. Navy ships (e.g., combatants) were not made available, as noted previously (see Chapter 1, Section 1.2). Throughout this section, only the direct links among ports and regions were evaluated, including LPOC and NPOC. Because vessels can often visit many ports with the potential to accumulate organisms, both on the hulls and in ballast tanks, indirect links among ports can also be important sources for invasions and are considered further in Chapter 5.

3.3.1 Sources of Data and Methods for Analyses

To characterize regional vessel traffic, data were collected and compared from multiple sources, as follows:

1. Data were obtained from Lloyds List Intelligence for commercial vessel arrivals to Micronesia over a 10-year period (1999-2009). For each unique vessel arriving to the region in Lloyds' database, an extensive synthesis of information concerning vessels and

maritime traffic on a global scale, we requested a complete history of all ports of call (globally) within this time period, including dates of arrival and departure.

2. Similar data were requested and obtained for MSC vessels arriving to Guam during the same time period.
3. For vessels that reported ballast water information to the National Ballast Information Clearinghouse (NBIC) (see Chapter 2 for description), we obtained (a) records of arrivals to Guam and CNMI, (b) records of ballast water discharge to Guam, and (c) records of ballast water discharge to U.S. ports for water aboard vessels that originated in Guam.
4. For vessels arriving to Guam and the Northern Marianas Islands, we obtained arrivals data reported to USCG National Vessel Movement Center (NVMC).

Each of these data sources provided individual vessel identification numbers, which could be used to identify unique vessels and subsequent vessel movements. These datasets were used to create a single synthetic dataset of unique vessel arrivals to Guam and other jurisdictions of Micronesia, and their voyage histories (ports of call) both before and after calling on Micronesia. This dataset provided the basis for analysis presented here for arrivals and direct linkages (LPOC and NPOC) of vessels calling on Micronesia; the scope of this analysis is expanded in Chapter 5 to also consider indirect linkages, based on these voyage histories over a multi-year time horizon.

Additional information was available for fishing vessels, which were excluded from this analysis. In particular, the Lloyds dataset contained some data on fishing vessels. This was combined with data from multiple ports throughout Micronesia, to estimate flux (number of arrivals) for fishing vessels that is presented below in Section 3.5. In many cases, LPOC and NPOC data were not available for fishing vessels, limiting the extent of analysis to flux measures (i.e., arrivals to a port) and preventing a broader consideration of geographic linkages such as the one presented for commercial and MSC vessels.

3.3.2 Unique Vessels Visiting Micronesia

Based on a synthesis of available datasets, 461 unique commercial vessels and 123 unique MSC vessels were identified with a record of arrival to Micronesia during the 11- year time period (Figure 3.3). As noted previously, the U.S. Navy would not provide unique vessel identifications (or voyage histories) for vessels other than MSC due to security restrictions, so it is not possible for us to provide a comparable estimate for the number of unique surface combatants or other U.S. military vessels visiting Micronesia.

Figure 3.3 also indicates the number of unique vessels found in each of the four respective datasets, which were compared to create a synthetic dataset for further analyses. As illustrated for commercial vessels (top panel), no single dataset had a comprehensive record of arrivals, so a combination of the four datasets provided a more complete record than any individual dataset. In contrast, the MSC dataset is thought to provide nearly a complete record of MSC vessel arrivals to Micronesia, and the other sources listed in Section 3.3.1 were used to fill in some gaps in voyage histories for these vessels.

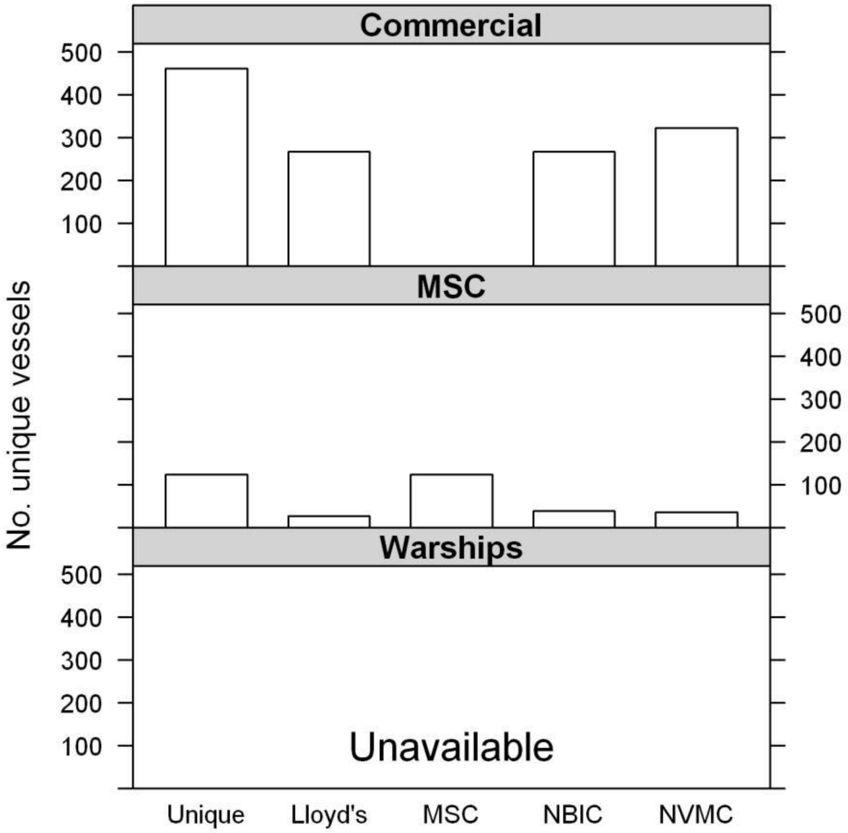


Figure 3.3. Number of unique vessels reported to have visited Micronesia from 1999-2009, according to data source. On the x-axis, "Unique" indicates the total number of unique vessels, based on synthesis and comparison across data sources (Lloyds, MSC, NBIC, NVMC; see text). Also shown for each data source is the number of unique vessels reported. Comparable data were not provided by DoD for warships (Navy vessels other than MSC).

We emphasize that neither synthetic dataset for commercial or MSC vessels is likely to be comprehensive, in terms of unique vessels, arrivals, or voyage histories. There is no clear way to verify or assess the percentage of all vessels included. Moreover, it is evident that vessel arrivals were missing from each dataset, suggesting the synthetic datasets are also likely to include omissions. For this reason, the information presented here and throughout should be considered a minimum estimate of vessel arrivals and connectivity among ports.

3.3.3 Vessel Flux for the Micronesian Region

The number of unique vessels is a useful measure to consider from a management and policy perspective, especially considering any possible future efforts to implement management actions or outreach, but the vessel arrival events are the operative measures from an invasion perspective. Each arrival event presents a potential opportunity for species transfer, and each arrival has a unique set of environmental and biological conditions that affect whether species can survive and spread. Even the same individual vessel arriving at different points in time will have a unique history of recent port visits and voyage conditions, husbandry or management conditions, and therefore a unique set of potential associated biota.

Figure 3.4 shows the mean number of arrivals per year to ports in Micronesia for each of three vessel types, based on available data (see Section 3.3.1). Commercial vessels accounted for 70% of reported arrivals to Micronesia, whereas the remaining 30% were attributed to MSC vessels (20%) and additional U.S. Navy and other military vessels (10%). This estimate includes each arrival to a port in Micronesia, regardless of LPOC; intra-regional flux (or traffic among ports within Micronesia) is addressed separately below (see Section 3.3.5).

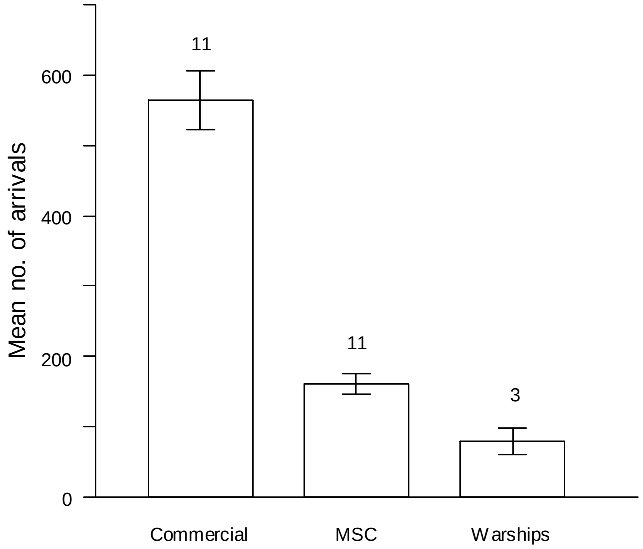


Figure 3.4. Annual mean (± standard error) for number of arrivals to Micronesia by vessel population. The number of years of data is indicated above each bar; commercial ships and MSC data are from 1999-2009, while the warships are from 2008-2010.

3.3.4 Vessel Flux into the Separate Countries within Micronesia

For commercial vessels, Guam had the largest number of arrivals for ports in Micronesia, with an average of 374 arrivals/year reported from 1999-2009 (Figure 3.5A), including vessels arriving from LPOCs both within and outside of Micronesia. This accounted for 66% of the commercial arrivals that we were able to document for the region during this time period. The second largest number of commercial arrivals was to CMNI (Figure 3.5A), with 26% of the average annual traffic for the region. Thus, Guam and CNMI account for > 90% of commercial vessel arrivals recorded in our dataset (see Section 3.3.1).

A similar pattern was observed for MSC vessel traffic, with over 90% of average annual arrivals in Micronesia recorded in Guam and CNMI over the same time period (Figure 3.5B). The relative contribution of arrivals to CNMI (~34% of total annual flux for MSC in the region) was slightly higher than that for commercial vessels (26%), during the same time period, as seen in comparison of Figure 3.5A and B.

A comparable analysis of vessel flux was not possible for other types of U.S. Navy vessels (or other military vessels), since we did not have access to data on arrivals or transit histories. Thus, beyond vessels operated by MSC, military vessels are excluded here and from subsequent analyses in this chapter, representing an information gap for vessel traffic associated with the Guam Buildup and Micronesia overall.

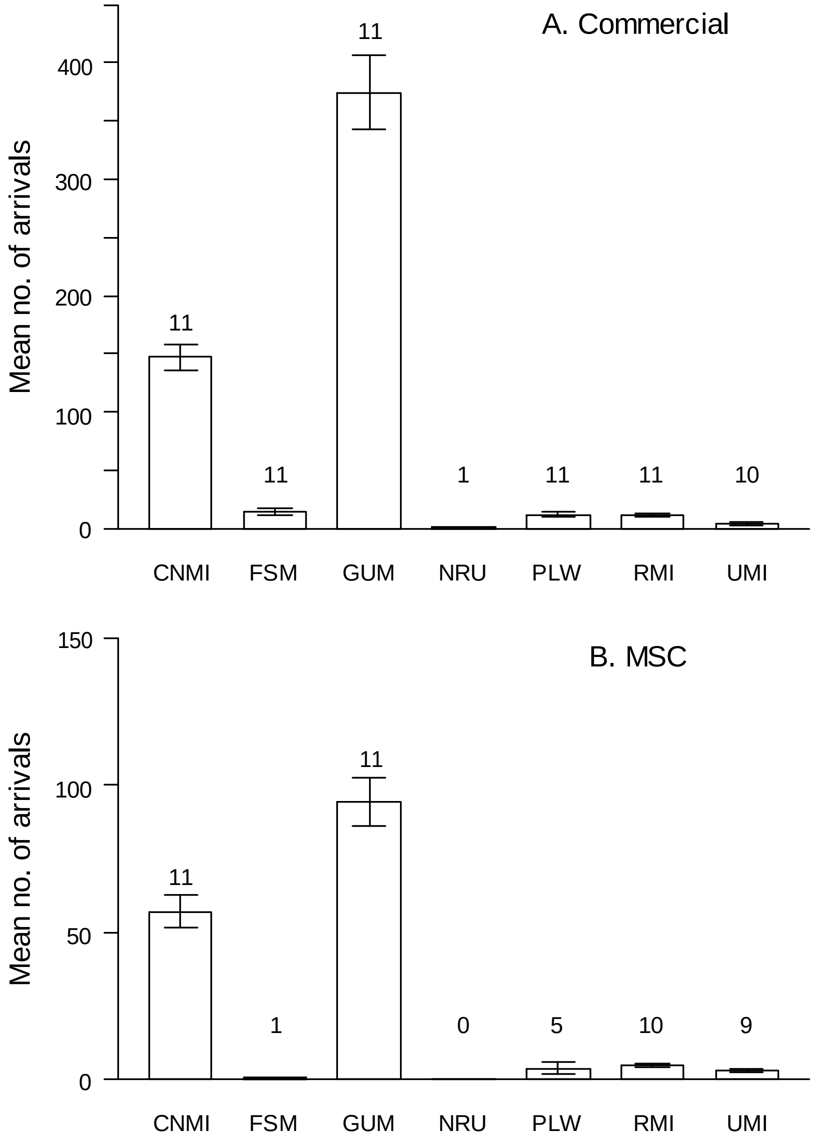


Figure 3.5. Annual mean (± standard error) number of arrivals for different regions of Micronesia for (A) commercial vessels and (B) MSC vessels. Shown are: Commonwealth of Northern Mariana Islands (CNMI), Federated States of Micronesia (FSM), Guam (GUM), Republic of the Marshall Islands (RMI), Nauru (NRU), Republic of Palau (PLW), and the U.S. Minor Outlying Islands (UMI). The number of years of data is indicated above each bar [Note: Only years for which arrivals were reported are included in the mean estimates for each country. Thus, overall mean arrivals for the entire 11-year period would be lower for those countries with fewer years of reported arrivals.]

3.3.5 Vessel Transit Histories

Across the entire 11-year time period, we documented 7,973 vessel arrivals to ports in Micronesia, including commercial and MSC vessels. MSC vessels represented 22% of the total arrivals. The distribution of these arrivals among countries is shown in Figure 3.6 (top panel). As expected from the previous section, the majority of arrivals for each commercial and MSC vessels occurred in Guam and CNMI.

We were able to document some portion of the previous voyage histories for most MSC and commercial vessel arrivals (see Section 3.3.1 for sources). Figure 3.6 (bottom panel) shows the percentage of arrivals to each country for which voyage history was available, according to type (extent) of historical data. Across all countries: (a) LPOC was available for ≥ 99% of arrivals of each vessel type; (b) NPOC was available for a smaller subset of MSC arrivals (94%) and commercial arrivals (84%); and (c) data on additional ports of call, or transit history, were available for 74% of commercial vessels and 97% of MSC vessels.

The sections below present an analysis to examine connectivity among ports, using these data for LPOC and NPOC. Although some additional transit information was obtained for most vessel arrivals, it is difficult to evaluate its completeness. One measure of completeness may be the temporal extent of records, which is < 100 days for 10-20% of arrivals. Analysis in Chapter 5 evaluates this extended transit history information, considering indirect connections (i.e., those ports visited beyond simply LPOC and NPOC). Characterizations of connectivity presented here and in Chapter 5 should be considered minimum estimates, because data on direct and indirect linkages are not available for all vessels that arrived in Micronesia.

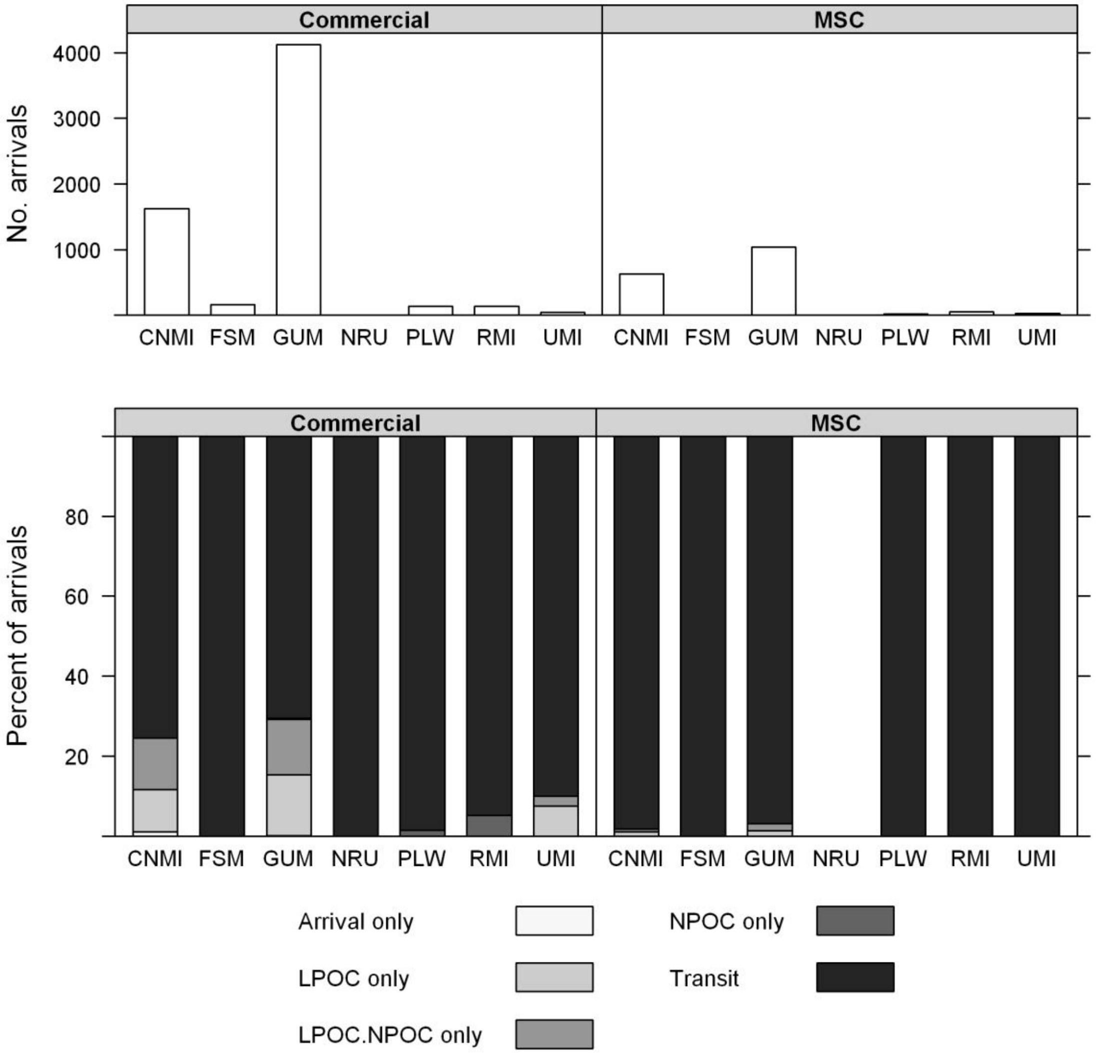


Figure 3.6. Data used in connectivity analyses of Micronesia and Hawai'i. Shown for each commercial and MSC vessel arrivals to Micronesia are (A) total number of arrivals by the country and (B) percentage of arrivals to each country with associated data on vessel transit history. Categories of vessel history types are: arrival record only; last port of call (LPOC) only; next port of call (NPOC) only; LPOC and NPOC only; extended transit history that includes additional ports beyond LPOC and NPOC.

3.3.6 Last and Next Ports of Call for Vessel Arrivals to Micronesia

Figures 3.7-3.10 show the geographic distribution of LPOC and NPOC of arrivals to Micronesia for each commercial and MSC vessel, from 1999-2009, indicating the connectivity that exists with specific geographic regions or countries around the globe. Overall, most connections for both vessel types were with Asia and the western U.S. As expected from above, Guam had the largest number of arrivals. For both MSC and commercial vessels, Guam was also connected to the largest number of ports (for both LPOC and NPOC). Finally, the extent of vessel traffic that connects Guam to other parts of Micronesia, as well as Hawai’i, is evident for both MSC and commercial vessels.

A more detailed view of connectivity for vessel traffic within Micronesia, and between Micronesia and Hawai’i, is presented in Figures 3.11 and 3.12 (for commercial and MSC vessels, respectively). As expected from previous maps, Figures 3.11 and 3.12 illustrate the strongest connections (in terms of vessel arrivals) were between Guam-Hawai’i and Guam-CNMI, for traffic moving in both directions between these locations. This pattern existed for both the commercial and MSC vessel traffic. In addition, commercial vessels exhibited relatively strong linkages between Guam-Palau, Guam-FSM, and Hawai’i-UMI (Figure 3.11).

Thus, both commercial and MSC vessels showed strong linkage between Guam-Hawai’i, with connectivity throughout Micronesia, illustrating the magnitude of vessel flux and the potential opportunity for ship-mediated species transfers to occur associated with biofouling (of hulls) or ballast water from these vessels. It should be noted that the scale differs between the two figures, and there is more commercial than MSC traffic overall.

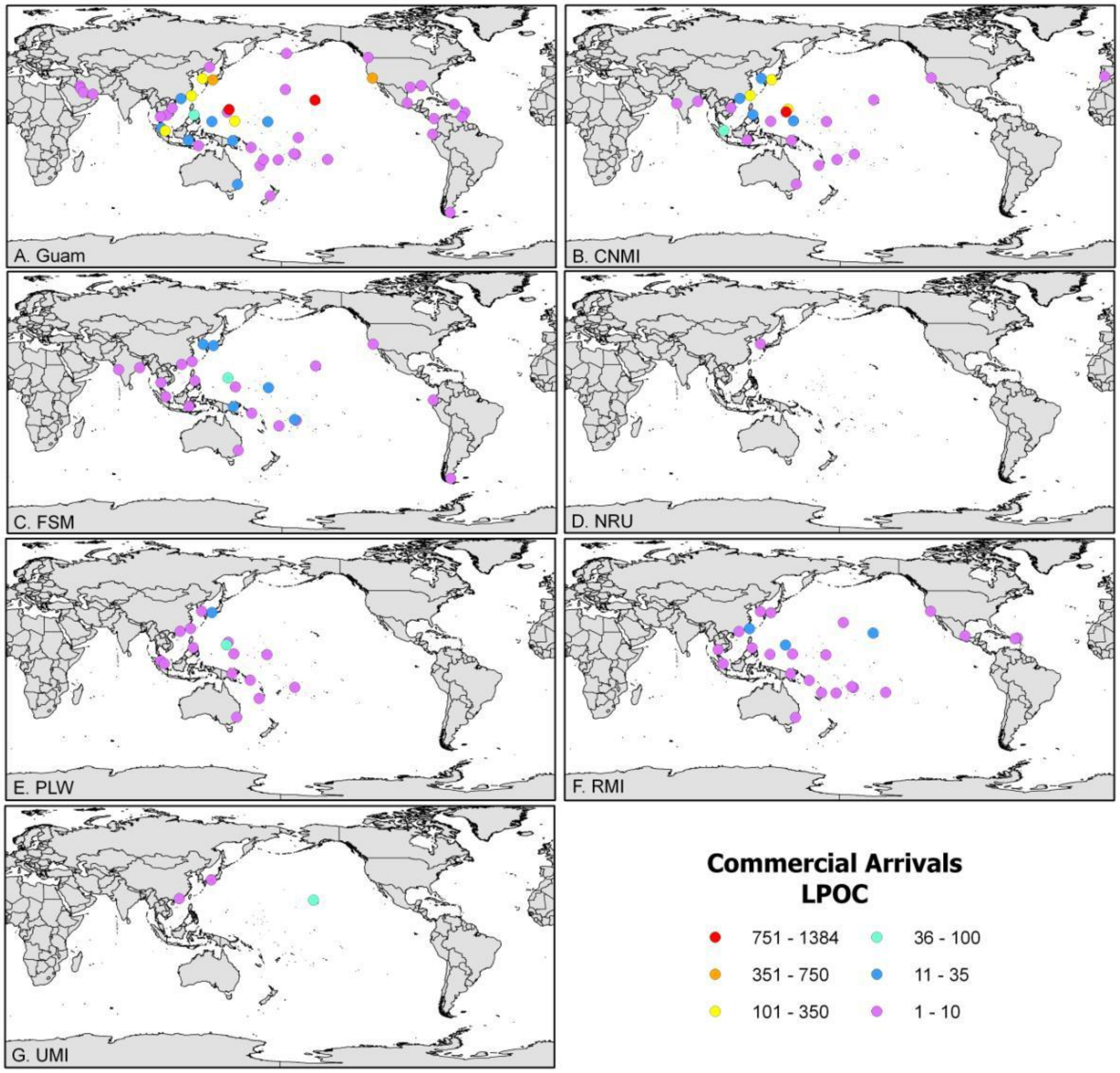


Figure 3.7. Last port of call (LPOC) of commercial vessel arrivals between 1999-2009 to different countries and states in Micronesia. Shown are: A. Guam, B. Commonwealth of Northern Mariana Islands (CNMI), C. Federated States of Micronesia (FSM), D. Nauru (NRU), E. Republic of Palau (PLW), F. Republic of the Marshall Islands (RMI), and G. U.S. Minor Outlying Islands (UMI).

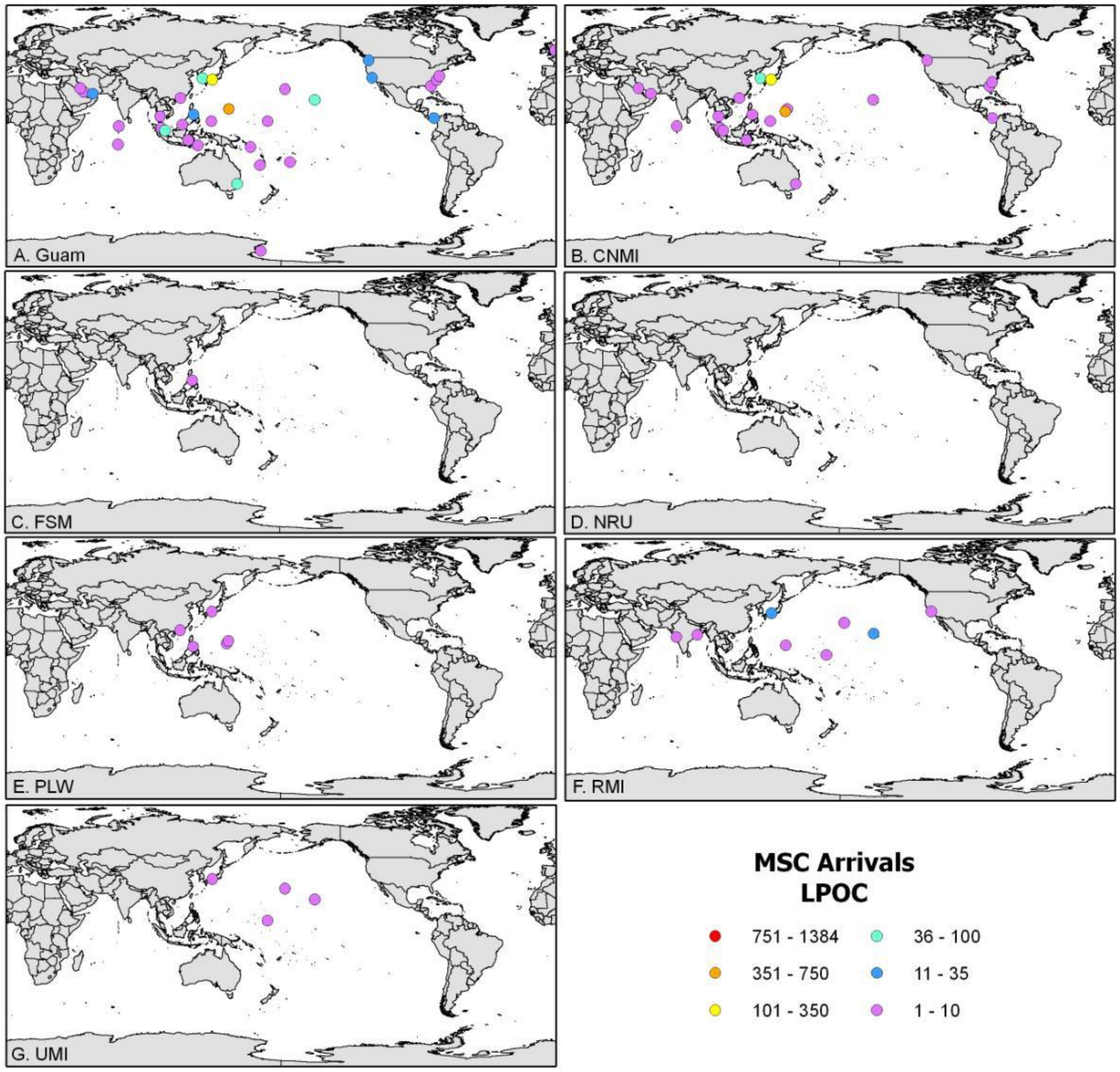


Figure 3.8. Last port of call (LPOC) of MSC vessel arrivals between 1999-2009 to different countries and states in Micronesia. Shown are: A. Guam, B. Commonwealth of Northern Mariana Islands (CNMI), C. Federated States of Micronesia (FSM), D. Nauru (NRU), E. Republic of Palau (PLW), F. Republic of the Marshall Islands (RMI), and G. U.S. Minor Outlying Islands (UMI).

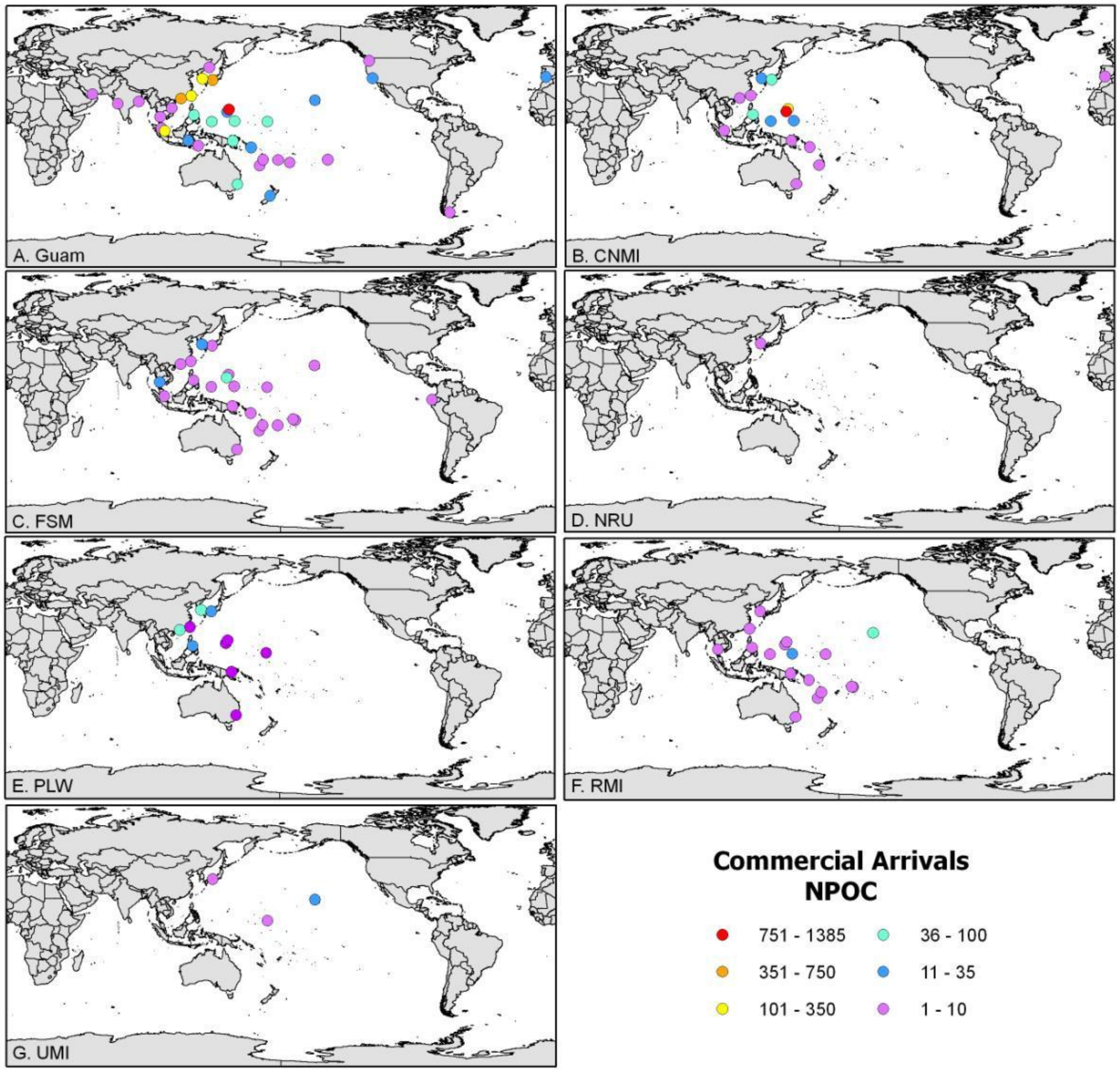


Figure 3.9. Next port of call (NPOC) of commercial vessel arrivals between 1999-2009 to different countries and states in Micronesia. Shown are: A. Guam, B. Commonwealth of Northern Mariana Islands (CNMI), C. Federated States of Micronesia (FSM), D. Nauru (NRU), E. Republic of Palau (PLW), F. Republic of the Marshall Islands (RMI), and G. U.S. Minor Outlying Islands (UMI).

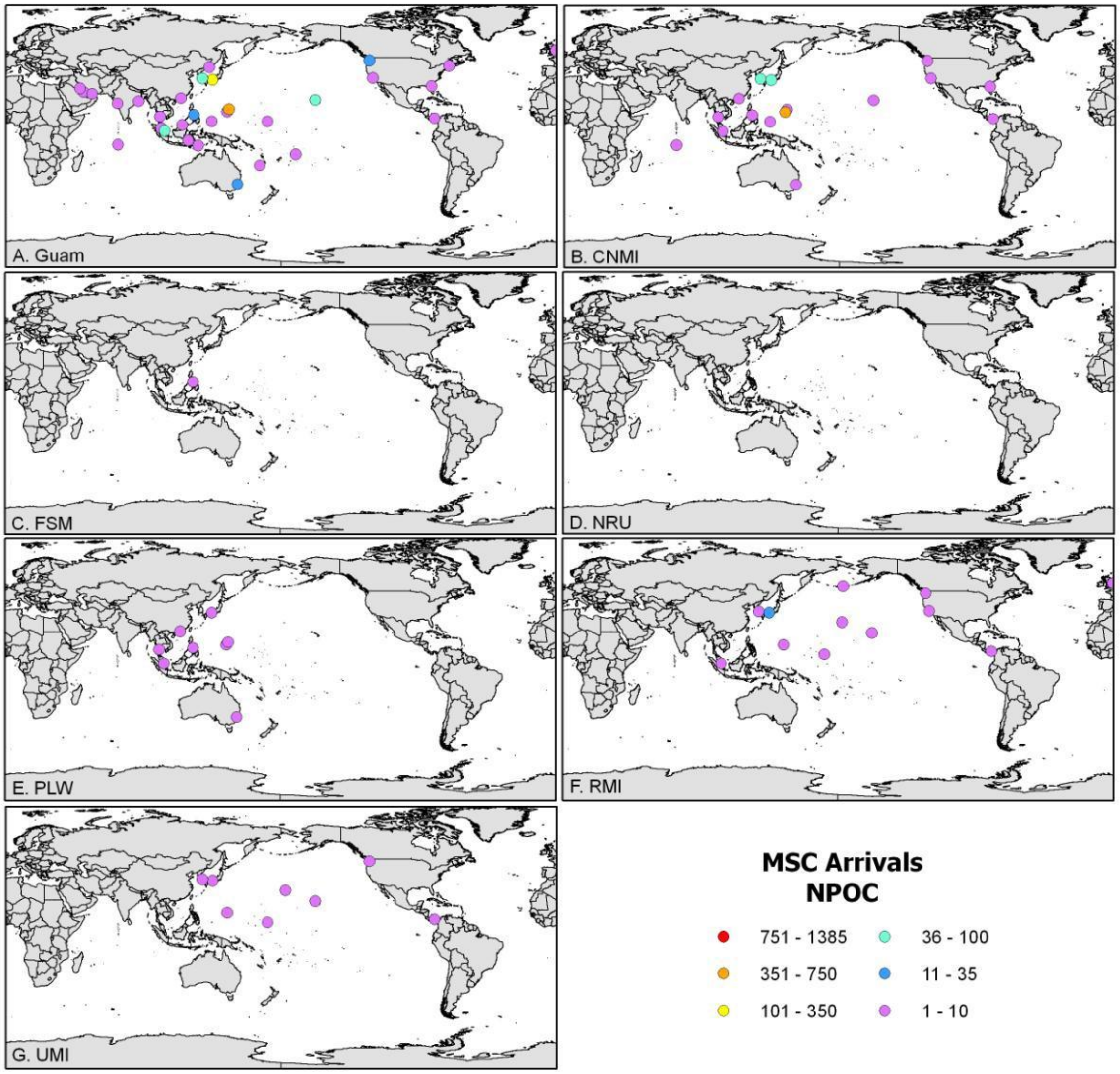


Figure 3.10. Next port of call (NPOC) of MSC vessel arrivals between 1999-2009 to different countries and states in Micronesia. Shown are: A. Guam, B. Commonwealth of Northern Mariana Islands (CNMI), C. Federated States of Micronesia (FSM), D. Nauru (NRU), E. Republic of Palau (PLW), F. Republic of the Marshall Islands (RMI), and G. U.S. Minor Outlying Islands (UMI).

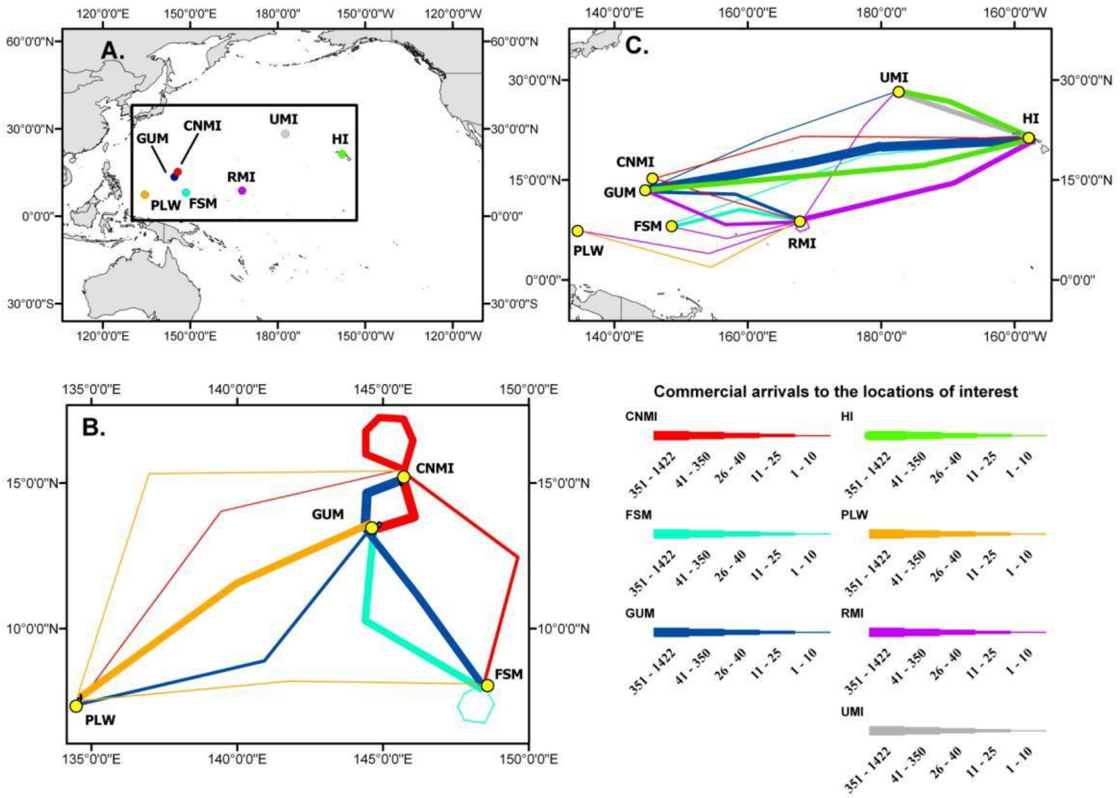


Figure 3.11. Maps showing the connectivity (number of arrivals) of Micronesia, Guam and Hawai'i resulting from commercial ship traffic. A) Color coding associated with the ports of arrival. B) Connectivity between Guam (GUM), the Federated States of Micronesia (FSM), the Commonwealth of the Northern Mariana Island (CNMI), and Palau (PLW). C) All arrivals to and from Hawai'i (HI), the Republic of the Marshall Islands (RMI), and the U.S. Minor Outlying Islands (UMI). In these figures, color denotes the destination port (as shown in panel A), and the width of line is scaled to the number of arrivals from the connected port. For example, the dark blue line between CNMI and Guam indicates the number of vessel arrivals to Guam from the Northern Marinas Islands (as LPOC). In contrast, the red line connecting these locations indicates traffic that originates in Guam and arrives to CNMI.

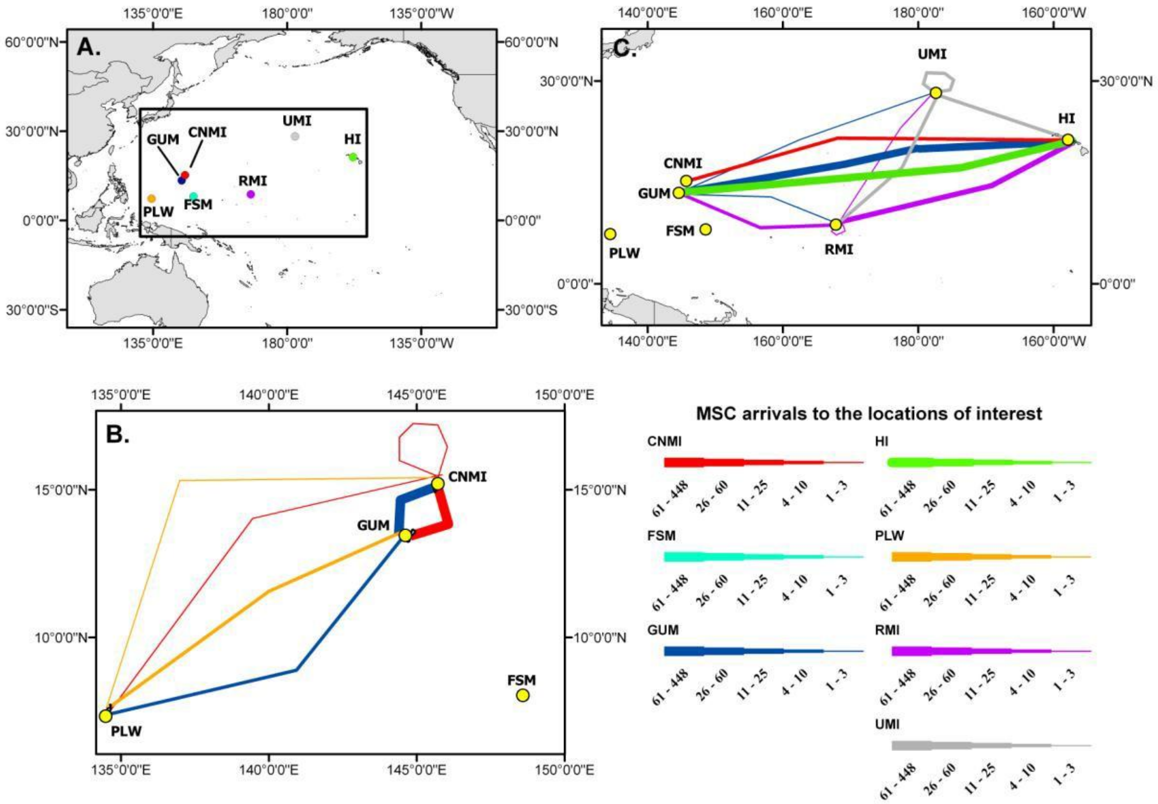


Figure 3.12. Maps showing the connectivity (number of arrivals) of Micronesia, Guam and Hawai'i resulting from MSC ship traffic. A) Color coding associated with the ports of arrival. B) Connectivity between Guam (GUM), the Federated States of Micronesia (FSM), the Commonwealth of the Northern Mariana Island (CNMI), and Palau (PLW). C) All arrivals to and from Hawai'i (HI), the Republic of the Marshall Islands (RMI), and the U.S. Minor Outlying Islands (UMI). In these figures, color denotes the destination port (as shown in panel A), and the width of line is scaled to the number of arrivals from the connected port. For example, the dark blue line between CNMI and Guam indicates the number of vessel arrivals to Guam from the Northern Marinas Islands (as LPOC). In contrast, the red line connecting these locations indicates traffic that originates in Guam and arrives to CNMI.

3.3.7 Ballast Water Flux Associated with Guam and the Northern Mariana Islands

Records exist for the discharge of 365,904 metric tons of ballast water to Guam between 2005-2009 for commercial and MSC vessels. Figure 3.13 shows the volume of this ballast water as a function of vessel type, geographic source region, and whether it was reportedly managed (treated by ballast water exchange) prior to discharge. As discussed in Chapter 2, most vessels do not discharge ballast water upon arrival, and information is available for only a subset of arrivals. The available data provide a minimum estimate for ballast volume discharged to Guam from various source regions and illustrate that some of this water was reported to be untreated.

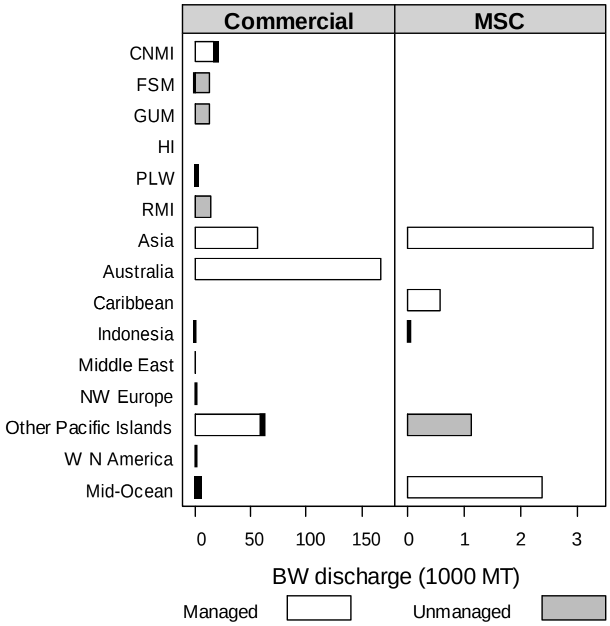


Figure 3.13. Source regions and volume of ballast water reported to USCG as discharged in Guam by commercial and MSC vessels, 2005-2009. Total volumes are shown in thousands of metric tons (MT) as a function of source and management (i.e., whether water was reported to be treated with ballast water exchange or not). The specific source regions of interest include the Commonwealth of Northern Mariana Islands (CNMI), Federated States of Micronesia (FSM), Guam (GUM), Hawai'i (HI), Republic of the Marshall Islands (RMI), and the Republic of Palau (PLW).

In similar fashion, Figure 3.14 shows data available for ballast water discharge to CNMI. Although many ships did not report information, the available data suggest a relatively small volume is discharged in this country. It is noteworthy that the small volume of ballast that originated in Guam was untreated, indicating than an occasional transfer of coastal organisms entrained in ballast tanks from Guam to CNMI may occur without any management to reduce concentrations (see Chapter 2 for discussion).

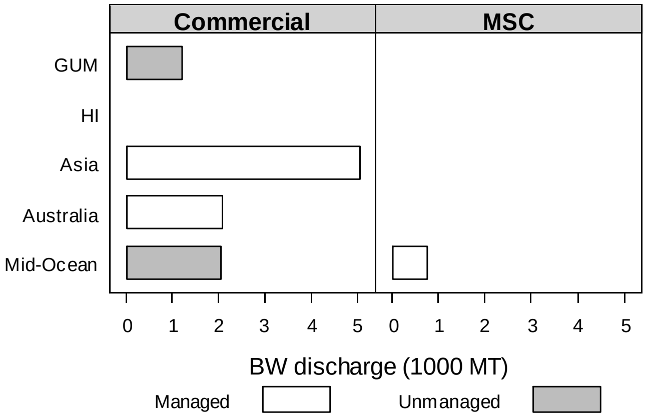


Figure 3.14. Source regions and volume of ballast water reported to USCG as discharged in the Commonwealth of the Northern Mariana Islands by commercial and MSC vessels, 2005-2009. Total volumes are shown in thousands of metric tons (MT) as a function of source and management (i.e., whether water was reported to be treated with ballast water exchange or not).

Figure 3.15 summarizes the data reported to USCG on ballast water discharged in the U.S. that originated in Guam and the Northern Mariana Islands. The largest reported volume is from MSC vessels, which reported discharge from Guam to Hawai'i and Puget Sound, Washington. All reported discharge was treated, although treated water may still contain coastal organisms (see Chapter 2 for further detail). Also, as noted throughout, this represents a minimum estimate, as only a fraction of MSC vessels appear to submit reports to USCG (as discussed in Chapter 2).

3.4 Barges

Barge traffic in Guam and Micronesia appears to be highly dynamic, making it particularly difficult to project traffic for future planning purposes. At the same time, barges may pose unique and relatively high risks with respect to transfers of non-native species, both as novel introductions into Micronesia and spreading non-native species within the region, due to the nature of their operation. Here, some of the key issues and uncertainties are highlighted for marine biosecurity associated with barges.

While included in the above analysis of regional traffic patterns, it is evident that fewer barge arrivals to Guam were reported or recorded in the broad-scale datasets used in this analysis (see Section 3.3.1) than were reported by the Port of Guam, suggesting that we have underestimated the magnitude of this traffic. In addition, barge traffic has been low in recent years, with as many as 100 barge arrivals reported to the Port of Guam in 2004 (as noted earlier; see Figure 3.2). We should expect barge traffic to Guam to increase, due to increased importation of materials and increased local activity (e.g., dredging, construction) surrounding the Buildup. The source(s) of these barges are not presently known, nor are the associated husbandry practices. Based upon interviews with DoD personnel, it appears likely that the geographic source of barges, their movement, and any associated biosecurity measures will be determined by contractors.

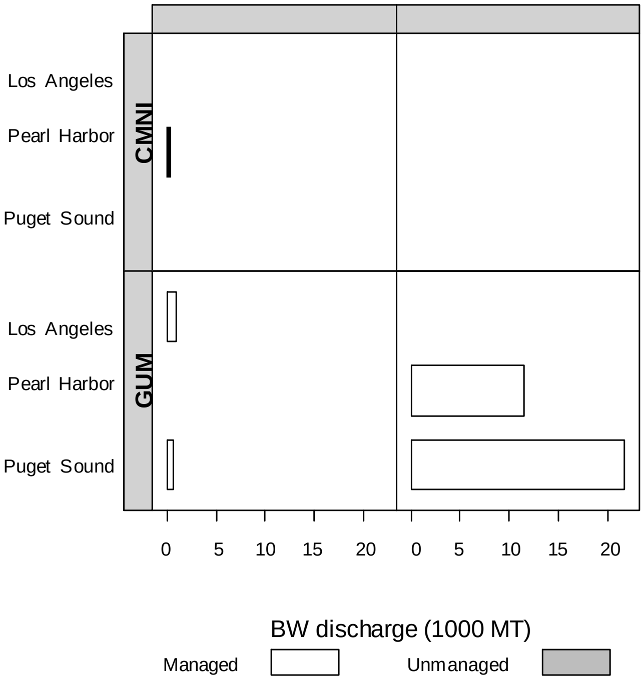


Figure 3.15. Ballast water discharge reported to USCG that originated in the Commonwealth of the Northern Mariana Islands (CNMI) and Guam (GUM) to other ports of the U.S., 2005-2009. Total volumes are shown in thousands of metric tons (MT) as a function of vessel type (commercial versus MSC), geographic recipient, and management (i.e., whether water was reported to be treated with ballast water exchange or not).

In general, barges can have a relatively high potential for transfer of marine species, because of their mode and tempo of operation. These vessels often have long residence times in a particular port or region, residing in shallow and productive waters, compared to a commercial vessel that is in transit and has shorter residence times in port. When barges are moved to new locations, the travel speed is relatively slow. As outlined in Chapter 2, the extent of biofouling is expected to increase with long residence times in port and slow vessel speeds when underway, when controlling for other factors (e.g., husbandry practices). Moreover, long residence time after arrival at a new location can increase the probability that the associated fouling organisms reproduce and colonize the recipient region.

There are several examples of extensive biofouling communities and non-native organisms associated with such slow-moving vessels (Coutts 2002; Coutts et al. 2010a; Hopkins and Forrest 2010), underscoring the biosecurity risks for barges brought into Guam. In an example from the region, a barge from China was brought in as a temporary bridge between Babeldaob and Koror in Palau. The barge did not have antifouling paint and apparently introduced at least one species, a hydroid, to Palau (Colin 2009).

Of additional concern is the potential use of these particular barges and associated construction equipment in other jurisdictions of Micronesia. Once in the region, there may be economic incentives to use such vessels and equipment for projects (e.g., dredging or construction) in other parts of Micronesia, creating the potential for intra-regional transfers of any associated organisms.

Beyond the Guam Buildup, several locations are or have been recently engaged in major construction projects such as roadway expansions/repairs (Chuuk, Yap and Palau) and airport expansions (Pohnpei and Majuro). Pohnpei anticipates that a foreign vessel will be used for its planned harbor dredging. If countries in the region responded to the increased population on Guam with increases in these types of projects, risk associated with this vector could also increase.

Another area of potential concern is a proposed plan to use Pagan Island in the Northern Marianas as a dumping site for debris from the March 2011 Japan tsunami. The proposal put forth by Japanese investors would involve bringing in vessels with tons of tsunami debris to Pagan, and bringing out mined volcanic ash (pozzolan) from the island for use in cement industry. Presumably, slow moving barges would be used for the transport of debris and pozzolan to and from Pagan. Implementation of the plan would furthermore require the construction of a seaport for docking vessels. All these activities could facilitate the establishment of invasive biofoulers originating from Japan. The Pagan dumpsite proposal first made the news in the second quarter of 2012 (Eugenio, 2012). There seem to be no recent updates on the status of the proposed plan, nor of the likelihood that the plan will push through.

While we provided recommendations to DoD in early 2011 to include biosecurity guidelines for barges associated with contracts and construction in Guam, to minimize the probability of marine invasions, it is also evident that barges pose significant risks in other parts of Micronesia, independent of DoD activities. Aggregate, loaded on barges, typically comes to Micronesia from China, Taiwan, and the Philippines. Rather than unloading in port, it appears to be common practice for barges to sit in harbors for long periods, with aggregate removed as needed (Figure 3.16).

Figure 3.16. A barge from the Philippines loaded with aggregate sits in Yap's harbor.

3.5 Fishing Vessels

Historically, Guam and Palau have had the most commercial fishing vessel arrivals in the region. Figure 3.17 shows the average number of arrivals per year for various parts of Micronesia, as provided by the respective regions, Lloyds, NVMC, and NBIC. However, based on discussions with local ports and resource managers, it appears that additional vessels arrive that do (a) come into port and (b) report arrivals to local authorities. Thus, as with commercial cargo vessels, the data presented represent a minimum estimate of actual arrivals.

The number of fishing vessels reported to visit Guam has declined significantly over the past several years. According to port statistics, visits by commercial fishing vessels have declined steadily from 1,332 in 2004 to 499 in 2009 (see Figure 3.3). This decline may be due at least in part to the Shark Finning Act of 2000, which prohibits vessels from countries engaged in shark finning from transshipping through Guam. In addition, there appears to have been a major shift in tuna fishing activities, moving away from Guam. Most other locations in Micronesia have also experienced a downturn in recorded fishing vessel visitation.

Although owned by foreign concerns, most fishing vessels in the region tend to fish within state or territory waters and return to local home ports, and thus represent little risk of non-native species transfer. However, in Palau, many vessels in the “local” fleet return home to Taiwan or the Philippines for New Year celebrations, staying away for a month or longer. These vessels are likely to be colonized by fouling organisms while abroad, especially given the relatively long residence times, having the potential to transport non- native species to Palau upon return. Fishing vessels based in foreign ports including Taiwan, China, Japan, Korea and Papua New Guinea also arrive to all Micronesian ports, including large “mother ships,” which take off-loaded catch from the locally based fleet (Figure 3.18). To our knowledge, the extent or composition of biofouling on fishing vessels arriving from outside of Micronesia has not been characterized, so the magnitude of any associated species transfers is unknown at the present time.

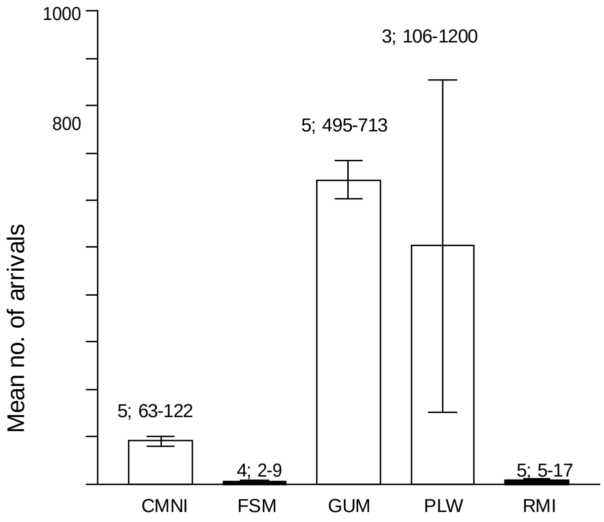


Figure 3.17. Annual mean (± standard error) for number of fishing vessel arrivals to countries in Micronesia. Shown are arrivals for Commonwealth of Northern Mariana Islands (CNMI), Federated States of Micronesia (FSM), Guam (GUM), Republic of the Marshall Islands (RMI), and the Republic of Palau (PLW). Above each bar the number of years of available data is indicated, followed by the range (minimum-maximum) in total number of annual arrivals reported per year.

Figure 3.18. A large fishing vessel at mooring in Pohnpei.

Despite a lack of available data, there is certainly a perception within Micronesia that many foreign fishing vessels may be significant sources of both marine and terrestrial non-native species. Scientists from USDA were told by Pohnpeian officials that Japanese long line vessels “are dirty and exchange commodities between ships”. On Kosrae, a new saltwater catfish reportedly first appeared in the area where Chinese vessels anchor, and locals associate this fish with those vessels. On Yap, invasive species managers suggest that the Norway rat may have been introduced to the islands from Chinese fishing vessels The concern over the perceived and in some cases demonstrated dirtiness of some fishing vessels in regards to potential invasive species is well known throughout the region.

In addition to vessel arrivals themselves, fishing vessels seized on suspicion of illegal fishing are another potential source of non-native species transfers, which may be unintentionally facilitated (enhanced) by increased residence times in port due to impoundment. Illegal fishing is a problem in most locations in Micronesia. Typically, following apprehension by marine patrols, these vessels are seized and brought into the nearest harbor, where they may sit for long periods as cases progress through the courts. Most locations report one to three such cases per year. Palau, the only locality for which we were able to obtain records, had 45 cases between 1994 and 2010. Vessels included steel and wooden hulled boats of various sizes and types, mostly from the Philippines, Indonesia, China and Taiwan.

There is no clear link between the population on Guam and the volume of fishing-vessel traffic; however, if new species become established in the region as a result of the Buildup, these vessels could provide a vector for the spread of non-native species within the region.

3.6 Cruise Ships

Cruise ship traffic to Guam is relatively minor, with six to eight calls on average each year in recent years. Cruise ships visiting Guam have ranged from 400 to 800 feet in length and tend to stay for only part of a day in port (PB International 2008).

Worldwide, cruising is expected to increase 4.5% to 5.5% from 2007-2017, then by 3.5% to 4.5% by 2017-2020, according to information collected from the International Cruise Line Association for the Guam's Port Master Plan (PB International 2008). However, cruise traffic to Guam may increase more rapidly. Several cruise lines have expressed interest in coming to Guam, with some projections of 20 to 30 vessel visits per year, if port improvements are made.

Cruise ships appear to be a minor part of shipping traffic to other locations in the region; most locations reported one to three ship arrivals per year with short (one day or less) stays. Palau receives about five to 10 ships a year, which typically stay three to four days, and arrive from Japan, the Philippines, and Australia. Few locations have sufficient harbor depth and dock capacity for large ships; those that do arrive tend to anchor outside the harbor, with smaller boats bringing passengers ashore. Pohnpei is intending to dredge its harbor channel with the goal of providing appropriate anchorage for cruise ships; cruise ships arriving in Pohnpei tend to have stopped previously in Guam and Papua New Guinea.

3.7 Private Yachts/Other Recreational Vessels

There are three marinas under control of the Port Authority of Guam, as well as a privately run marina and a private yacht club on Guam. The Gregorio D. Perez Marina near downtown (also known as Agana Boat Basin or Hagatna Marina) provides berthing and mooring space for approximately 165 recreational, charting, fishing and public agency boats. The Agat Marina, on Guam's west coast, has capacity for 150 boats. Both the Perez and Agat marinas have launch ramps for trailered boats. The Port of Guam also controls the Harbor of Refuge, at the eastern end of Piti Channel, which is primarily used as shelter for boats during typhoons and for long-term storage for boat owners. Aqua World Marina, which leases land adjacent to the Harbor of Refuge, also has a small number of berths as well as commercial marine-based businesses. The nearby Marianas Yacht Club has moorings for members, which are also used by visitors.

We were unable to determine the volume of recreational boating in the region. The yacht club currently has 90 members. There are several races each year, including one from Guam to Rota, and an annual fishing derby on Saipan, which attracts upwards of 70 boaters from different parts of Micronesia and farther abroad. The number of participants coming from afar is at least partially dependent on weather conditions and fuel costs in a given year. The Marianas Yacht Club hosts only four to five visiting yachts each year. Many of these boats come from Southeast Asian and long stays are fairly typical. Although we could not find any projections for recreational boating traffic during the Buildup and post-

Buildup, it is reasonable to assume that the number of recreational boaters will increase to some extent with the influx of new island residents. Membership at the yacht club was higher before the recent decline in military personnel on the island, so it is likely to rise again when greater numbers of troops move to Guam.

The master plan for the port calls for expansion of Gregorio D. Perez marina, where there is a waiting list for slips (PB International 2008). At Agat, the master plan recommends the replacement of slips and piers and potentially the extension of a breakwater. General repairs to anchorages are proposed for the Harbor of Refuge, along with maintenance and repair facility and a haul out facility.

Yacht arrivals to many parts of Micronesia appear to be a minor component of boating traffic. A few details from visits to some locations throughout the region serve to illustrate this:

- Chuuk reported between two and 11 yacht arrivals a year over the past four years, and some of these stayed a week or longer. Previous ports of call included many locations in Japan, Australia, Solomon Islands, and elsewhere in Micronesia. About 1/3 of these vessels were headed to Guam from Chuuk, and nearly all were planning to stop elsewhere in Micronesia.

- Palau receives about two yachts a month, and many of these travel to Guam and have stopped previously in the Philippines.

- Kosrae receives about eight to 10 yachts a month from numerous locations including Panama, U.S., Netherlands, and elsewhere in Europe. Most of these have stopped in either Fiji or Pohnpei before arriving to Kosrae.

- Yap reports about six yacht arrivals a year. Data on LPOC were not available, but in 2005 and 2007, Koror was the next port of call for over half of the yachts calling on Yap. Other vessels went to Rota, Cebu and Kosrae from Yap.

- Pohnpei also has small vessel traffic (Figure 3.19) from Australia, New Zealand, and possibly the Philippines; these rarely travel to Guam or CNMI, but more regularly visit Palau, other states of the FSM, and RMI.

Figure 3.19. Recreational vessels in Pohnpei's Harbor.

3.8 Miscellaneous Small Vessels

This group includes any small craft, including research vessels, training or educational vessels ("semester at sea" type vessels), missionary boats, traditional voyaging canoes, etc. that fall outside of the normal vessel traffic. Research vessels occasionally visit Guam and Saipan, sometimes without having made prior contacts with the port, management agencies, and/or educational organizations. Saipan has also hosted a Japanese "school afloat" vessel, and Palau has been visited by a heavily fouled missionary boat from Korea. Traditional voyaging canoes also sometimes visit Guam; in the past these have come from the Carolines and Hawai'i.

For these vessels in Micronesia, as well as for recreational vessels discussed in the previous section, there was no information available about the marine biota (biofouling) that may be associated with them.

There are also various passenger/cargo vessels that run between islands within and between some of the Micronesia jurisdictions. These would include vessels which go from the main islands in most jurisdictions such as Majuro, Chuuk, Pohnpei, Yap, and Palau to smaller islands within the jurisdictional boundaries of these island groups, but some vessels also cross between jurisdictions, especially within the FSM where vessels travel between the four states and the various islands within each of the states. For these types of vessels as well as private yachts, there is typically little to no biosecurity mechanisms currently in place when arriving at an outer island group port of call.

3.9 Grounded and Abandoned Vessels

Shipwrecks, vessel groundings on the reef, and abandoned vessels are not uncommon on Guam or elsewhere in Micronesia (Figure 3.20). While the Buildup is not expected to directly result in more groundings, there is a higher likelihood of such incidents as vessel traffic of all kinds increases. In Guam, previous cases of grounded vessels that were reportedly abandoned by owners remained on the reef for months, while agencies attempted to determine who was responsible for cleanup. Although jurisdictions in Micronesia appear to often have the legal authority to collect damages and payment for cleanup from ship owners, logistical difficulties of removal or prosecution appear to hinder actions, especially when vessels have been abandoned by the owners. Again, no information is available on biofouling associated with these vessels, but long residence times can facilitate species transfer (as discussed above), and vessels on reefs can potentially release species directly into highly valued natural habitats (versus harbors).

Figure 3.20. Abandoned vessels are a problem in all locations in Micronesia.

3.10 Laid-up Vessels

Worldwide, shipping is down due to the economic downturn, and commercial vessels are sitting in ports while shipping agencies wait for shipping to pick up (Floerl and Coutts, 2009). We are unaware of any plans in Guam to allow such laid-up vessels to reside locally, but such a plan was being discussed in Palau, and it is possible that this may come under consideration for Guam or elsewhere in Micronesia in the future. Palau was approached by a group that wished to explore moving 30 vessels laid up in Davao, Philippines to the Palau harbor, where mooring spaces are less costly; any action on this proposal had been deferred at the time of this report.

Pearl Harbor in Hawai’i has recently received decommissioned U.S. Navy vessels from the West Coast of the U.S. Additional decommissioned vessels are expected to be moved to Pearl Harbor, but information was not available on how many of these vessels are expected or what the ultimate plans are for them. While these vessels are expected to adhere to U.S. Navy protocols with regards to ballast water (see Chapter 2), we were unable to determine if and how hull fouling is addressed for these and other inactive Navy vessels surrounding movements. Given that the existing protocols for hull maintenance are motivated by the need to maintain operational readiness (see Chapter 2), it is not clear whether these also apply to (and are implemented for) decommissioned vessels, which can have extensive biofouling communities and may be transferred to other locations (Davidson et al. 2008, deFelice and Godwin 1999), presenting a risk of non-native species transfer.

3.11 Ship Breaking

There are no current plans in Guam for breaking of decommissioned vessels for scrap metal, but this is being discussed for a location just south of the port in Saipan. If this plan goes forward in Saipan, it could lead to increased species introductions (for the same reasons outlined above), depending on the extent and nature of biosecurity protocols that could be used.

3.12 Fish Aggregating Devices

On Guam, the Department of Aquatic and Wildlife Resources (DAWR) uses old U.S. Navy buoys from Portland, Oregon as fish aggregating devices (FADs). These arrive clean and dry and are assembled on Guam. There are 14 designated locations for FAD deployment at depths between 500 and 3,000 fathoms. FADs are monitored by aerial survey twice a year. On Yap, FADs are constructed on island using coconut fronds and other local materials; these are fished regularly by the local fleet with the Yap Fishing Authority in control of deployment and maintenance.

While these particular practices appear to be extremely low risk for non-native species introductions and spread, elsewhere in Micronesia abandoned boats and other floating objects are sometimes deployed as FADs and are not well-monitored. We are aware of several that have been deployed around Saipan and Palau. One of the Palauan FADs, an abandoned vessel, ran aground and had to be broken up and sunk. In such cases, the source(s) and relocation of floating objects is of paramount concern in minimizing the potential translocation of non-native species; it is often not clear what policies or practices may exist for use of vessels or other floating materials throughout the region.

3.13 Dry-docks

Guam has two floating dry-docks, owned and operated by the Guam Shipyard. Both dry-docks were towed to Guam from other locations: the Adept, from Subic Bay, Philippines and the Machinist ("Big Blue") from Pearl Harbor, Hawai'i. Based on interviews with U.S. Navy and Port of Guam personnel, there are currently no plans to bring in additional dry-docks to Guam associated with the Buildup.

There is a proposed transfer of a dry-dock from Guam to Saipan by a ship maintenance company. A new dry-dock has been proposed for Majuro to service the purse seiner fleet, and permits have been approved, but problems with the site are holding up development; the proposed dry-dock, Ching Fu, would come from Taiwan. There have been some discussions about bringing a dry-dock to Pohnpei in the future. Small non-floating dry-docks (slipways) also exist on Yap and Kosrae (Figure 3.21), but no plans for changes to these facilities were reported.

Figure 3.21. A slipway in Yap servicing a small vessel.

In addition to concerns about biofouling on floating dry-docks that may be moved from one location to another, as observed with the transfer of the Machinist to Guam (Paulay et al. 2002), biofouling organisms removed from ships in the dry-dock and released to local waters may affect invasion probability. There are currently no management practices in place addressing biofouling organisms released by dry-docks. In Guam, Hawai'i and Saipan, the EPA regulates dry-dock activities under the Clean Water Act, specifically focusing on the prevention of water pollution from rinse water and from dry materials removed from ships in dry-dock. These regulations do not specifically address the risks of non-native species transfers. Resource managers and officials throughout Micronesia expressed concerns with such issues and unregulated boat maintenance associated with dry-docks.

The DoD runs a dry-dock on Kwajalein Atoll. Information was not available to determine how frequently this dry-dock is used and what environmental regulations the DoD might have in place to prevent non-native species transfers from dry-dock activities.

3.14 Floating Docks/Pontoons and Other Structures

The docks at Perez and Agat marinas on Guam are floating structures, moored to fixed structures. Many of these are in disrepair. The Port Master Plan (DB International 2008) calls for replacing and expanding the floating docks and slips in these two marinas. Floating security barriers are planned for the DoD side of Apra Harbor.

The Port Master Plan for Guam proposes the construction of an additional 2,250 feet of refurbished and new wharf structures on the commercial side of the harbor. At the Agat Marina, the plan proposes extending the existing breakwater and general repairs and expansions at both Perez and Agat marinas which include the placement of concrete and/or metal fixed piers and pilings.

Significant additions to the DoD side of Apra Harbor are planned and/or are in progress, including dredging to create a new deep-draft channel, construction of a new wharf at Polaris Point to accommodate an aircraft carrier, a rip-rapped revetment, and an extension of Kilo Wharf using concrete caissons. The concrete caissons brought to Guam for Kilo Wharf construction were built in Japan and towed to Guam, after several months of sitting in the water. It is not clear what biofouling organisms were associated and transferred to Guam on these structures, which were cleaned only after being sunk in Apra Harbor.

The source of materials for the proposed structures on Guam was not known at the time of this report, and the development or application of any biosecurity protocols to minimize associated species transfers is also uncertain.

No other ports in the region except Guam report current plans for construction or replacement of existing floating or other structures. Most port agencies indicated that they were under capacity in terms of operations, with the exception of being able to accommodate cruise ships, and did not believe the Guam Buildup would require port expansions. Only Pohnpei was considering dredging and construction for cruise ships; this idea is still in an initial phase and is not yet part of any written plan.

3.15 Oil Drilling Platforms, Oil Production, and Exploration Vessels

Exploratory drilling for oil is being proposed in Palau. As with barges, drilling platforms can reside in one location for long periods and develop extensive biofouling communities and are transferred (under slow speed) to other locations, posing a high risk of species introductions. There are currently no regulations on Palau for biofouling on drilling rigs and platforms.

As far as we could determine, there are no drilling or underwater exploration plans elsewhere in Micronesia. Nonetheless, given the shipping connection between Palau and Guam, activities in Guam could affect regional spread of species, should an invasion occur in Palau.

3.16 Buoys and Channel Markers

Navigation aids, such as buoys and channel markers, are maintained in Guam and CNMI by harbor staff, the USCG, and (in the case of CNMI channel markers) by the Division of Fish and Wildlife. Elsewhere in the region, navigation aids are maintained by harbors and marine resources agencies. As with other floating artificial substrata, these navigation aids become covered with biofouling. As long as they remain in place (and are generally not moved to other locations for relocation or cleaning), they do not present a high risk of non-native species transfer.

3.17 Dive and Recreational Fishing Gear

Scuba diving and recreational fishing are popular activities on Guam for military personnel, locals, and tourists alike. Scuba gear is also used for work activities for military and research personnel. If wet gear is moved between locations, there is a possibility of transferring organisms. Although we have not seen any official estimates of predicted growth in participation in these activities, we expect that an increase in population will result in an increase in recreational/charter fishing activities and snorkeling and scuba both on Guam and within the region in general.

Palau, Chuuk, and Yap are considered world-class dive destinations, with many divers visiting each of these islands in turn. Currently about 40,000 visitors come to Palau annually; about 80% of these are divers. Chuuk receives 3,000 visitors a year, nearly all of whom come to dive; Yap receives 4,000-5,000 a year, with 80-90% coming to dive. Tourism increases are also anticipated on Pohnpei, which, along with Palau, is expanding its airport to accommodate more visitors. Palau has officially invited the U.S. military for R&R (rest and relaxation); the Chuuk Visitor’s Bureau was planning to attend a tourism trade show to court military visitors, and is working to get direct flights to Chuuk from the Philippines (and/or Taiwan).

To our knowledge, there are no management practices in place in the U.S. military, Guam or elsewhere in Micronesia to reduce the risk of transfer of non-native species through recreational fishing or diving activities. In the Papahanaumokukea Marine National Monument (Northwestern Hawai’ian Islands), strict protocols are in place to prevent transfer of organisms on scuba gear, clothing or research equipment (PMHM Best Management Practices 2009).

3.18 Kayaks, Outriggers, and Personal Watercraft

Water activities are popular on Guam and elsewhere in the region for military personnel, locals, and tourists. Although there are no official estimates of predicted growth in participation in these activities, it is likely that increases in the local population size will result in an increase in water activities of all sorts, including those that involve small boats and personal watercraft. Military personnel coming to Guam may also ship such vessels with their personal goods. We are unaware of any existing management practices in Micronesia to reduce the transfer of marine organisms on or in small watercraft.

3.19 Summary

The goal of this chapter was to review current and projected future activities surrounding vessels, considering what is known about magnitude of these activities and existing practices from a marine biosecurity perspective. The treatment here summarizes available details compiled during the scope of the current project, but this is by no means a comprehensive or complete view of all relevant information. As noted at various points throughout this treatment, there are some gaps in the available data, such that the analysis presented here provides a minimum estimate of magnitude and geographic connectivity for some key mechanisms for species introduction and spread.

Conspicuous gaps in the current analysis exist for traffic patterns and ballast water delivery patterns associated with U.S. Navy ships and other military vessels. While estimates were made available for the number of arrivals for these vessels to Guam, but the following limitations exist:

- LPOC and voyage histories were not made available for U.S. Navy vessels, or other military vessels, except for those provided by MSC for supply vessels.

- While voyage histories were available for many MSC vessels, these were often limited to a short time horizon and appear to be incomplete records.

- Most vessels that operated under MSC did not report ballast water discharge or management data to USCG, so there is a major gap in information about the volume, geographic source(s), and management for water discharged in Guam and CNMI.

- No information was provided from DoD on ballast water discharge and management for any U.S. Navy, MSC, or other military vessels arriving to Micronesia or Hawai’i.

For non-military vessels, some additional information gaps are also apparent for Micronesia, as follows:

- Except for Guam and CNMI, commercial ships arriving to ports in Micronesia do not report ballast water discharge and management information, as there are no existing requirements or programs for this purpose.

- Information on voyage histories (and even LPOC) is only available for a small fraction of fishing vessels and barges arriving in Guam and other jurisdictions of Micronesia.

- The numbers of barge arrivals in Micronesia appear to be underestimated in many of the existing datasets.

Despite these limitations, the current analysis provides an estimate of current vector activity in Micronesia and illustrates the connectivity that exists, both within the region and globally, especially for vessels. This information, along with that presented in other chapters, provides an important background for developing the biosecurity plan and recommendations outlined in the final chapter. Toward that end, we have included above some activities that are not currently prevalent, or even now in operation, within Micronesia but may become relevant in the near future; in nearly all cases, these activities are at least under consideration, even if they are not now operating in the region. This approach was intended to be as comprehensive as possible, in order to advance a biosecurity plan that captures as many future activities as possible that are relevant to the region.

Chapter 4: Live Marine Organism Importation and Trade

By Chela J. Zabin, Lucius G. Eldredge, and Gregory M. Ruiz

4.1 Importation Regulations and Enforcement

Trade in certain live organisms is regulated at the international level by CITES, to which the U.S. and Palau are signatories, and whose conventions are followed by the FSM and RMI. With the goal of protecting endangered or threatened species, CITES restricts the trade of organisms appearing in its three appendices. Of relevance to the region, giant clams (those in the Family Tridacnidae) and many coral species are CITES species, and are thus subject to specific restrictions. However, there are no international conventions prohibiting trade of marine organisms considered to be non-native, invasive [4]or nuisance species.

In the U.S., some non-native species are specifically listed and prohibited from importation by the Lacey Act 1900 (for animals) and the Plant Protection Act 2000 (for plants and plant pests). Few marine and estuarine organisms are prohibited under these statutes. Exceptions under the Lacey Act include mitten crabs (crabs in the genus *Eriocheir*) and snakehead fishes (in the family Channidae, largely restricted to freshwater), which are listed as "injurious wildlife," prohibiting any foreign export or interstate movement of live organisms without a federal permit. To similar purpose, the marine alga *Caulerpa taxifolia* (aquarium strain) is listed as a "noxious weed" under the Plant Protection Act, which prohibits importation into the U.S. or transportation across state boundaries without federal permit.

Current regulations for the importation and movement of live marine organisms in Micronesia are summarized in Table 4.1 and are reviewed in more detail below.

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[4] Note: in this section, the term "invasive" is used to describe non-native species that are perceived to be or perceived to have the potential to be problematic, as opposed to those being imported purposely. Worldwide, most aquaculture species and other live trade (pets, live food) species are non-native to the regions to which they are imported.

4.1.1 Importation Regulations

4.1.1.1Guam.

DAWR maintains an informal "white list" of marine and aquatic organisms that can be imported live, including aquarium species and food species, such as New England lobster (*Homarus americanus*) and Pacific oysters (*Crassostrea gigas*). The white list mainly includes species already present on Guam (native or already established non-natives) and those that have a long history of importation into Guam with no known negative impacts. A few organisms are allowed for import only for Underwater World, Guam's aquarium, as the biosecurity and sanitation procedures at the aquarium presumably meet high standards.

Permits must be obtained to bring in species on the white list, even small numbers of individuals for personal use. Importers can submit requests for permits to import organisms not on the list; these are reviewed and approved on a case-by-case basis, with the onus on the importer to prove an organism is not harmful. Importers must have a certificate of health from the point of origin for organisms being brought to Guam.

4.1.1.2 Hawai'i.

Hawai'i's Department of Agriculture maintains a list of organisms that cannot be brought into the state, including many marine fishes and some species of crabs, octopus and jellyfish (scyphozoans), as well as a list of conditionally approved and restricted organisms, both of which contain numbers of marine species. An importer must have a permit to import anything on the list of conditionally approved organisms. Businesses wishing to import organisms on the restricted list must, as a condition of obtaining a permit, undergo a site inspection. Although terrestrial plants, microorganisms and pathogens appear on the various lists, we could find no lists for macroalgae. The state's rules and lists are available on the state Department of Agriculture's website http://Hawai'i .gov/hdoa/pi/pq/import.

4.1.1.3 Commonwealth of the Northern Marinas Islands (CNMI).

Imports to CNMI are regulated by USFWS and the Commonwealth's Department of Fish and Wildlife (DFW) and Department of Agriculture. The DFW website (http://www.dfw.gov.mp/Enforcement/Fishing%20Regulations.html) lists species that are allowed for importation; these include several species of birds and mammals. No amphibians or reptiles are permitted. For invertebrates, including marine invertebrates, only those that can be demonstrated to be "not harmful" are permitted. Marine invertebrate importations tend not to be closely regulated. Giant clam spat have been provided to the CNMI from Palau on several occasions over the past 25 years. The only requirements were health certificates from Palau that stated that the clams were not harmful for human consumption. No fish or algae are listed on the DFW website, although enforcement officers are using an unofficial "white list" of freshwater fish species from Australia to make determinations for import permits to CNMI. These rules apply regardless of the number of individuals or purpose of the importation.

4.1.1.4 Republic of the Marshall Islands.

Republic of the Marshall Islands (RMI) does not maintain a list of either prohibited or allowed marine species. Requests for importation permits are decided on a case-by-case basis by Marine Resources and Agricultural Quarantine. For a permit to be approved, an importer must make the case that a proposed species does not pose an environmental threat. A health certificate from an independent veterinarian must accompany live imports. RMI is in the process of reviewing its quarantine regulations. A draft biosecurity bill is also now in progress, which may revise import and export regulations and practices.

4.1.1.5 Federated States of Micronesia.

By federal law, Federated States of Micronesia (FSM) prohibits the importation of exotic plants or animals, except under permit by the Director of Resources and Development (FSM Code, Title 23, Resource Conservation, Section 315). The code also states that no CITES species can be imported (FSM Code, Title 23, Section 8). All import permits must be approved by federal quarantine and undergo a pest risk analysis before a permit is approved. Under Kosrae State Code, if a plant or animal is not already found in the state, an importer must apply to the Department of Agriculture, Land and Fisheries for permission (KSC Title 14 Section 14.204), but it appears that review of permit applications happens at the federal level. Importers must have a certificate of health from the point of origin. Elsewhere in FSM, there do not appear to be any additional regulations at the state level regarding the importation of live marine species. All these regulations will be reviewed and updated after the approval of the new biosecurity bill.

4.1.1.6 Palau.

Palau's Plant and Animal Quarantines and Regulations (1999) contain schedules of prohibited plants and animals. These schedules were updated in 2002 to include any species or hybrid of tilapia (*Oreochromis* spp.), which is currently the only listed marine or aquatic species; however, the government is currently considering removing tilapia from the prohibited list, to promote its use in agriculture (see Section 4.2.1).

In 2006, the regulations were again amended, giving the Palau National Invasive Species Council (Palau NISC) the responsibility of reviewing an application for the importation of any species not already present on Palau. The Palau NISC has 30 days to carry out its review, but may request longer if further study (at the importer's expense) is required. This amendment also gives the Palau NISC the responsibility of advising the Palau Department of Agriculture on species that should be added or removed from the prohibited species schedules.

At ports of entry, including the post office, inspectors from the Palau Department of Agriculture are charged with carrying out inspections of cargo, mail, baggage, passengers, ships and airplanes. All live imports must have a permit issued by the Palau Department of Agriculture and live organisms must have received a certificate of health from their country of origin. Imported organisms can be placed in quarantine for further observation and treatment at the importer's cost if necessary. Although we were told that no live organisms could be imported for food, we did not find this restriction in the regulations.

In Palau, species intended for aquaculture must be approved by the Bureau of Aquaculture, and are to be held in quarantine for seven days for observation by the Marine Resources Bureau. Nonetheless, there appears to be little capacity to do more than qualitative, visual screening to make a judgment about whether organisms “look healthy” and to sort out obvious non-target species accidentally included in shipments before release. Quarantine officials have the legal authority to inspect an importer’s facilities after organisms have passed through quarantine and can order organisms back into quarantine and/or destroy them after release, but it is not clear how frequently, if ever, this has been done.

4.1.3 Effectiveness of Port Inspections.

Details on interceptions of non-native marine and aquatic species were not available from local agencies, but anecdotal information suggests that smuggling of these organisms certainly occurs at some locations:

- The golden apple snail (*Pomacea canaliculata*) was discovered in Guam in 1984 in Agana Spring and 1986 in Laguas River, where it was being collected for food by local residents (Smith 1992). As the two water bodies are not connected, it is likely that the snail was moved by humans (See Section 4.2.2).

- Saipan has a large population of workers from countries that prize live food, especially fish and other seafood. Officials from management agencies there report having seen Chinese mitten crabs (*Erocheir sinensis*), non-native snails, non-native groupers, (subfamily Epinephelinae) and live swamp eel (probably *Monopterus albus*), for sale at local markets three to four years ago. None of these species can be legally imported.

- On Palau, it is assumed there is a large amount of unregulated trade between the southwestern islands, the Philippines and Indonesia.

- On Majuro, a crocodile apparently smuggled in as a pet was later released on the island and had to be captured by management agencies.

4.2. Aquaculture

4.2.1 Regulations and Industry Standards

Import regulations provide one level of biosecurity, providing pre-border protection from introductions of unwanted species. Another level of protection can result from post-border regulations or practices, which limit potential movement of organisms (and any associated biota) through various means. In many regions of the world, aquaculture species are typically non-native to the areas where they are raised. Even with permitted use, regulations or guidelines are sometimes used to prevent escape of the target organisms or associated species, especially parasites and pathogens, into natural habitats (e.g., National Research Council 2003, European Union 2007, Padilla et al. 2011).

Currently, there are no international conventions that address aquaculture practices to reduce the risk of invasive species. Despite the lack of binding instruments, there are several voluntary guidelines regarding the introduction and transfer of aquatic organisms.

The Convention on Biological Diversity, acknowledging the risk of invasive species transfer via this vector, strongly urges the consideration of native species for aquaculture and requests signatory countries to conduct scientific risk assessments for introductions before allowing the importation of new species (COP 7 Decision VII/5 45: http://www.cbd.int/decision/cop/?id=7742). Guidelines for the prevention of invasive-species transfers from aquaculture have been developed by the Food and Agriculture Organization (Food and Agriculture Organization 1995, 1996, 1997; Arthur et al. 2008; Bondad-Reantaso et al. 2008), the International Council for the Exploration of the Sea (International Council for the Exploration of the Sea 2005), and the World Conservation Union (IUCN) (Hewitt et al 2006) These guidelines have not been adopted by the U.S. or any of the countries in Micronesia. Recommendations for quarantine procedures for the region were made by the Secretariat of the Pacific Community (Humphries 1995), but most of the localities in Micronesia do not presently follow these recommendations, likely due to lack of capacity. SPC is currently working on an Aquatic Biosecurity Regional Strategy, as it has been identified as one of the main priorities at the SPC Head of Fisheries meeting held in Noumea in 2011. This regional strategy will have several components, one of which will be exclusively focused on aquatic species introductions. This component will include technical guidelines for import risk analysis, minimum requirements for pre and post-border quarantine methods, species lists, countries/competent authorities' lists, diseases list, among others.

The U.S. Department of Commerce is developing a national aquaculture policy that would provide a uniform set of regulations for all open ocean aquaculture in federal waters (http://aquaculture.noaa.gov/). However, at this time in the U.S., there is no single body that regulates aquaculture; a number of federal, state and local agencies may have jurisdiction, and oversight has been characterized as inadequate for dealing with invasive species (Naylor et al. 2010).

Despite a long history of aquaculture, and significant current official investment and interest, the Micronesian region has not had a uniform aquaculture policy and little attention appears to be focused on the issue of marine invasions. As an example, the alga *Kappaphycus alvarezii* has been brought to numerous Pacific Island countries and territories, beginning in the 1970s. A review of these introductions (Sulu et al. 2004) found only a single case in which a documented quarantine effort was made. Within individual countries, permits and approvals for aquaculture ventures are needed from multiple agencies, most of which deal with issues such as water pollution, earthmoving and construction, but none specifically address non-native species transfer. However, recently there have been several examples of introductions of aquatic species for aquaculture purposes within the Pacific where a risk analysis prior the introduction was carried out, and proper pre- and post-border quarantine measures were implemented. These include introduction of seaweeds from Indonesia to FSM, introduction of sandfish (holothurians) from Fiji into Kiribati, introduction of seaweed (improved variety) from Indonesia to Fiji, introduction of red tilapia from American Samoa to Samoa, introduction of GIFT tilapia from Malaysia to Solomon Islands, introduction of freshwater prawn from Thailand to Fiji, introduction of seaweeds from Malaysia to Papua New Guinea (PNG), and introduction of blue shrimp from Brunei to Fiji.

Other than import regulations, we were not able to find regulations that dealt with preventing escapes (or movement) of non-native species or genetic material (although the new biosecurity bills being developed for Palau, FSM and RMI have specific sections dealing with the introduction and transfer of live organisms, including pre- and post-border quarantine measures, required certificates, and health certificates). On the whole, aquaculture policies and practices generally do not seem to be integrated with biosecurity plans or concerns. For example, the government of Palau is now considering the removal of tilapia from its list of prohibited species, and promotion of its use in aquaculture, despite many years of effort on the part of conservation agencies and community volunteers to eradicate tilapia there. The new plan, however, is an improvement over earlier tilapia introductions into Palau because it involves the introduction of GIFT Nile tilapia, which is a good option for aquaculture development and income generation. Previous introductions of tilapia in Palau involved the mossambicus tilapia (*O. mossambicus*), which is not only less suited for aquaculture, but also has a high invasiveness potential.

Biosecurity issues, both in terms of aquaculture disease and non-native species that might escape into the wild, are addressed in a draft version of CNMI’s Aquaculture Development Plan. The policy is being developed by the Northern Marianas College Cooperative Research Extension and Education Service (NMC-CREES); its overarching goal is to increase aquaculture over the next five years. The plan specifically identifies the need to (a) establish a quarantine facility, (b) improve the capacity to diagnose aquaculture diseases, (c) carry out a risk assessment for any aquaculture species proposed for import into CNMI and (d) develop a list of potentially invasive species for CNMI. The draft plan lays out the need for funding for additional personnel with technical expertise in several areas. However, there also was no specific request that would increase local capacity to carry out risk assessments for proposed non-native species introductions, to monitor for escapes, or to carry out a rapid response if such escapes are detected; it is not clear what resources would be available to implement this plan.

A draft Guam Aquaculture Plan is currently being reviewed by the SPC and the University of Guam, but the plan does not directly address biosecurity issues.

In the FSM, the National Aquaculture Plan will be developed through a national consultation which will be held in 2013. A profile of aquaculture on Pohnpei (Pohnpei Marine Development 2004) outlines opportunities and constraints for further development of the industry. Non-native species are addressed only briefly. The report acknowledges the lack of regulation on the importation of aquaculture species and on the industry itself, as well as the lack of ability to enforce any existing permit requirements.

The aquaculture policy for RMI is currently under revision. We were unable to obtain a copy of the current plan but were told that issues of non-native species would be addressed in the revised version.

4.2.2 Compliance with Regulations and Practices

We were unable to determine the degree of compliance with existing regulations for import and use of aquaculture species, or the ability of agencies to enforce them. Data collected by relevant agencies are sparse; most available information was anecdotal, being limited to observations and incidents with little or no documentation.

Within Micronesia, as elsewhere, there is likely some amount of unofficial or unapproved aquaculture using non-native species. We were told of such attempts that were started without the approval of relevant agencies, including the following:

- In 2009, an algal species (*Gracilaria* sp.) from the Philippines and approximately 5,000 Japanese abalone (*Haliotis asinina*) were reportedly set out in pens near the Tinian port without an environmental review. We were told that the algae were hand-carried on an airplane to Tinian in coolers, which were not inspected by quarantine officers. The operation has since been shut down by management agencies, but approximately 1,700 abalones are apparently still present on the island.

- In 1989, the introduced golden apple snail (*Pomacea canaliculata*) was discovered growing in tilapia aquaculture ponds on Guam. The snail was being harvested and sold by the farmer, who told government officials that it had arrived accidentally with the tilapia fry imported from Taiwan (Smith 1992). In 1990, officials ordered the farmer to destroy the snails and subsequent surveys of his ponds and nearby stream indicated that he had complied. However, a dense population of the snail was found one year later in a Mangilao wetland, some 20 miles from the aquaculture facility, where it was being collected by local people.

- A student at the University of Guam reportedly planted two non-native oyster species from the Solomon Islands and Palau in Sasa Bay (Apra Harbor), Guam, in 1978 and 1979 as an aquaculture experiment. At least one of these two non-native species successfully spawned and recruited (Braley 1984); oysters were stolen from one of the student's study sites. The outcome of this intended transplant is unknown.

- On Kosrae, there are reports of a non-native, salt-water catfish species that first appeared around the harbor area where Chinese fishing vessels anchor, according to officials there. It is unclear whether this species was intentionally brought or might have been an accidental release.

In addition, poaching is reported to be a problem for aquaculture on Chuuk, and could potentially compromise any biosecurity measures in place. We were told that a Korean operation brought coral perch (family Scorpaenidae) from Korea to Chuuk Lagoon, where they were kept in pens to be raised to market size. In the first year, someone cut the pen net, releasing approximately 1,000 individuals. It is believed that all of the fish were caught, as they tend to school and are unafraid of humans. Poaching of smaller-scale local operations is apparently also not uncommon. Enforcement agencies apparently lack the capacity to deal with this problem.

Table 4.1 Summary of current regulations, standards, enforcement and compliance for the imports of live organisms.

	U.S. Military	Guam	Hawai'i	CNMI	RMI	FSM	Palau
Regulations	Abides by local regulations	No restrictions for 8 or fewer individuals; unofficial white list for >8; additional permits decided case-by- case	Lists of conditional, restricted and prohibited species. Permits for restricted species require site inspection.	"Harmful" invertebrates disallowed; other permits on case-by-case basis; unofficial white list used for freshwater fish	Permits on case-by-case basis	No CITES organisms; organisms not already in FSM, case-by-case basis	Tilipia only prohibited marine/aquatic species; organisms not already in FSM, case-by-case basis with NISC review; aquaculture imports held in quarantine 7 days for observation, sort out non-target species
Enforcement at ports of entry	Civilian enforcement at ports	Seaports/airports: cargo inspected based on bills of lading, baggage based on declarations; no mail inspection without probable cause					
Post-entry enforcement	Same as civilian	Not illegal to possess import-restricted organisms	N/A	No capacity	No capacity	No capacity	Quarantine can seize illegally imported organisms

	U.S. Military	Guam	Hawai'i	CNMI	RMI	FSM	Palau
% cargo, baggage, passengers screened	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Effectiveness of screening	Unknown	Unknown	Unknown	Unknown; reports of illegal organisms in food markets; one case of high-profile illegal aquaculture	Unknown; little anecdotal evidence of smuggling	Unknown; little anecdotal evidence of smuggling	Unknown; suspected smuggling and illegal trade especially in the southwestern islands
Export screenings	Prior to moving personnel, all personal effects screened in-home	Brown tree snake only.	Ag X-ray screening on departure for U.S. Mainland	None			Ag can inspect

4.3 Current and Anticipated Live-organism Trade

4.3.1 Aquaculture

Hawai’i and Micronesia have a long history of moving organisms into and within the region for aquaculture and for restocking declining wild populations. Some of these efforts have ceased, such as the introduction of the topshell (*Trochus niloticus*), which now has protected status on some islands where it has become established; others, such as the intra-regional movement of giant clams (family Tridacnidae), continue to this day. This history of marine species transfers is detailed by Eldredge (1994) and includes fish, crustaceans, mollusks and algae from both temperate and tropical locations. In addition, the spread of diseases and pests of aquaculture species in the Pacific is reviewed by Humphries (1995). Currently, there are a number of aquaculture facilities in the region.

Nearly all countries and island groups in Micronesia promote aquaculture as a way to increase local food supply and income. Below, we outline briefly some of the current activities by location.

4.3.1.1 Guam

On Guam there are three commercial facilities and a facility run by the University of Guam. The main species being imported are tilapia (*Oreochromis* spp.), white-legged shrimp (*Litopenaeus vannamei*), walking catfish (*Clarias batrachus*), and milkfish (*Chanos chanos*); the first three species are raised for food, and the latter is used for bait by tuna longliners. These organisms are generally imported from Taiwan, Malaysia and the Philippines. Some trials are also currently underway for red snapper and humpback grouper imported from Palau. The one facility we visited on Guam is located on a cliff and drains water from its tanks onto a limestone pond above the reef flat. Stock of the diatom *Chaetoceros gracilis* culture for this facility is occasionally imported from Hawai’i, and brine shrimp (*Artemia* sp.) is ordered from various off-island businesses; neither food source is included on Guam’s white list.

Other marine species that have been imported for the aquaculture trade include giant clams, the Australian oyster (*Crassostrea echinata*), the Pacific oyster (*Crassostrea gigas*), the Australian rock oyster (*Saccostrea commercialis*), the Solomon Island mangrove oyster (*Saccostrea cucullata tuberculata*), the topshell (*Trochus niloticus*), the limpet (*Cellana mazatlandica*), the penaeid shrimps (*Penaeus monodon* and *P. stylirostris*), the mangrove crab (*Scylla serrata*), and the mullet (*Mugil cephalus*) (reviewed in Eldredge 1994).

The draft Development Plan for Aquaculture on Guam includes a section evaluating high-potential species for aquaculture development. For several of the candidate aquaculture products (e.g., grouper, mangrove crabs, freshwater prawn), the fry will probably need to be imported from overseas.

4.3.1.2 Commonwealth of Northern Mariana Islands.

On Saipan, NMC-CREES is active in promoting aquaculture, including tank-reared white-legged shrimp (*Litopenaeus vannamei),* various tilapia, wild-caught rabbitfish (*Siganus* sp.), and mullets (*Mugil* spp.). NMC-CREES was also involved in a venture on Tinian that involved placing Japanese abalone (*Haliotis asisina*) and algae (*Gracilaria bailinae*) from the Philippines in cages near the seaport (as noted previously). The latter operation was shut down following questions about whether it had received appropriate environmental review. NMC-CREES has recently sponsored a conference on open ocean cage culture, which it is promoting as easy to do and harmless to the environment, and is the lead agency in charge of developing an aquaculture plan for CNMI.

The history of aquaculture on Saipan includes (a) the rearing of shrimp imported from Guam and the Philippines in a flow-through system, (b) giant clams brought from an aquaculture center on Palau and placed in the lagoon (these efforts failed due to poaching), and (c) the importation of the topshell (*Trochus niloticus*) in 1938, during the Japanese period. The last is now a protected species. Currently, a private venture, Saipan Aquaculture, raises white-legged shrimp which it sells locally and exports to Guam for food and to Asia for broodstock. There are eight tilapia growers in CNMI raising three strains of the fish.

4.3.1.3 Republic of the Marshall Islands.

On Majuro, current aquaculture ventures include giant clams (broodstock from various locations in the Marshall Islands), corals raised for the aquarium trade and black pearl oysters (*Pinctada margaritifera*). Microalgae are brought in from Australia, Hawai'i and Florida and used as food for these ventures. A barramundi (*Lates calcarifer)* and cobia (*Rachycentron canadum*) aquaculture project, which brought stock from a hatchery in Australia, failed about two years ago for economic reasons. Marine Resources officials had raised concerns about whether cobia, which are a highly migratory species, were appropriate for aquaculture, but the project was ultimately approved. It appears that all animals were removed when the facility closed. *Trochus niloticus* was also brought to the Marshalls by the Japanese and is still present there.

4.3.1.4 Kosrae.

Giant clams (with broodstock from various locations within Micronesia) and corals are now being raised on Kosrae. A state-funded project to raise local mud crabs (*Scylla serrata*) is also in operation, with crabs cultured in a state-run hatchery and out planted to grow-out tanks. The topshell (*T. niloticus*) from Pohnpei and the green snail (*Turbo marmoratus*) were brought to the island in the 1940s or 1950s, with *T. niloticus* having become established; *T. marmoratus* was an unsuccessful introduction. Kosraean officials report that *T. niloticus* were protected from fishing until they established populations.

4.3.1.5 Federated States of Micronesia.

The development and promotion of aquaculture is one of the major program areas under development for the College of Micronesia, which has campuses in all the FSM states. Among the targeted organisms are pearl oysters, sea cucumbers and rabbit fish (College of Micronesia 2009). The pearl-oyster program is the most developed of these programs, and is underway on Pohnpei. The Pohnpei Agricultural and Trade School previously cultured pearl oysters, sponges, corals, and marine ornamental, but closed in 2005.Other species recently proposed or tried for aquaculture there include the alga *Kappaphycus* (introduced in the late 1980s from the Philippines, and slated for re-introduction from Indonesia in the near future), white-banded sea perch and milkfish (the latter having been brought in 2004-2005, probably from the Philippines). A successful private sponge culture in Pohnpei Lagoon was established in the 1980s and exported quality sponges. We were unable to determine whether these operations are still in existence. A proposal to farm tilapia was recently turned down by Marine Resources, however these fish have recently become established in the island's streams and are thought to be an escaped or intentional illegal aquaculture species.

The red alga *Euchema spinosum* and one additional *Euchema* species were also attempted for aquaculture on Pohnpei, but low yields due to grazing by rabbit fishes made this economically unfeasible, and the project was abandoned in the early 1980s. However, these algae species were also brought from Pohnpei to Kosrae, Majuro, Mili and Likiep. While it does not seem that the algae survive well on the reef, they were reported growing on aquaculture structures in Likiep (Eldredge 1994). The topshell (*T. niloticus*) was brought to Pohnpei from Chuuk and Palau in the 1930s, resulting in a fishery peaking in 1951 (Eldredge 1994).

On Chuuk, known established non-native species are the result of aquaculture introductions. These include *T. niloticus*, established in the 1930s, and one or two species of sea cucumbers. A more recent attempt at largescale aquaculture by a Korean firm was foiled by poachers (see Section 4.22). The company has an ongoing Memorandum of Understanding with the Chuukese government to continue aquaculture research, but no new activity has occurred for two to three years. A government hatchery raises pearl oysters, but these are derived from local stock. There are about 20 giant clam farms on Chuuk, with seed material coming from Pohnpei. Poaching is reported to be a problem for these smaller local farmers as well.

On Yap, native sea cucumbers, coral and fish are raised in aquaculture, as well as giant clams from Palau. Non-native tilapia have invaded mangrove system and are perceived to be bothering native fishes.

4.3.1.6 Palau.

The Micronesian Aquaculture Demonstration facility on Palau produces giant clams for outplanting and export for aquariums and is involved in pilot projects for the rearing of other local organisms. Other aquaculture species include groupers (*Epinephelus fuscoguttatus*), shrimp, milkfish and mangrove crabs from the Philippines and Taiwan. Species that have also been tried in Palau include the Pacific oyster (*Crassostrea gigas*), rabbit fish (*Siganus* sp.), coral trout (*Plectropomus leopardus* and *P. aerolatus*), and Napoleon wrasse (*Cheilinus undulatus*).

4.3.2 Pet/Aquarium Trade

Because detailed records are not kept in the various jurisdictions of Micronesia on pet trade of aquatic organisms, we were unable to obtain much information on the types and numbers of marine species imported to Micronesia for home and commercial aquaria. Overall, the region is likely a net exporter of marine aquarium species. However, an estimated 149,650 fish for aquaria (reported only as "tropical fish") were imported to Guam from foreign sources between 2007-2009 (Walsh et al. 2010). It is unknown how many additional fish may have arrived from domestic sources or how many of the total were marine species. Additional unrecorded sources of marine species for aquaria include species ordered online and arriving to the region via domestic postal mail or courier services. It is expected that most aquarium species are shipped via air (Cole et al. 1999). Inspections are challenging because these shipments tend to not be well-labeled and inspectors have insufficient training to identify species. There is also little self-regulation within the industry to screen for potential invasive species (Gertzen et al. 2008).

There are relatively few retail outlets in Micronesia for aquarium fish, invertebrates and algae. For example, we are aware of two commercial outlets on Guam. Freshwater aquarium plants and animals are also sold at the local farmer's market and at a store located on one of the U.S. military bases on Guam (the Navy exchange). DAWR receives about 15 import requests a year from pet trade importers, with organisms coming mostly from Taiwan, Malaysia, Philippines, Korea, and the U.S. mainland.

4.3.3 Live Food Imports

On Guam, some 30 importers currently bring in about 50 live-food imports a year. These include live lobster, clams, abalone, mangrove crabs, and coconut crabs. These live-food items are imported from a variety of locations, which include the FSM, Philippines, U.S. mainland and New Zealand. Biologists from the USGS and the Smithsonian Institution visited seafood markets that carried live fish and shrimp on Guam in Feb 2010. Customers had the option of taking home live seafood (Walsh et al. 2010). We also observed live fish, coconut crabs (*Birgus latro*) and shrimp for sale at the Farmers Market in Dededo, Guam.

While it is possible that fishing vessels may also carry live seafood (see Section 4.2.2), we have no data on the frequency or extent to which this occurs or the possible species involved.

4.3.4 Live Bait and Other Vectors

Milkfish, imported from outside the region, are raised commercially for bait. Other than this, there does not seem to be a market in the region for imported live bait. We did not find any evidence of the importation into the region of live marine species for other uses, such as biological control or scientific research.

4.3.5 Expected Increase in Live Organism Importation

Currently, legal importation of live marine organisms appears to be fairly limited in the region; however, this may shift with an increase in population on Guam.

Globally, aquaculture production has more than doubled both in value and volume in the past decade, becoming one of the fastest-growing sectors in the world food economy (Naylor et al. 2010). This trend is likely to increase as pressure increases on dwindling wild populations of fish and other seafood. In the region, aquaculture is expected to increase

(Ponia 2010), and local aquaculture projects will likely continue to be encouraged as the population grows. In addition to increasing the risk of importing pest species (including disease organisms), aquaculture-related activities, such as the movement of stock animals and aquaculture equipment and structures into and within the region may also increase the risk of non-native species transfer.

It is also likely that the number of aquarium enthusiasts and the demand for salt water aquarium species will rise along with the general increase in population related to the Guam buildup.

Relevant to the Buildup, demand for live food could rise with increase in population and prosperity. The species and number of individuals being imported both legally and illegally is likely to be tied to the ethnic makeup of workers and military personnel coming to the region. For example, seizures of illegally imported animals and animal products on Saipan increased with the increase in Chinese nationals who came to work at the island's garment factories (see Section 4.1.3). Among the risks of live-food imports are accidental or intentional releases by individuals hoping to start populations they can harvest. With the closure of the garment factories on Saipan, the grow-out of non-native species for use as a food resource by alien workers is reported to have declined, and will likely continue to decline (barring the growth of similar new industries on the island).

While numbers of organisms and sources are unknown, it is certain that the amount of goods and personnel moving into and within the region will increase. It appears that such an increase could strain the available capacity to inspect and control the flow of these organisms, since there are reported to already be limitations in this regard at the present time.

4.3.5.2 Other Micronesian Countries.

Officials we spoke with at nearly every jurisdiction in the region felt they were understaffed, underequipped, and undertrained to carry out thorough inspections of the current amount of cargo, baggage and passengers, much less handle any potential future increase or carry out any post-border enforcement. Other barriers to effective detection and enforcement include social and cultural factors. For example, one agriculture inspector in FSM indicated that he was embarrassed to search the suitcases of female passengers. Other possible hurdles to biosecurity measures mentioned by inspectors and managers in the region included nepotism, favoritism, public distrust of the government, and land-ownership regulations that hamper government agencies from carrying out management/eradication programs that require access to privately-held lands.

4.4 Conclusions

4.4.1 Pre-border Biosecurity

Trade in live marine organisms is a major vector for the transfer of non-native species around the globe. However, there are no international conventions prohibiting or regulating trade that focus explicitly on non-native species. U.S. federal law prohibits the importation of a few non-native species under the Lacey Act (1900) and the Plant Protection Act (2000), however only a few marine or estuarine species are listed.

Within the Micronesian region, most jurisdictions maintain either “white lists” of allowed species, or lists of prohibited or restricted species. With the exception of Hawai’i, Guam, and Saipan, few lists or regulations address marine species, having been developed primarily to protect agriculture. Several other gaps exist in terms of pre-border biosecurity for movement of live marine organisms:

None of the states or countries in the region appears to have the capacity to carry out thorough inspections of luggage and cargo in terms of trained personnel. Many lack equipment such as X-ray machines and computers that could make enforcement more efficient and effective. Anecdotal information indicates that smuggling of live species is occurring throughout the region, including estuarine and marine organisms.

None have the capacity to carry out investigations or effective enforcement beyond ports of entry. In some cases, this is due to discrepancies between import regulations and other laws, as in Guam, where it is not illegal to possess certain species prohibited for import. Domestic mail is not routinely inspected, providing a potentially important (but poorly documented) pathway for trade in non-native species between the continental U.S. and Hawai’i, Guam and CNMI.

Even for declared or permitted live imports, species-level identifications, labels and any certification (of disease-free status or absence of associated organisms) are often poor, making any assessment and pre-screening difficult at best. Little to no screening of outgoing cargo occurs in the region.

4.4.2 Post-border Biosecurity

While it is clear that live marine species are currently imported into the region and also transferred between island groups for food, bait, pets/aquaria and aquaculture, there are few regulations, guidelines, and plans to minimize potential invasion risks. This is perhaps most relevant for aquaculture, because (a) the Micronesian region has a long history of aquaculture and (b) most countries and island groups are actively encouraging the expansion of aquaculture.

Few countries or island groups in the region have an articulated plan for aquaculture development and practices (such plans are being developed for Saipan and the RMI). We did not encounter any regulations that dealt with preventing escapes of non-native species or genetic material. Many of the species used for aquaculture are non-native and potentially carry a high risk of invasion, relative to accidental introductions, having been selected explicitly for traits including hardiness, rapid growth, and large body sizes, and for the ability to do well in the salinity and temperature regimes in the region.

Aquaculture species also present a risk of introducing plant pests, animal parasites, pathogens, and other hitchhikers that could impact the aquaculture species, native communities, or natural resources.

We found several gaps in biosecurity related to aquaculture, including:

- The decision process for permitting use of selected species for aquaculture, in terms of assessing possible risks of invasion, is often not well defined.

- While many of the countries and states in the region have regulations aiming at insuring that such imports arrive disease- and pest-free, there appears to be little capacity (including quarantine facilities and technical staff) to ensure that this is the case.

- Measures to prevent the escape of non-native aquaculture species have not been entirely successful. Breakage of pens, poaching, natural disasters (e.g. typhoons, floods), and other incidents have resulted in the release of non-native species.

Illegal aquaculture using non-native species also appears to be occurring to some extent in the region, in the form of small scale backyard aquaculture setups. On the whole, aquaculture policies and practices generally do not seem to be integrated with biosecurity plans or concerns, either on a regional basis or even within individual countries.

4.4.3 Live Trade and the Buildup

It is likely that the Buildup will result indirectly in some increased trade in live marine organisms for the following reasons:

- An increased demand for live seafood. Construction workers and other workers moving to the region to provide services for the increased number of service personnel and their families are expected to come from Asian countries in which fresh food, including live seafood, is highly prized. An increase in the island's population due to the Buildup is also likely generally to result in a greater number of people who can afford to purchase fresh, imported seafood.

- An increased demand for pets and aquarium species due to the expected increase in population and income.

- An increase in aquaculture ventures. As the population of Guam increases, aquaculture may be increasingly promoted as a way to provide local food and to replenish or replace dwindling wild-caught stocks.

It is not clear how management agencies will respond to minimize risks of invasions associated with any such increase in live organism trade. The enforcement of border and post-border regulations on trade in live organisms is the responsibility of civilian governments and outside of the jurisdiction of the U.S. military. Management agencies throughout the region appear to be operating at or beyond capacity at the present time, and are likely to be further taxes by any increases in activity unless systems across the board are enhanced and improved in step with any increases.

PART II.
Risk Assessment

Chapter 5: Assessment of Marine Invasion Risks Associated With Relocation of U.S. Marine Corps Forces to Guam

By Chad L.Hewitt, Marnie Campbell, Paul W. Fofonoff, and Mark Minton

5.1 Introduction

Global marine biosecurity efforts for the last several decades have focused on ballast water (and sediment) mediated species transfers, with several nations developing independent management arrangements while the international community moved towards a binding agreement (e.g., Gollasch et al. 2007; Hewitt et al. 2009a). Ballast water had been implicated as the most likely vector responsible for several high profile marine species invasions (e.g., Carlton 1985; 2001; Carlton and Geller 1993). Examples include:

- the global increase in toxic dinoflagellate blooms (Hallegraeff 1993);
- the introduction of the comb-jelly (*Mnemiopsis leidyi*) into the Black, Azov and Caspian Seas contributing to the collapse of the anchovy fishery (e.g., Kideys 2002);
- the dominance of the Asian clam (*Corbula* (*Potamocorbula*) *amurensis*) in San Francisco Bay, California (Nichols et al. 1990); and
- the invasion of the northern Pacific seastar (*Asterias amurensis*) into Hobart, Tasmania and Port Phillip Bay, Victoria (Ross et al. 2003).

The finalization of a ballast water convention by the IMO (International Maritime Organization 2005; see also Chapter 2 for discussion), following more than fourteen years of negotiations (Gollasch et al. 2007; Hewitt et al. 2009b, b), has resulted in a refocus on the potential for biofouling to transport species (e.g., Hewitt et al. 2009c, d). Biofouling has long been recognized as an introduction mechanism (e.g., Carlton 1979; Carlton and Hodder 1995) and has been increasingly identified as an equal if not greater risk than ballast water during the last decade (e.g., Hewitt et al. 1999, 2004; Thresher 2000; Gollasch 2002; Hewitt 2002, 2003; Lewis et al. 2003, 2004; Minchin 2006, 2007; Schaffelke et al. 2006; Schaffelke and Hewitt 2007; Hewitt and Campbell 2008, 2010; Lewis and Coutts 2010).

Despite increasing awareness of these transport mechanisms, our knowledge base is limited, resulting in the need for decision support tools that provide consistency and transparency during decision making in the face of uncertainty. Risk based decision frameworks for the management of ballast water mediated introductions have been under development since the mid-1990s. The implementation of these Decision Support Systems (DSS) has demonstrated the utility of risk analysis in the field of marine biosecurity.

Application to biofouling however has been slow.

Risk analysis is commonly used for management of such issues because pragmatic decisions can be made that provide a balance between competing environmental and socio-economic interests, despite limited availability of information (e.g., Hayes and Hewitt 1998; Campbell 2005, 2006, 2008, 2009; Hayes et al. 2004a; Hewitt et al. 2006; Barry et al. 2008; Campbell and Hewitt 2008, 2011).

In a marine biosecurity context, conventional risk assessment methodology consists of five steps:

1. Identifying endpoints (within biosecurity common endpoints are a breach in quarantine or a subsequent impact)

2. Identifying hazards

3. Determining likelihood

4. Determining consequences and

5. Calculating risk

This process is similar (following the five step process) to the risk management standard used in Australia and New Zealand (Standards Australia 2000, 2004) and the risk framework agreed by U.S. Aquatic Nuisance Species Task Force and National Invasive Species Council (2007). Marine biosecurity risk endpoints are typically (a) inoculation (breaking the quarantine barrier), (b) establishment, and (c) spread (Figure 5.1).

This chapter concentrates on developing an understanding of the hazards (i.e., potential non-native species which could be transported to Micronesia) and the relative likelihoods of their arrival, based on records of shipping over an 11-year period, resulting in an assessment of the most likely species to arrive in Guam which would break the quarantine barrier (inoculation endpoint) and spread subsequently to other jurisdictions of Micronesia and Hawai'i. Based on information collected from USCG ballast water reporting forms (see Chapter 4), the majority of vessels arrive fully laden and do not discharge ballast in Guam. The situation is less clear for the rest of Micronesia and for vessels transiting from Micronesia to Hawaii. Where vessels arriving to Guam do arrive in ballast, or need to undertake ballast management for trim during off-loading, the discharges are generally small. As a consequence of these low ballast discharge volumes, and also limited data availability for many parts of Micronesia, this risk evaluation concentrated on biofouling related transport alone.

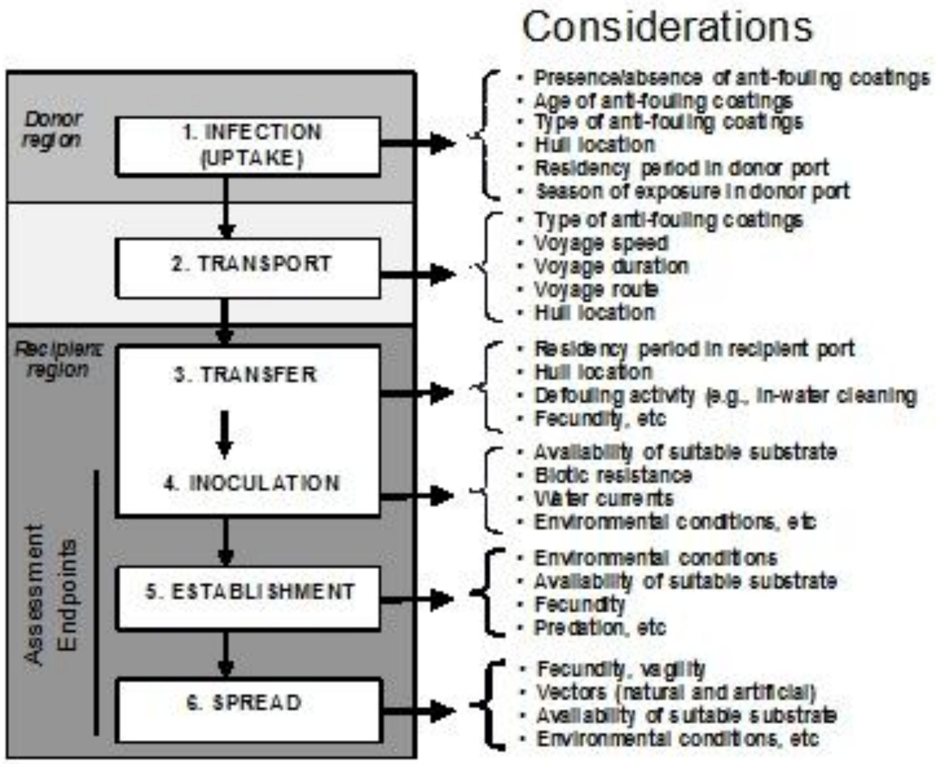

Figure 5.1. Conceptual model of the invasion process, with explicit identification of assessment endpoints in the recipient region and considerations in the risk analysis (adapted from Lewis and Coutts 2010).

5.2 Methods

This risk assessment followed the previously described five step process: identify endpoints; identify hazards; determine consequences; determine likelihood; and calculating risk (*sensu* Standards Australia 2000, 2004). For this assessment, consequence was deemed to be high for any species that was capable of "breaking" the quarantine barrier. Therefore, it evaluates risk across two identified endpoints, inoculation and spread (Figure 5.1), including the initial likelihood of inoculation to Guam was subsequently evaluated for spread to other jurisdictions of Micronesia and Hawai'i (Figure 5.2). This risk assessment focused on two elements: (a) the likelihood of a species' arrival to Guam, and to Micronesia as a whole and Hawai'i, and (b) evaluating the arrival likelihood independently for each Micronesian State and Hawai'i and via Guam. Likelihood was determined based on analysis of international vessel voyages prior to entry into Micronesia between 1999 and 2009, and Hawai'i between 2006 and 2011, to determine the exposure to global bioregions and using information on the global distribution of known non-native marine species to determine the likelihood of transport. This data range was the most recently available at the time that the analysis was undertaken and the period for which information on the majority of vessel types was available. Earlier records were not used due to data inconsistencies and cost constraints.

Global non-native marine and estuarine species data derived from Hewitt and Campbell (2008, 2010) were used as a starting point to identify hazards (i.e., marine and estuarine species with known invasion history), with significant effort by the current team to update the known information on global marine and estuarine invasions through literature and web-based reviews of species reports for known invaders and collection of reports of new invaders.

Global non-native marine and estuarine species were categorized as hazards based upon their potential to breach the Micronesian quarantine border, as demonstrated by a history of invasions in other regions.

Based on information collected from ballast water reporting forms, the majority of vessels arrive fully laden and do not discharge ballast in Guam (see Chapter 3). Where these vessels do arrive in ballast, or need to undertake ballast management for trim during off-loading, the discharges are generally small. However, as outlined in Chapter 3, the data for ballast water discharges is incomplete for Guam, especially for U.S. Navy vessels, and also for all ships in other countries throughout Micronesia.

This risk evaluation concentrated exclusively on biofouling related transport alone. The movement of vessel’s hulls themselves (instead of ballast water) is the mode of transport for organisms which is analyzed here, and extensive information on geographic origins and traffic history for commercial and MSC vessels was obtained for this analysis. Data on vessel traffic was not available for U.S. Navy combatants, due to concerns about national security (see Chapter 1), and were therefore excluded entirely from this analysis. Hull biofouling is a key vector for marine introductions, as summarized below (see also Chapter 1), and biofouling by ships may provide a useful model for evaluating marine invasion risks.

5.2.1 Identifying Endpoints

The endpoint of the risk analysis is a critical stage in scoping the context of the assessment and determines the detail of consequence analysis to be used (e.g., Campbell 2006, 2008). For example, unintentional introductions of non-native marine species associated with the movements of species, feed stocks, and movement of equipment would typically consider quarantine endpoints – that is any un-permitted breach of the border (e.g., Hewitt and Hayes 2001, 2002; Hayes 2002; Campbell 2006, 2009). Marine biosecurity risk can be evaluated across three endpoints, inoculation (or entry), establishment, and spread.

This risk assessment focuses primarily on the international entry of vessels (inoculation endpoint) into Guam and the subsequent assessment of spread to other jurisdictions of Micronesia and Hawai’i, with less extensive evaluations of establishment. It is worthwhile to note that while the role of Guam as a shipping hub for the Micronesia region and as a primary departure point for shipping heading from Micronesia to Hawaii is important, there are other potential direct and indirect routes for shipping in the region, all of which may assist in the spread of non-native species to both individual jurisdictions as well as the region as a whole. For example, there is shipping from various Asian ports directly and indirectly to a variety of the jurisdictions of Micronesia as well as ship movement between various islands of Micronesia that may or may not include stops in Guam.

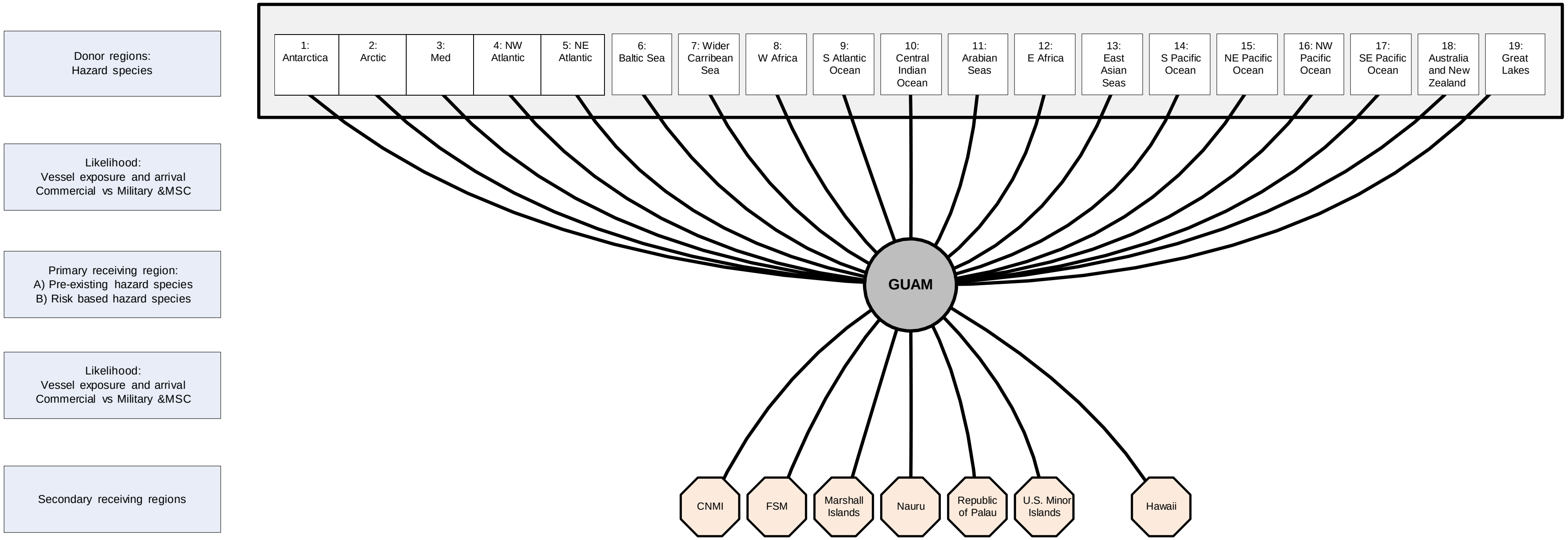

Figure 5.2. Conceptual model of this risk assessment.

5.2.2 Identifying Hazards

Hazards have been defined in this context as non-native marine and estuarine species that:

- have the potential to transcend the Micronesian quarantine border and
- have demonstrated or inferred potential to cause impact.

A comprehensive assessment of the recognized marine and estuarine invasions from throughout the globe was conducted building upon the work undertaken by Hewitt and Campbell (2008) and Hayes et al. (2004a). This provided the basis for identifying species level hazards. This report has compiled information from over 1,000 data sources including primary (peer reviewed journals and books) and secondary (‘grey’ literature such as websites, policy documents, online databases, reports; typically not peer- reviewed) literature, and information derived from a number of researchers.

Data for global species distribution was recorded using the 18 large scale IUCN marine bioregions (Kelleher et al. 1995) identified in Hewitt and Campbell (2008) (Figure 5.3). These are considered close representatives of widely accepted biological provinces rather than the finer scale ecoregions of Spalding et al. (2007) or the Large Scale Marine Ecosystems (Watling and Gerken 2004). The designation and use of biogeographic boundaries has engendered significant debate in the literature, however the use of provinces with recognition of overlapping boundaries provides the basis for the Kelleher et al. (1995) designation. This system creates a sequence of ‘core’ and ‘transitional’ areas which are roughly equivalent to the Spalding et al. (2007) ‘ecoregions’ used by Molnar et al. (2008). Hayes et al. (2004a) used these ‘core’ and ‘transitional’ areas described by Kelleher et al. (1995) in their identification of ‘next pests.’ However, these finer scale regions do not represent provincial boundaries and therefore do not offer a conservative approach to estimating species distributions.

By recording species at the bioregion level it is assumed that the species is present in all ports in the bioregion. Due to limitations on the data available from many parts of the world, and the rapidity with which species can be transported and spread within a region, this assumption avoids an overly restrictive data collection exercise. Also, pragmatically, data are simply not available on occurrence for a finer-grain spatial scale for many marine species.

The database of global marine and estuarine introductions developed here now includes 2,365 species. Over 98% of the 2,365 species were allocated to possible transport vectors. This followed the criteria and methods proposed by Hewitt and Campbell (2008, 2010) and was based on:

- examination of life history characteristics (at the species level where available);
- morphological characteristics and
- habitat distribution.

Where species-level information was not readily available, genus-level characteristics were used to classify morphological characteristics and habitat associations.

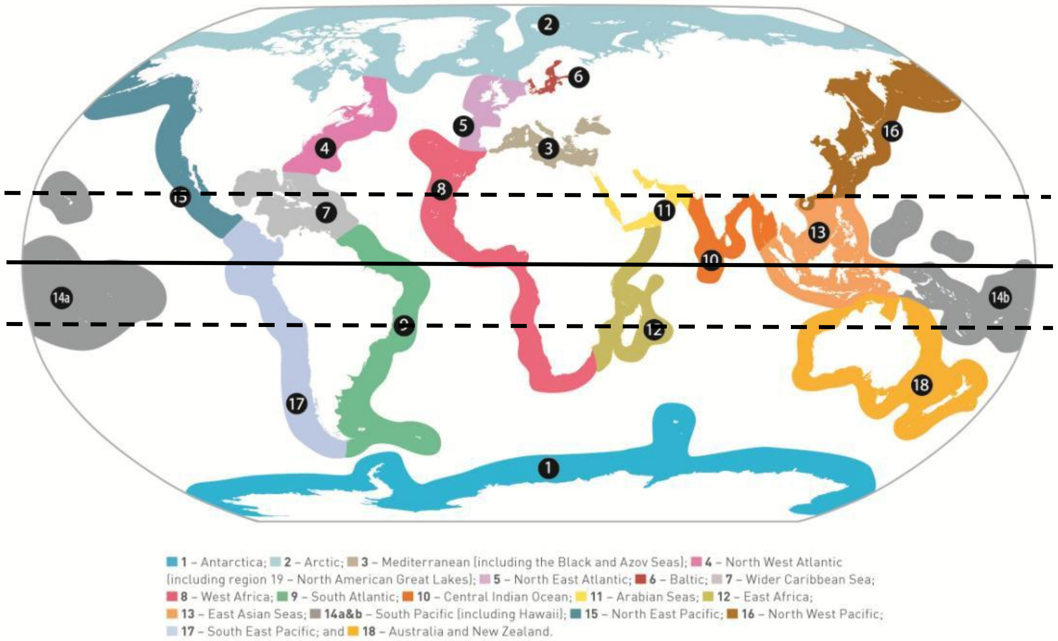

Figure 5.3. IUCN Bioregions as defined by Kelleher et al. (1995) and modified following Hewitt and Hayes (2002). Solid line represents the equator (0º) and dashed lines represent the tropics (±23.5º) [Figure from Hewitt et al. 2011; provided with permission from Australian Department of Agriculture, Fisheries, and Forestry (DAFF)]

The global dataset indicates that more species have life history characteristics associated with vessel traffic (ballast water and biofouling combined) than any other vector (Figure 5.4).

This species dataset was restricted further on the basis of records of species in each of the jurisdictions of Micronesia. Within the global dataset, 136 species are recognized as native to Micronesia resulting in a reduction to 2,229 species that have a known history of invasions and are not naturally present in jurisdictions of Micronesia. An additional 109 species are recognized as non-native or cryptogenic in Guam, restricting the hazards to Guam to 2,120 species. A total of 1,358 species were identified as being associated with vessel biofouling in the global dataset, and 1,241 of these species were not known to be present in Guam. Of the 109 non-native or cryptogenic species to Guam, 84 are associated with biofouling. Not all species currently introduced to Guam are present at other Micronesian locations resulting in a latent risk to the various jurisdictions of Micronesia (except Guam) and Hawai'i from Guam identified in Table 5.1.

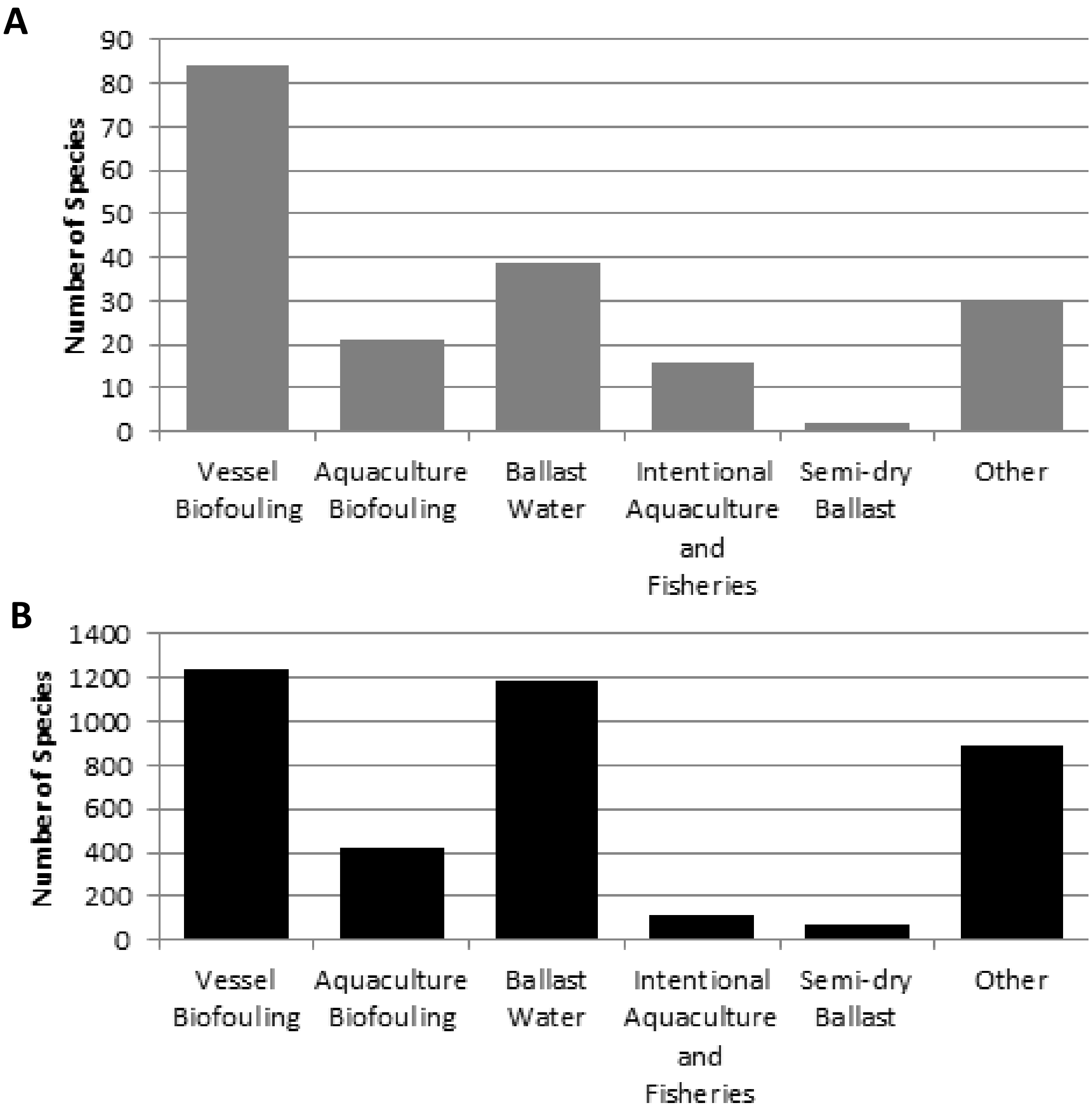

Figure 5.4. Number of non-native and cryptogenic species identified in the global dataset as present in Guam (A) or absent from Guam (B), which are likely to be transported by different vectors.

**Table 5.1. Potential exposure to non-native and cryptogenic species already present in Guam (109) or globally (2,365) that are not known to be present in the various jurisdictions of Micronesia (except Guam)or Hawai'i, for A) all transport vectors
and B) restricted to species inferred to be transported by biofouling. FSM = Federated States of Micronesia; RMI = Marshall Islands; CNMI = Commonwealth of the Northern Mariana Islands; Palau = Republic of Palau; UMI = United States Minor Islands; HI = U.S. State of Hawai'i**

A) All Transport Vectors

Potential Exposure	*Guam*	*FSM*	*RMI*	*CNMI*	*Palau*	*UMI*	*HI*
Guam (109)		83	79	91	82	100	30
Global (2365)	2,120	2,226	2,238	2,256	2,242	2,297	1,898

B) Biofouling Transport

Potential Exposure	*Guam*	*FSM*	*RMI*	*CNMI*	*Palau*	*UMI*	*HI*
Guam (84)		65	61	74	66	77	20
Global (1358)	1,241	1,293	1,297	1,333	1,324	1,341	1,018

5.2.3 Determination of Likelihood

The likelihood (or probability) of an event occurring was categorized using a likelihood matrix (Table 5.2). In this risk assessment the likelihood of a biofouling species not currently present in Guam was assessed as a function of the proportion of vessel arrivals in Guam that were likely to transport a species based on the voyage histories of vessels and the global distribution of species. For example, if more than 75% of the vessel arrivals in Guam had visited bioregions with Species X during a voyage duration of 365 days, then Species X would be categorized as having a "high" likelihood of inoculation for the 365 day window: this is an expansion (to include probabilities) on the standard likelihood matrix that has been used in marine biosecurity assessments in New Zealand

(Campbell 2005, 2008; Campbell et al. in review), Australia (Campbell and Hewitt 2011) and the Mediterranean (Campbell 2006). Two significant likelihood endpoints were identified for evaluation of international biofouling species:

- inoculation of species to Guam
- spread from Guam to other jurisdictions of Micronesia.

Table 5.2. Likelihood measures for marine biosecurity risk analysis (modified from Campbell and Gallagher 2007). An event is defined as an activity that may lead to an undesirable outcome.

Descriptor	Description	Probability of event occurring
Negligible (N)	The event is unlikely to occur	<1%
Extremely Low (EL)	The event will only occur in exceptional circumstances	1-10%
Very Low (VL)	The event could occur but not expected	10-25%
Low (L)	The event could occur	26-50%
Moderate (M)	The event will occur in many circumstances	51-75%
High (H)	The event will occur in most circumstances	76-100%

5.3 Inoculation to Guam

The likelihood of species inoculation to Guam was evaluated as transport pressure for each species (ranked negligible to high). Transport pressure can be derived from:

- the species uptake/settlement opportunity to colonize the vessel based on connection with overseas ports,
- the number of vessels arriving from regions where the species is present based on extended voyage characteristics (ranging from 30 days to 5 years) and
- species transport survival based on physical and physiological stress during the voyage.

Several assumptions were made in this analysis:

1. Species were assumed to be able to infect a vessel (via biofouling settlement) at any time throughout the year (equivalent to assuming reproductive activity throughout the year).
2. Species detected in a bioregion and reported in the literature were assumed to have established in the bioregion.
3. Species detected in one location within a bioregion were assumed to be present in all areas (ports) of a bioregion.
4. Vessels were assumed to have some areas without fully active antifouling coatings, such that they were vulnerable to colonization by biofouling organisms;
5. Vessels were assumed to have some areas protected from the hydrodynamic (sheer) forces created by vessel speed.
6. Inoculum pressure was calculated for all of the target locations (jurisdictions of Micronesia or Hawai'i) rather than on a port by port basis.
7. All vessel categories were assumed to be equally able to transport all species.
8. All pathways from various bioregions to Micronesia are equally 'stressful' (e.g. no influence of trans-equatorial transits).
9. Only species listed in the invasive species database are considered a threat, or can be introduced.
10. The invasive species database has complete distribution records for all species.
11. Cryptic diversity, while known to be common in marine organisms, is ignored.

5.3.1 Transport Pressure

Transport pressure was comprised of several elements including:

- the transport frequency (number of opportunities for transport),
- a measure of how readily a species can survive the transport process and
- the inoculation opportunity for a species to depart the vessel and settle in the receiving port.

Similar to the analysis by Hayes et al. (2004a), this assessment assumes that the opportunity for organisms to be transported is directly correlated with the number of ship visits from a region. In keeping with previous assessments (Hayes and Hewitt 1998, 2000; Hayes and Sliwa 2003; Hayes et al. 2004a; Barry et al. 2008), it also assumes that a species record in a bioregion is considered a demonstration of establishment throughout the bioregion, and that all ports in that bioregion are infected.

For the purposes of transport pressure the element of assessment is the vessel, therefore the demonstration of a species likely presence in/on a vessel is the focus, rather than the abundance of a species in/on any individual vessel.

Analysis of vessel activity was initially based on the Lloyds Maritime Intelligence Unit dataset (hereafter Lloyds MIU dataset) representing commercial vessels, petroleum vessels, non-trading vessels, naval vessels, commercial fishing vessels and recreational vessels (>25

m) entering Micronesia from 1999 – 2009 and including all ports of call during this period (this of course does not include items such as the numerous smaller yacht which enter and depart the various jurisdictions of Micronesia and Hawaii). The Lloyds MIU dataset allowed a further differentiation of vessel categories, including separating petroleum vessels from commercial (merchant) vessels, and identifying sub-categories of non-trading vessels.

The Lloyds MIU dataset represents an accumulation of Port State reports and does not represent a complete set for a number of vessel categories. Vessels not able to be self-propelled (barges) are rarely recorded by Port State control. Similarly vessels under 25m length, such as recreational vessels and fishing vessels, are rarely recorded. Military vessels frequently claim sovereign immunity and do not report to Port State control but are hosted by local military. As a consequence, the DoD was requested to provide entry and voyage information on Military vessels, specifically MSC and Warships. Entry information was provided for MSC vessels with limited voyage history; however Warship entry information was only provided for a three year period (2008-2010) and did not include voyage history (see Chapter 3). As a consequence, warships (combatants) could not be assessed herein.

The Lloyds MIU dataset required significant error checking for overlapping voyage statistics. To reduce the overlapping voyage statistics in which individual vessels are represented in multiple records (i.e., locations) at the same time, records from earlier than 1999 were removed as consistency of reporting could not be verified. Poor spatial resolution such as designation of ports as ‘Pacific Ocean,’ ‘Australasia,’ and ‘Southeast Asia’ were assigned to IUCN bioregions where unequivocal, or removed from the dataset. These changes resulted in <5% removal rate for the Lloyds MIU dataset.

Vessels are not of a consistent size, nor do they ‘behave’ in an identical fashion (e.g., Carlton 1985, 1996, 2001; Hewitt et al. 1999, 2004; Ruiz et al. 2000; Gollasch 2002; Fofonoff et al. 2003; Minchin 2006). As a consequence, vessels were divided into a number of categories (and further into subcategories where appropriate) to reflect the various management regimes and previously recognized differences in vessel activity (e.g., Ribera and Bouderesque 1995; Ruiz et al. 2000; Carlton 2001; Lewis et al. 2004; Floerl and Inglis 2005; Floerl et al. 2005; Minchin 2006; Hulme 2009). These are assumed to approximately correspond to vessel behaviors (e.g., maintenance history, voyage characteristics, speed [see Section 5.3.1.3]) however; it has been assumed here that no particular vessel characteristic is more or less likely to transport a species.

Vessel categories identified in the Lloyds MIU dataset include (see glossary also):

- **commercial vessels** including merchant vessels and cruise ships,

- **petroleum production and exploratory industry vessels** including offshore anchor handling/support/supply, pipe laying vessels, drilling platforms/ships and floating production, storage and offloading (FPSO) given they are solely employed within the sector,

- **naval vessels** (both foreign and domestic) including primarily naval auxiliary tankers and MSC vessels,

- **non-trading vessels** which encompass a wide variety of vessel types including the sub-categories of tugs, research vessels, dredges, barges and yachts > 25 m or super yachts (differentiated based on differing behaviors including speed, duration in port, and voyage characteristics) and

- **fishing vessels** including commercial vessels engaged in the industry of capturing wild stocks of living marine resources: fishing (general); trawler (all types); whaler; fish carrier; and fish factory.

As stated above, petroleum industry vessels represent a significant class of commercial (merchant) vessel with widely varying characteristics including long residence times and slow speeds for some vessel types.

Elements of transport pressure are further analyzed below.

5.3.1.1 Opportunity to Infect the Vessel in the Donor Port.

The opportunity for a species to infect (e.g., be taken up in ballast water, settle on or recruit to) a vessel is a combination of the location of operations, the timing of the opportunity being coincident with a reproductively active period for sessile and sedentary species, maintenance history (including antifouling paint condition), and the amount of time available for a species to settle or colonize the vessel.

Biofouling community development begins as soon as materials are placed in the water (e.g., Sutherland and Karlson 1977; Floerl 2002; Prendergast 2010). As a consequence, shortly after being cleaned (in dry-dock or in the water), the settlement of marine organisms and development of a biofouling community begins (see Hayes et al. 2004b; Lewis et al. 2004; Jenkins and Martins 2010). The rate of this development can be reset or delayed through various means, including in-water cleaning and appropriate application of antifouling paints. However, when the vessel is taken as a whole, the ’niche‘ biofouling areas including sea-chests, bow and stern thrusters, propellers, propeller shafts and rudder areas are likely to have established biofouling communities shortly (3 – 6 months) after cleaning or antifouling paint application (e.g., James and Hayden 2000; Floerl 2002; Hayes 2002; Coutts et al. 2003; Coutts and Taylor 2004; Hayes et al. 2004b; Lewis et al. 2004; Piola et al. 2009). Therefore, few limitations to settlement exist for any individual species when considering the vessel as a whole, hence, all vessels can be colonized.

Settlement opportunity for some species also involves an element of timing. Mobile species associated with biofouling have the ability to swim to the vessel hull or into niche areas; therefore no restriction on the timing of settlement occurs. For species that are sessile or sedentary, typical means of establishing in a new location are either by accidentally getting ‘swept’ to another location by hydrodynamic forces (e.g., waves, propeller wash, currents), or by reproduction. Many sessile or sedentary marine species spawn gametes (reproductive elements) into the water column where fertilization and development occurs, or hatch larvae directly into the water column – these species are known as meroplankton since they spend a portion of their life-cycle in the water column. Once development has progressed sufficiently (ranging from minutes to months for different species), the larval form is able to settle onto hard substrate by metamorphosing into an adult.

In order for a meroplanktonic species to be taken into the ballast of a vessel or to settle on a vessel, it is necessary that the species' timing of reproduction (reproductive phenology), and settlement viability for biofouling species, is coincident with the duration in port. Assessing settlement opportunity directly requires a significant increase in our current state of knowledge – there is limited data on the timing or triggers (cues) of reproduction for many non-native marine and estuarine species, particularly in non-native regions. This is particularly important as non-native species expanded on their realized niche to utilize their fundamental niche and hence they often behave in ways that are not recorded within the literature. For example, *Mytilopsis sallei* (black striped mussel) in Darwin harbor, Northern Territory, Australia, produced two, potentially three cohorts in a seven-month period (Campbell and Hewitt unpubl. manuscript). In Hong Kong Harbor, where it is also introduced, it produces two cohorts per 12 months (Morton 2009).In its native environment, *M. sallei* reproduces once every 12-18 months (e.g., Kalyanasundaram 1975). Similarly, the larval durations and metamorphosis requirements have yet to be determined for many non-native species.

Given that settlement opportunity acts to reduce risk, it is more conservative to assume that all species reproduce year-round and therefore have the ability to inoculate any vessel that comes to port, regardless of port stay duration. As more information comes to light, or when the focus is reduced to a smaller subset of species, better life-history information can be obtained and applied to refine predictions in a management context.

5.3.1.2 Transport Frequency.

The number of vessel entries arriving from each bioregion (LPOC) over the period from 1999 to 2009 was calculated as a total across all vessel categories and for MSC. For each of the 1,241 biofouling species not currently established in Guam, the number of vessels arriving from bioregions in which the species was known to be present, either as a native, cryptogenic or a non-native marine species based upon the revised species database from Hewitt and Campbell (2008; 2010), was calculated to represent the raw transport frequency of each species. This number represents the number of potential opportunities for the species to have been transported into Guam waters over the 11-year period based on voyage histories.

In contrast to ballast water transported species, biofouling species accumulate since the last cleaning (including in-water cleaning, dry-docking or antifouling paint application); however this data is infrequently available for evaluation. Most commercial vessels have dry-docking rotations of greater than three years and up to five years (Lewis 2002a; Davidson et al. 2009). In order to capture the likely accumulation of species, the influence of voyage duration on species exposure was assessed by creating voyages into classes of 30 days, 60 days, 90 days, 183 days, 365 days (1 year), 730 days (2 years), 1,095 days (3 years), 1,460 days (4 years), and 1,825 days (5 years) prior to entry into Guam.

The commercial and MSC fleet entering Guam traded with all global bioregions within voyage durations of 365 days (1 year) for either commercial or MSC vessels (Figure 5.5). In other words, the vessels entering Guam had visited all 18 global bioregions within 365 days prior to arrival.

Transport patterns differed between bioregions (Figure 5.6). The increase in transport frequency from bioregions (i.e., number of vessels that had previously visited a particular bioregion) as voyage durations are increased from 30 days to 365 days can be seen with the addition of lighter shades of grey. As would be expected, more distant bioregions such as the North West and North East Atlantic, Wider Caribbean, and the Arabian Seas are largely represented in voyage lengths greater than 183 days.

Commercial vessels (Figure 5.7A) are unevenly distributed across bioregions (Simpsons Evenness = 0.518), with a higher connection (>800 vessel entries) to the East Asian Seas and South Pacific Ocean and a second tier of association (>400 vessel entries) to NE Atlantic and Central Indian Ocean. In contrast, MSC vessels (Figure 5.7B) are more even in their biogeographic spread (Simpsons Evenness = 0.658) with high connectedness (>800 vessel entries) to the Wider Caribbean, NW Atlantic, NW Pacific East Asian Seas and Arabian Seas, and a second tier of association (>400 vessel entries) to the South Pacific, NE Pacific, SE Pacific and Australasia.

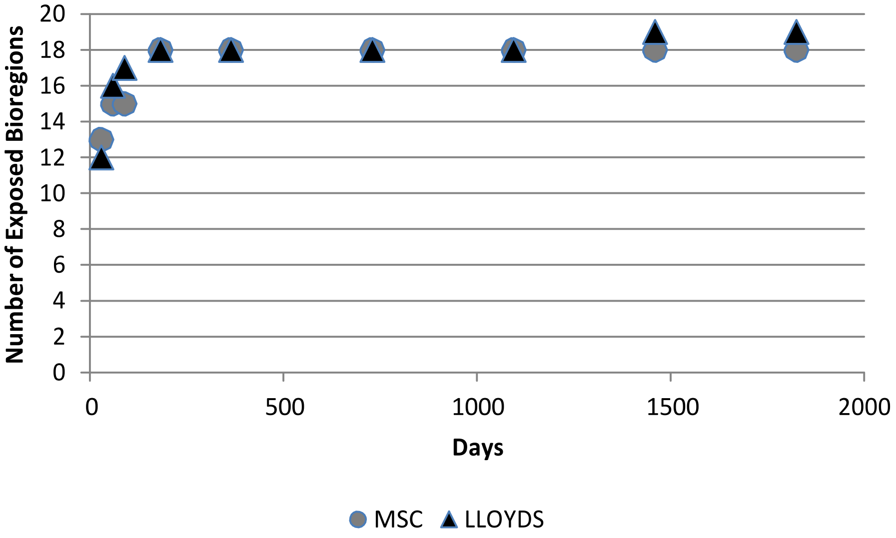

Figure 5.5. Number of bioregions visited by vessels entering Guam between 1999 and 2009 with increasing voyage duration (data from Lloyds MIU and DoD datasets).

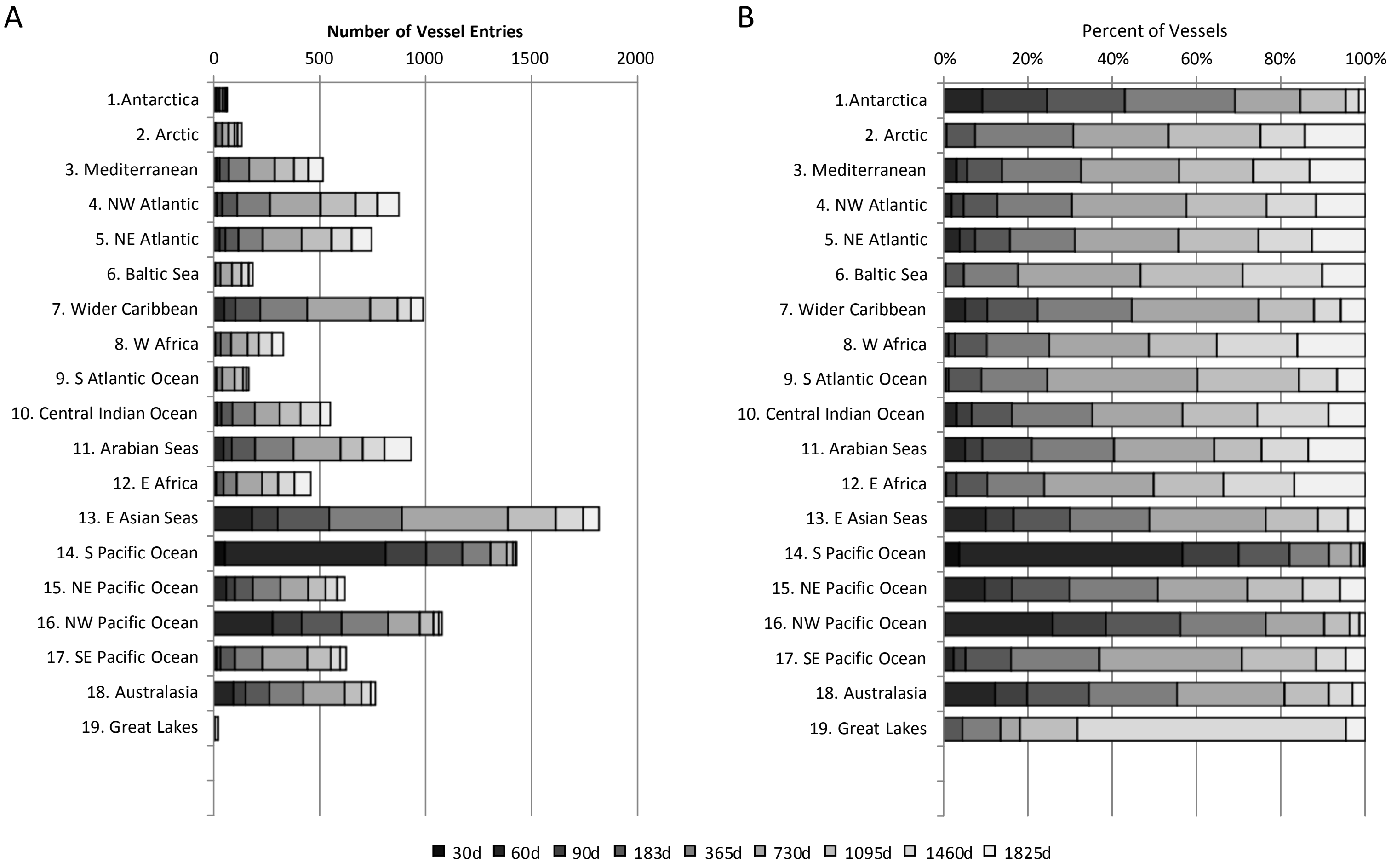

Figure 5.6. Number and percentage within a bioregion of all vessel (all categories of commercial and MSC vessels) entries to Guam from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU dataset and DoD dataset).

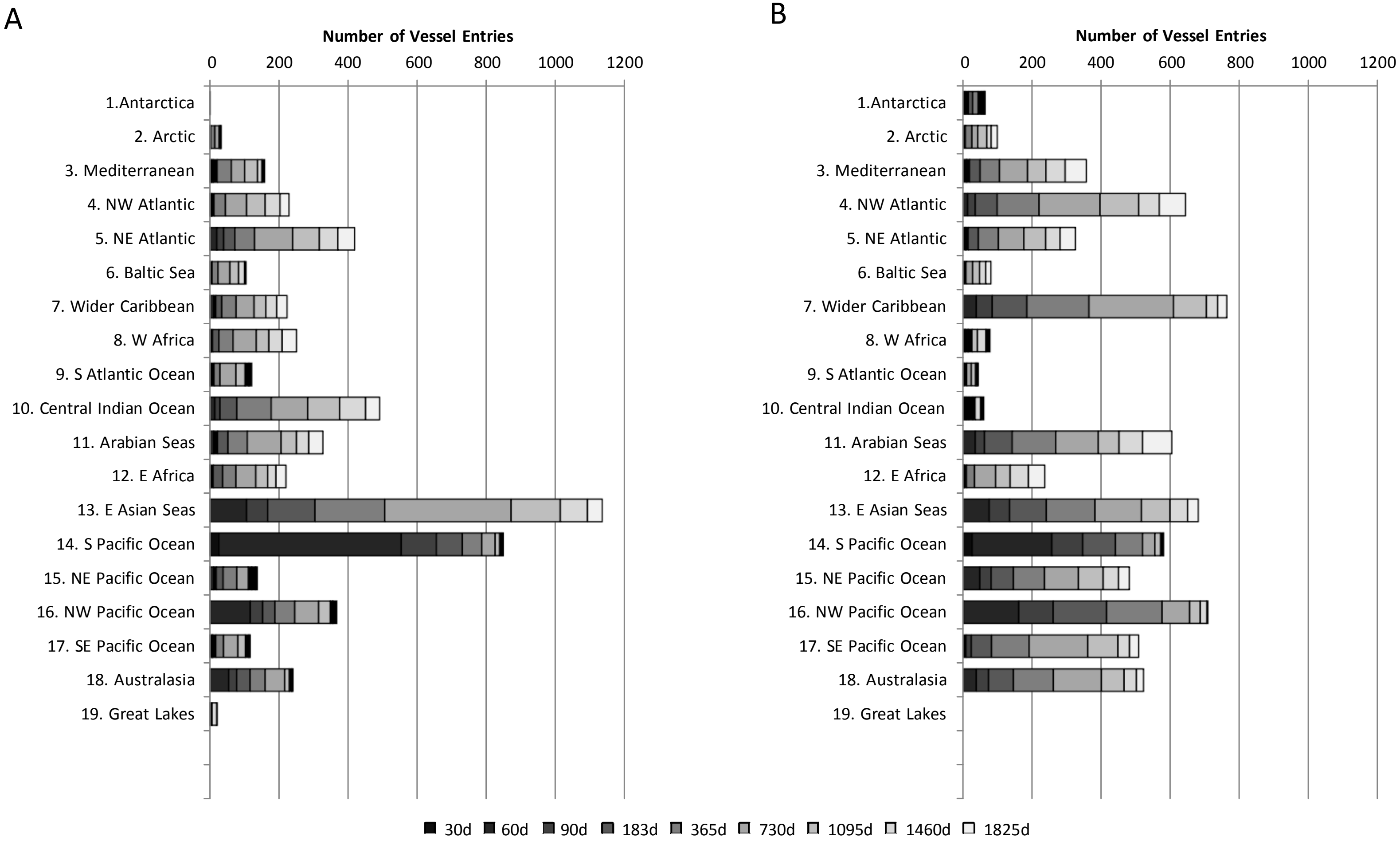

Figure 5.7. Number of A) commercial vessels (all categories) and B) MSC vessel (all categories) entries to Guam from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period (Lloyds MIU and DoD datasets).

5.3.1.3 Transport Survival.

The transport process can create significant physical and physiological stresses on species that influences the ability of a species to survive a voyage.

Physical stress on species is primarily associated with vessel speed, with several studies demonstrating the relationship between speed and shear stress on species survival (e.g. Coutts 1999; Davidson et al. 2009; Coutts et al. 2010a, b). Analyzing the Lloyds MIU dataset for vessel speeds across vessel categories (Figure 5.8) revealed no significant differences across the broad vessel categories, despite significant differences between individual vessels within categories. Vessels in the categories commercial, petroleum, non-trading (specifically tugs, barges, and dredges), illegal foreign fishing vessels (IFFVs) and recreational vessels are known to operate under slow speeds, which can support significantly increased survival (e.g., Floerl and Inglis 2005; Floerl et al 2005; Davidson et al. 2009; Coutts et al. 2010a, b).

Additionally, while vessel speed is correlated with species presence on exposed hull surfaces (e.g. Coutts et al. 2010a, b), numerous protected niche areas such as sea-chests (e.g., Coutts et al. 2003; Coutts and Taylor 2004; Coutts and Dodgshun 2007), bow and stern thrusters, propellers and propeller shafts, will act to provide species the opportunity to survive despite high vessel speeds (e.g., James and Hayden 2000; Hayes 2002; Coutts and Taylor 2004; Hayes et al. 2004b). As a consequence, speed may not provide differentiation between vessel types or significantly reduce risk.

Physiological stress can be created by the type and condition of antifouling paints (e.g., Piola and Johnston 2006) as well as the voyage route. Antifouling paints are explicitly designed to minimize and delay the settlement of epibenthic species on the hull surface. Exhaustive research accounts detail the efficacy and various failures of antifouling paints (e.g., Minchin 2006; Dafforn et al. 2008; see also various publications in the journal *Biofouling*). Most recently, the ban on organotin paints, specifically tri-butyltins (TBTs) has increased the investigations into viable alternatives and resurrected the concerns over biofouling mediated invasions. Note, that Navy and Coast Guard vessels are exempt from the ban on organotin paints. Antifouling paints differ significantly in their intrinsic effectiveness, but also vary according to the method and location of application (Lewis 2002; Lewis et al. 2004; Piola et al. 2009). From a management perspective, information on antifouling paint type, application procedures, efficacy and timing of application is difficult to obtain. As a consequence, the use of antifouling paint information was not considered in this risk assessment.

Physiological stress associated with exposure to changing environmental conditions is likely for biofouling species associated with the external hulls of vessels. Transport between high or mid-latitude regions on either side of the equator will expose species to the physiological stresses of increased water temperature during transit. Similarly, freshwater species in transit across oceanic barriers (e.g., between the North American Great Lakes and the inland waters of Europe) will experience fully marine waters during transit across the North Atlantic. Many trade routes to Micronesia include a significant change in latitude, or transits accompanied by a freshwater transit through the Panama Canal, or a high salinity transit of the Suez Canal. Quantifying the effect of these transits is difficult without specific laboratory analyses of physiological tolerance and exposure for individual species. As this factor only acts to **decrease** the likelihood of transit survival, leaving it out of the current assessment provides a conservative result until definitive information is available. Therefore we have assumed that all voyage pathways are equally stressful.

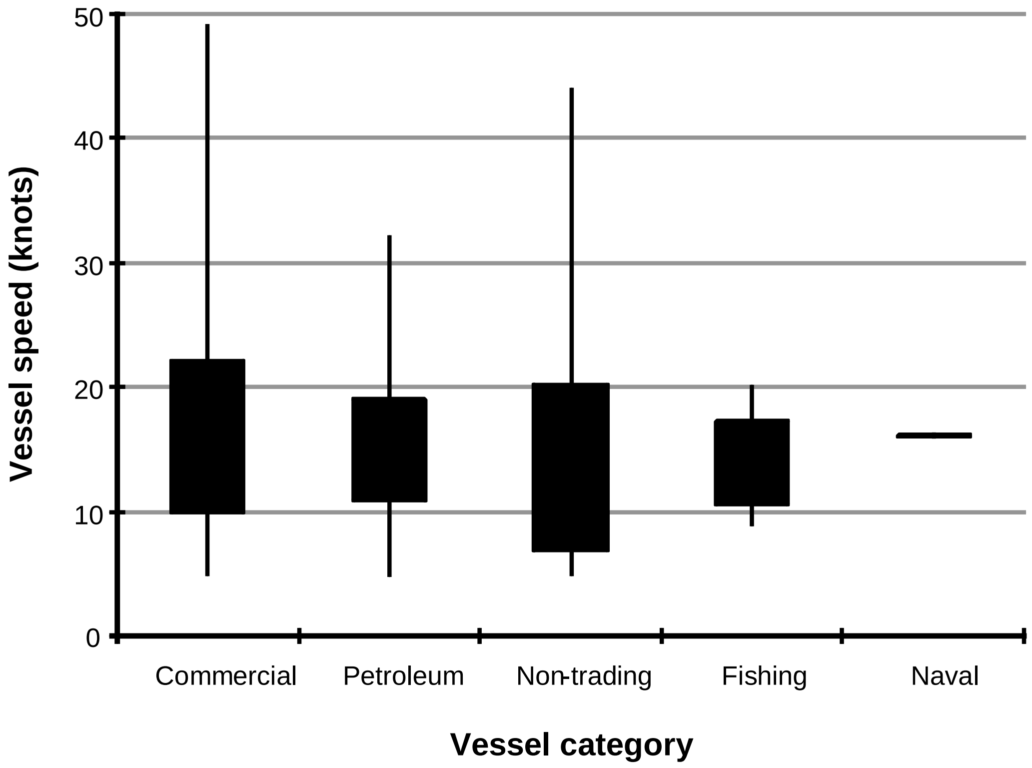

Figure 5.8. Reported speeds for vessels based on vessel categories (maximum/minimum reported range indicated by line, 90%confidence intervals around the mean represented by blocks). Slow moving drill rigs and drill ships have been estimated to have a vessel speed of 5 knots and are included in with petroleum vessels; recreational vessels >25 m are included in non-trading vessels. Vessel speeds for IFFVs and recreational vessels <25 m could not be obtained. Data from the Lloyds MIU dataset (Hewitt et al. 2009e).

5.3.1.4 Inoculation Opportunity.

Similar to the opportunity for species to settle in the donor port, attached biofouling species need to either reproduce (sexually or asexually) or be scraped off the hull to inoculate a receiving port. Any sedentary, infaunal and mobile fauna associated with biofouling assemblages (e.g., gastropods, crabs and other mobile crustaceans, small fishes such as blennies and gobies, seastars), including those occurring in sea-chests, will have increased opportunity to depart the vessel either by being dislodged or by swimming or dropping off the vessel. Inoculation opportunity is typically believed to be a function of port duration, and the reproductive maturity or vagility (ease of movement) of individual species.

As with the previous discussion, reproductive activity can be influenced by many factors including the intrinsic maturation rate of the individual, and extrinsic factors such as temperature and day length (e.g., Minchin and Gollasch 2003). These influences on reproduction are difficult to ascertain and expected to vary among ports. The action of being scraped off a hull is a stochastic process and depends on a number of elements including the species location on the hull, type of antifouling coating, its attachment mode, and the handling of the vessel in port. The vagility of sedentary and mobile fauna associated with biofouling is, by definition, high. These species are capable of moving and will therefore have the opportunity to leave the vessel at any time once in port. As a consequence, biofouling and biofouling associated species were assumed to have the ability to reproduce (sexually or asexually), escape and/or swim away or be scraped off, all year around.

5.3.2 Summary of Inoculation to Guam Likelihood

One approach to estimate likelihood is to determine the relative number of opportunities for a species arrival and entry into a new location as outlined previously. To reiterate the various assumptions used in this approach: species were assumed to be present in all areas (ports) of bioregions to which they had been introduced or were native; all vessels were deemed to have an equal opportunity of a species settling, regardless of time of year or of time since dry-docking, in-water cleaning or antifouling paint application; and all transport pathways were considered to be equally stressful. Note that this is a conservative estimate and it is not currently possible to refine further as data are not sufficient at the present time for this.

To determine likelihood of inoculation for an individual species, the number of vessels arriving from all bioregions where that species was present (as a native, cryptogenic or non-native population) was summed to provide a cumulative number of vessel opportunities for that species to be transported into Guam. This value was then divided by the number of vessels entering Guam to provide the percentage of total opportunities for entry as a relative measure. This relative probability was then categorized into Likelihood probabilities (Table 5.2) to provide a categorical rank for each of the nine voyage periods (30 days, 60 days, 90 days, 183 days, 365 days, 730 days, 1,095 days, 1,460 days, 1,825 days) as a function of percentage of total visits (Figures 5.9 & 5.10).

Twenty-one per cent (n=264) of the 1,241 biofouling associated non-native species not present in Guam were identified as having a negligible inoculation likelihood in the initial 30 day voyage period (Figure 5.9B), however the number of species categorized as “Negligible” reduced to 8% for 60 day voyages and subsequently to <1% for voyages greater than 365 days. In other words, as the assessment examined longer voyage durations, more bioregions were visited resulting in fewer species assessed as having less than 1% of vessels likely to transport the species.

In contrast, more than 18 per cent of the 1,241 biofouling associated non-native species not in

Guam were ranked as having Moderate or High inoculation likelihood across all voyage lengths and vessel types (ranging from 26.3% in 30 day voyages to 18.3% in 1,825 day voyages), with **72 biofouling species having a “High” likelihood** (>75% probability) and **155 biofouling species having a “Medium” likelihood** (>50% probability) of inoculation to Guam after 1,825 day voyages (5 years) (Table 5.3).

In evaluating the inoculation likelihoods, the relative contribution of MSC vessels to the number of “High” and “Medium” likelihood species were examined. Military vessels were found to increase the “High” likelihood of inoculations for voyages greater than 60 days (2 months), with a peak after voyages of 183 days (40 species), reducing to a shift of 10 species for 1,460 days (4 years) and 1,825 days (5 years) voyage lengths (Figures 5.9, 5.10 & 5.11). These shifts in additive inoculation likelihood attributed to military vessels is greater than their contribution to vessel numbers alone, particularly recognizing the significant limitations of data gaps and noting that MSC vessels are likely to spend a greater amount of time in port, thus increasing both the vessel infection and port infection likelihoods.

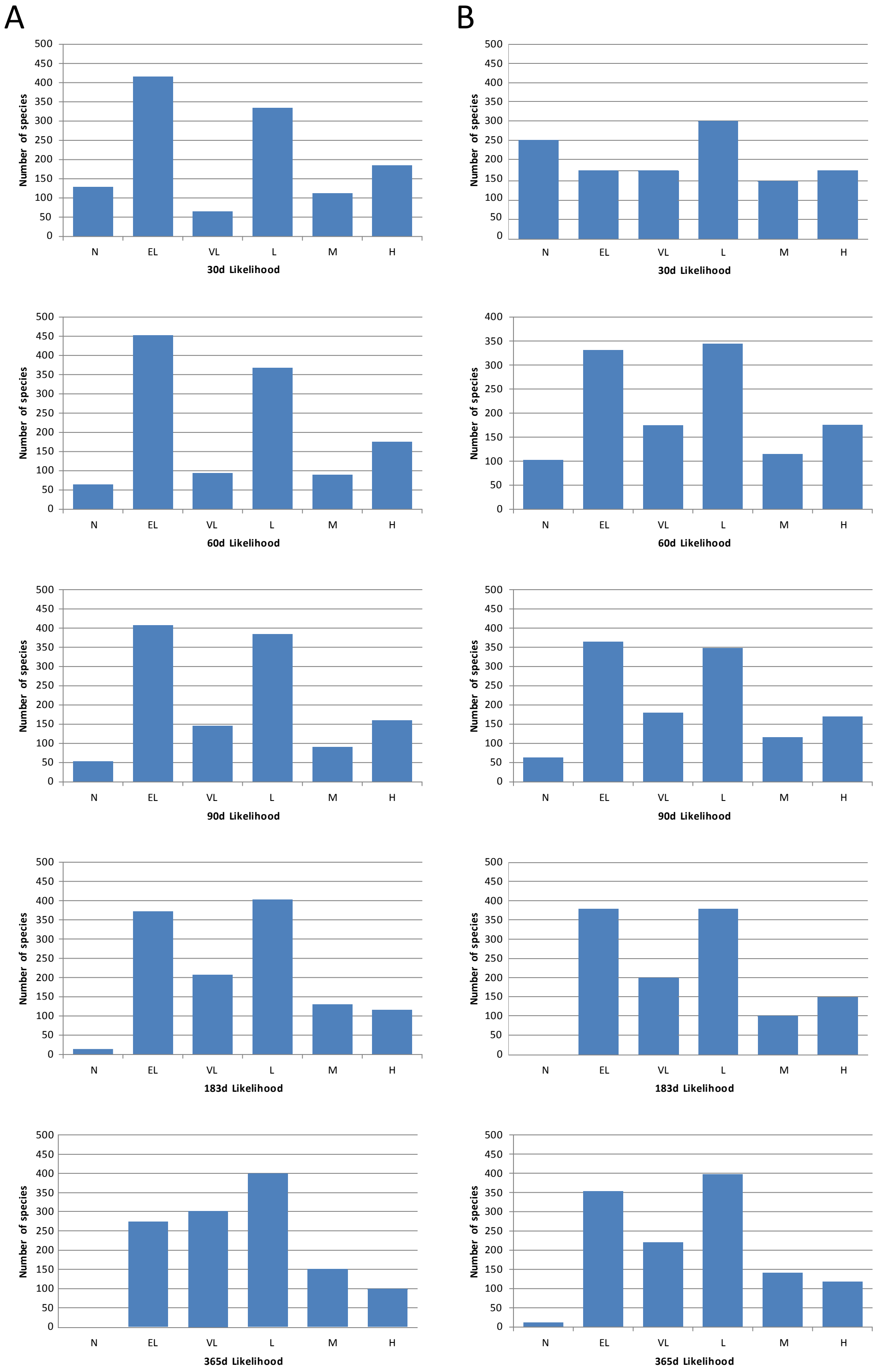

Figure 5.9. Number of species for Inoculation Likelihood Ranks to Guam for voyage durations less than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

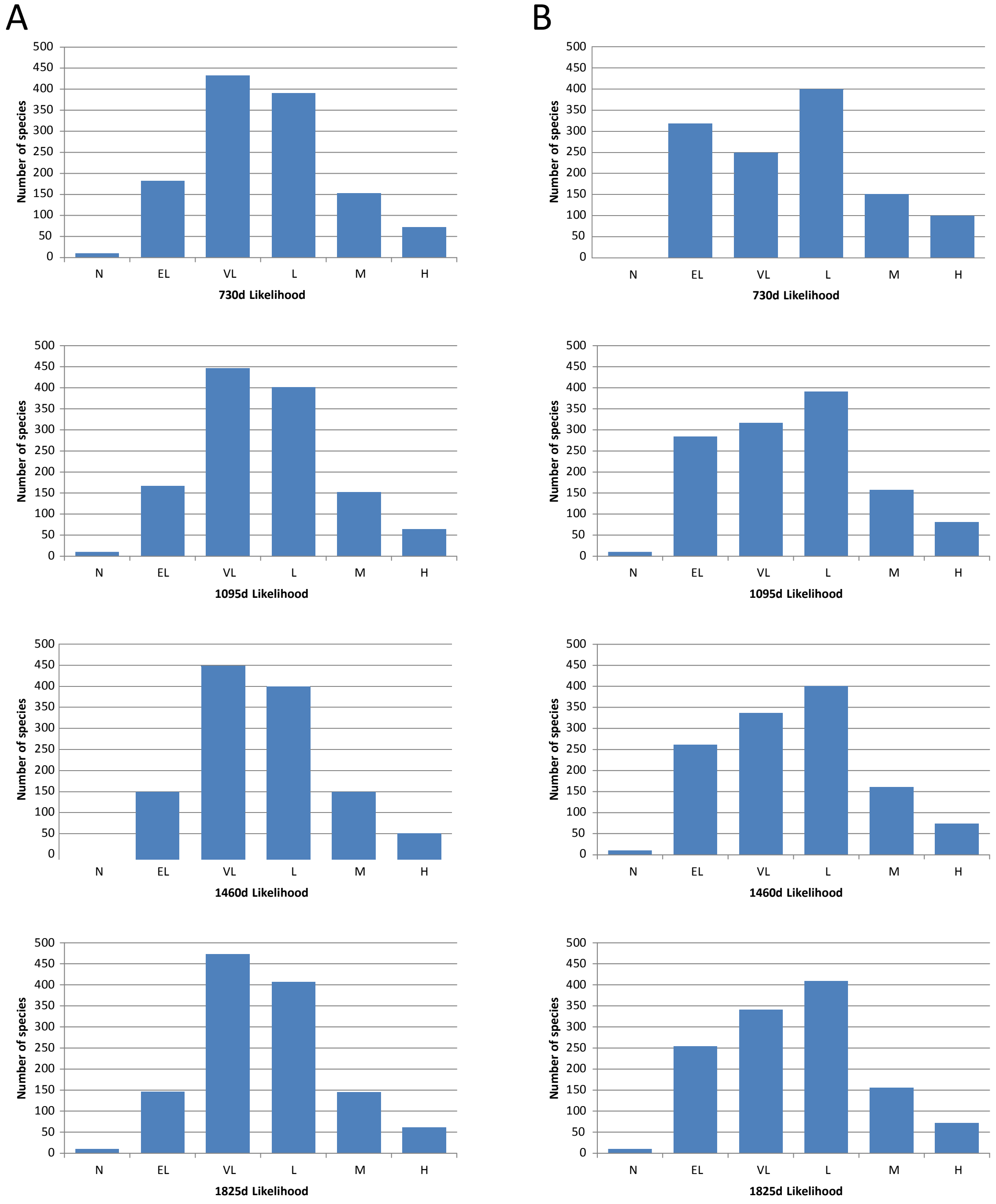

Figure 5.10. Number of species for Inoculation Likelihood Ranks to Guam for voyage durations greater than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoDdatasets.

Table 5.3. Biofouling species with a "High" (n=72) and "Medium" (n=155) likelihood of arrival in Guam associated with all vessel traffic.

Phylum	Scientific name	Likelihood
Annelida	*Alitta (Neanthes) succinea*	M
Annelida	*Dipolydora armata (=armarta)*	H
Annelida	*Eumida sanguineum*	M
Annelida	*Eunice antennata*	H
Annelida	*Ficopomatus enigmaticus*	H
Annelida	*Ficopomatus uschakovi*	M
Annelida	*Glycera capitata*	M
Annelida	*Heteromastus filiformis*	M
Annelida	*Hydroides albiceps (casual)*	M
Annelida	*Hydroides diramphus*	H
Annelida	*Hydroides elegans*	H
Annelida	*Janua pagenstecheri*	H
Annelida	*Lysidice collaris*	M
Annelida	*Myrianida pachycera*	M
Annelida	*Neodexiospira brasiliensis (=Janua (Dexiospira) brasiliensis)*	M
Annelida	*Pileolaria berkeleyana*	M
Annelida	*Polydora cornuta*	M
Annelida	*Polydora websteri*	M
Annelida	*Pomatoleios kraussii*	M
Annelida	*Pseudopolydora paucibranchiata*	M
Annelida	*Streblospio benedicti*	M
Chlorophyta	*Avrainvillea amadelpha*	M
Chlorophyta	*Bryopsis pennata*	H
Chlorophyta	*Bryopsis plumosa*	H
Chlorophyta	*Caulerpa mexicana*	M
Chlorophyta	*Caulerpa racemosa var. lamourouxii*	M
Chlorophyta	*Chaetomorpha aerea*	H
Chlorophyta	*Chaetomorpha linum*	H
Chlorophyta	*Cladophoropsis herpestica*	M

Table 5.3: Continued.

Phylum	Scientific name	Likelihood
Chlorophyta	*Cladophora patentiramea*	M
Chlorophyta	*Cladophora prolifera*	M
Chlorophyta	*Cladophora sericea*	H
Chlorophyta	*Cladophoropsis membranacea*	M
Chlorophyta	*Codium ovale*	M
Chlorophyta	*Derbesia marina*	H
Chlorophyta	*Dictyosphaeria cavernosa*	M
Chlorophyta	*Neomeris annulata*	H
Chlorophyta	*Ulva clathrata (=Enteromorpha clathrata var. crinata)*	H
Chlorophyta	*Ulva flexuosa*	H
Chlorophyta	*Ulva pertusa*	M
Chlorophyta	*Ulva reticulata*	M
Chlorophyta	*Ulva rigida*	H
Chlorophyta	*Ulva taeniata*	M
Chlorophyta	*Valonia fastigiata*	M
Chordata (Ascidieacea)	*Ascidia archaia*	M
Chordata (Ascidieacea)	*Botrylloides leachi*	M
Chordata (Ascidieacea)	*Botrylloides perspicuum*	M
Chordata (Ascidieacea)	*Botryllus schlosseri*	H
Chordata (Ascidieacea)	*Ciona intestinalis*	H
Chordata (Ascidieacea)	*Cnemidocarpa irene*	M
Chordata (Ascidieacea)	*Didemnum candidum*	H
Chordata (Ascidieacea)	*Microcosmus squamiger*	M
Chordata (Ascidieacea)	*Perophora multiclathrata*	M
Chordata (Ascidieacea)	*Polyandrocarpa zorritensis*	M
Chordata (Ascidieacea)	*Styela plicata*	M
Chordata (Ascidieacea)	*Symplegma reptans*	M
Cnidaria	*Blackfordia virginica*	M
Cnidaria	*Bougainvillia muscus*	H
Cnidaria	*Cladonema radiatum*	M

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Table 5.3: Continued.

Phylum	Scientific name	Likelihood
Cnidaria	*Clytia hemisphaerica*	H
Cnidaria	*Cordylophora caspia*	H
Cnidaria	*Coryne eximia (=Sarsia eximia)*	M
Cnidaria	*Coryne pusilla*	M
Cnidaria	*Diadumene lineata*	H
Cnidaria	*Eucheilota paradoxica*	M
Cnidaria	*Eudendrium capillare*	H
Cnidaria	*Eudendrium carneum*	M
Cnidaria	*Gonothyraea loveni*	M
Cnidaria	*Obelia longissima*	M
Cnidaria	*Phyllorhiza punctata*	M
Cnidaria	*Plumularia setacea*	H
Cnidaria	*Sarsia tubulosa*	M
Cnidaria	*Scolionema suvaensis*	M
Cnidaria	*Sertularia tongensis (=Sertularia stechowi, S. theocarpa)*	M
Cnidaria	*Tubastraea coccinea*	H
Arthropoda	*Alpheus rapacida*	M
Arthropoda	*Amphibalanus amphitrite*	H
Arthropoda	*Amphibalanus improvisus*	M
Arthropoda	*Amphibalanus reticulatus*	H
Arthropoda	*Balanus trigonus*	H
Arthropoda	*Caprella danilevskii*	M
Arthropoda	*Caprella equilibra*	H
Arthropoda	*Caprella penantis*	H
Arthropoda	*Caprella scaura*	H
Arthropoda	*Carcinus maenas*	H
Arthropoda	*Chelura terebrans*	M
Arthropoda	*Conchoderma virgatum*	M
Arthropoda	*Dromia wilsoni*	M
Arthropoda	*Elasmopus rapax*	H

Table 5.3: Continued.

Phylum	Scientific name	Likelihood
Arthropoda	*Ericthonius brasiliensis*	H
Arthropoda	*Eucrate crenata*	M
Arthropoda	*Idotea metallica*	M
Arthropoda	*Jassa marmorata*	M
Arthropoda	*Kotoracythere inconspicua*	M
Arthropoda	*Laticorophium baconi*	H
Arthropoda	*Lepas (Anatifa) anatifera*	H
Arthropoda	*Lepas (Anatifa) anserifera*	H
Arthropoda	*Lepas (Anatifa) hillii*	M
Arthropoda	*Leptochela dubia*	H
Arthropoda	*Ligia exotica*	H
Arthropoda	*Megabalanus occator*	M
Arthropoda	*Menaethius monoceros*	M
Arthropoda	*Merocryptus lambriformis*	M
Arthropoda	*Monocorophium acherusicum*	H
Arthropoda	*Monocorophium insidiosum*	H
Arthropoda	*Nanosesarma minutum*	M
Arthropoda	*Paracaprella pusilla*	H
Arthropoda	*Paracerceis sculpta*	M
Arthropoda	*Paradella dianae*	M
Arthropoda	*Plagusia depressa tuberculata*	M
Arthropoda	*Porcellio lamellatus lamellatus*	M
Arthropoda	*Sinelobus cf. stanfordi*	M
Arthropoda	*Sphaeroma quoianum*	M
Arthropoda	*Sphaeroma walkeri*	H
Arthropoda	*Stenothoe gallensis*	H
Arthropoda	*Stenothoe valida*	H
Arthropoda	*Synidotea laevidorsalis*	M
Dinophyta	*Ostreopsis ovata*	M
Dinophyta	*Prorocentrum lima*	H
Echinodermata	*Protoreaster nodosus*	M

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Table 5.3: Continued.

Phylum	Scientific name	Likelihood
Bryozoa	*Aetea anguina*	M
Bryozoa	*Aetea truncata*	M
Bryozoa	*Bowerbankia gracilis*	H
Bryozoa	*Bowerbankia imbricata*	M
Bryozoa	*Bugula dentata*	M
Bryozoa	*Bugula stolonifera*	H
Bryozoa	*Caberea boryi*	M
Bryozoa	*Celleporaria brunnea*	M
Bryozoa	*Cryptosula pallasiana*	H
Bryozoa	*Hippopodina feegensis*	M
Bryozoa	*Hippothoa distans*	M
Bryozoa	*Jellyella tuberculata*	H
Bryozoa	*Scruparia ambigua*	M
Bryozoa	*Synnotum aegyptiacum*	M
Bryozoa	*Tricellaria occidentalis*	M
Bryozoa	*Victorella pavida*	M
Bryozoa	*Watersipora arcuata*	M
Bryozoa	*Watersipora subtorquata*	H
Bryozoa	*Zoobotryon verticillatum*	M
Mollusca	*Anadara granosa*	M
Mollusca	*Anteaeolidiella foulisi (=Anteaolidiella indica)*	H
Mollusca	*Bankia bipalmulata*	M
Mollusca	*Caloria indica*	M
Mollusca	*Cycloscala hyalina*	M
Mollusca	*Dendrodoris fumata*	M
Mollusca	*Diodora ruppelli*	M
Mollusca	*Doxander vittatus*	M
Mollusca	*Elysia tomentosa*	M
Mollusca	*Hiatella arctica*	H
Mollusca	*Hypselodoris infucata*	M

Table 5.3: Continued.

Phylum	Scientific name	Likelihood
Mollusca	*Isognomon ephippium*	M
Mollusca	*Lienardia mighelsi*	M
Mollusca	*Martesia striata*	M
Mollusca	*Musculista senhousia*	H
Mollusca	*Mytilopsis sallei*	M
Mollusca	*Mytilus galloprovincialis*	M
Mollusca	*Nanostrea fluctigera (=Nanostrea exigua)*	M
Mollusca	*Okenia pellucida*	M
Mollusca	*Perna viridis*	M
Mollusca	*Sabia conica*	M
Mollusca	*Strombus mutabilis*	M
Mollusca	*Syrnola cinctella*	M
Mollusca	*Tenellia adspersa*	M
Mollusca	*Teredo clappi*	M
Mollusca	*Teredo navalis*	H
Mollusca	*Teredora princesae*	M
Mollusca	*Thecacera pennigera*	H
Phaeophyta	*Chnoospora minima*	M
Phaeophyta	*Cutleria multifida*	M
Phaeophyta	*Ectocarpus fasciculatus*	M
Phaeophyta	*Ectocarpus siliculosus*	M
Phaeophyta	*Hincksia granulosa*	M
Phaeophyta	*Hincksia mitchelliae*	H
Phaeophyta	*Hincksia ovata*	M
Phaeophyta	*Hincksia sandriana*	M
Phaeophyta	*Leathesia marina (=Leathesia difformis)*	M
Phaeophyta	*Macrocystis pyrifera*	M
Phaeophyta	*Myrionema strangulans*	M
Phaeophyta	*Nemacystus decipiens*	M
Phaeophyta	*Padina antillarum*	M
Phaeophyta	*Padina boryana*	M

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Table 5.3: Continued.

Phylum	**Scientific name**	**Likelihood**
Phaeophyta	*Pylaiella littoralis*	H
Phaeophyta	*Punctaria latifolia*	M
Phaeophyta	*Rugulopteryx okamurae*	M
Phoronida	*Phoronis hippocrepia*	M
Porifera	*Dysidea fragilis*	M
Porifera	*Halichondria panicea*	M
Porifera	*Mycale parishii (=Zygomycale parishii)*	H
Pycnogonida	*Ammothea hilgendorfi*	M
Pycnogonida	*Pigrogromitus timsanus*	H
Rhodophyta	*Acanthophora spicifera*	M
Rhodophyta	*Agardhiella subulata*	M
Rhodophyta	*Aglaothamnion cordatum*	H
Rhodophyta	*Antithamnion hubbsii (=nipponicum, pectinatum)*	M
Rhodophyta	*Apoglossum gregarium*	M
Rhodophyta	*Asparagopsis taxiformis*	H
Rhodophyta	*Bangia atropurpurea*	H
Rhodophyta	*Caulacanthus ustulatus*	H
Rhodophyta	*Centroceras clavulatum*	H
Rhodophyta	*Ceramium virgatum*	M
Rhodophyta	*Chondria arcuata*	M
Rhodophyta	*Chroodactylon ramosum*	M
Rhodophyta	*Corallina officinalis*	M
Rhodophyta	*Dasya baillouviana*	H
Rhodophyta	*Eucheuma denticulatum*	M
Rhodophyta	*Gracilaria gracilis*	M
Rhodophyta	*Grateloupia subpectinata (=Grateloupia filicina var luxurians)*	M
Rhodophyta	*Gymnothamnion elegans*	H
Rhodophyta	*Herposiphonia parca*	M
Rhodophyta	*Centroceras clavulatum*	H

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Table 5.3: Continued.

Phylum	Scientific name	Likelihood
Rhodophyta	*Ceramium virgatum*	M
Rhodophyta	*Hildenbrandia rubra*	H
Rhodophyta	*Hypnea anastomosans (=Hypnea esperi)*	M
Rhodophyta	*Hypnea cornuta*	H
Rhodophyta	*Hypnea nidifica*	M
Rhodophyta	*Hypnea spinella (=Hypnea cervicornis)*	H
Rhodophyta	*Hypnea charoides - valentiae*	H
Rhodophyta	*Kappaphycus striatum*	M
Rhodophyta	*Laurencia brongniartii*	M
Rhodophyta	*Laurencia okamurae*	M
Rhodophyta	*Neosiphonia harveyi (=Polysiphonia harveyi)*	M
Rhodophyta	*Polysiphonia brodiei*	M
Rhodophyta	*Polysiphonia sertularioides*	M
Rhodophyta	*Polysiphonia subtilissima*	M
Rhodophyta	*Porphyra suborbiculata*	M
Rhodophyta	*Pterosiphonia bipinnata*	M
Rhodophyta	*Sarconema filiforme*	M
Rhodophyta	*Spongoclonium caribaeum (=Pleonosporium caribaeum)*	M
Rhodophyta	*Symphyocladia marchantioides*	M

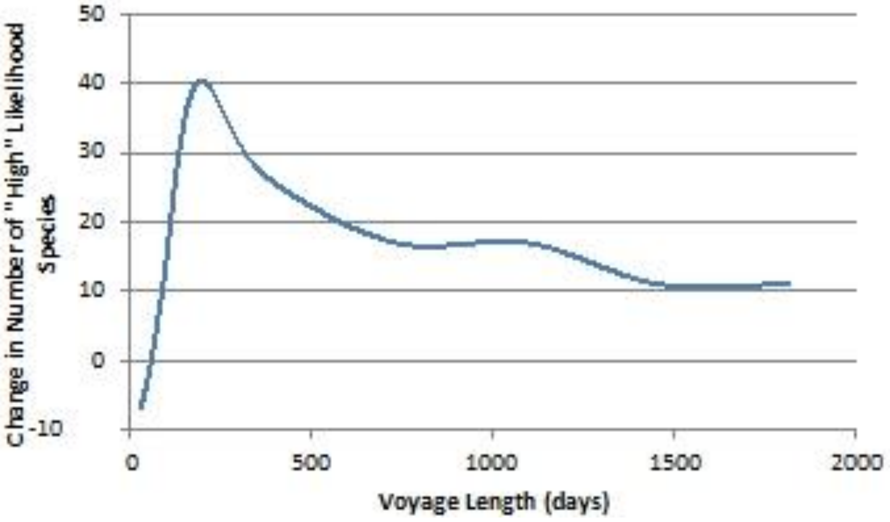

Figure 5.11: The estimated change in the number of “High” likelihood of inoculation species between analysis of commercial vessels alone and commercial and MSC vessels.

5.4 Spread from Guam to other jurisdictions of Micronesia

Spread is the progressive expansion and establishment in locations beyond the first site of establishment in the receiving region. This can be facilitated either by natural or human mediated means, however in this assessment the evaluation is restricted to human mediated spread. This assessment is interested in the increased likelihood of inoculation into a jurisdiction of Micronesia or Hawai’i as a consequence of trading activity in Guam. For this evaluation each jurisdiction of Micronesia (CNMI, FSM, RMI, Palau, and also the UMI) was evaluated for species arrival likelihoods based on direct entry (following the methods described in Section 5.2), with comparison between commercial vessel entries and the additive effect of MSC vessels.

Ultimately, once a species has become established in a high traffic port, or ‘transport hub’, there is some probability that domestic vessels will be colonized by non-native species and translocated to more locations across a region. As successive hubs are colonized, the number of populations from which natural spread can occur increases via natural dispersal (Floerl 2002). This pattern of spread, termed the ‘hub and spoke’ dispersal (*sensu* Cartlon 1996) is typical of marine non-native species (Carlton 1996, Cranfield et al. 1998). Recent modeling analysis indicates that spread of non-native organisms can not only occur from hubs, but also from seemingly unimportant transport nodes (Floerl et al. 2009). Nonetheless, transport hubs were consistently more likely to become infested by an invader and to accelerate spread to secondary locations faster when compared with low traffic nodes (Floerl et al. 2009).

The role of Guam as an entry port to Micronesia and Hawai'i using a "hub and spoke" model was assessed, where the likelihood species already present in Guam or deemed to have a high likelihood of inoculation in Guam (Section 5.2, above) was compared with the species with high likelihoods of direct entry to determine the extent to which increased likelihood of transfer and arrival to a jurisdiction of Micronesia other than Guam. The likelihood of arrival of species to each jurisdiction of Micronesia (other than Guam) and Hawai'i for commercial, MSC and all (commercial and MSC) vessels across the nine voyage durations was assessed.

5.*4.1 Commonwealth of the Northern Mariana Islands (CNMI)*

The CNMI received 3,312 commercial and 4,769 MSC vessel entries during the assessed period (Figures 5.12 and 5.13). Approximately 19% of these vessels arrived directly from Guam. Commercial vessels had strong affinities with the NE Atlantic (5) and the East Asian Seas (13) bioregions, with a decreased trade across a wide number of bioregions. The NE Atlantic and East Asian Seas bioregions represent more than 20% of commercial vessel trade. In contrast, Military vessels exhibit a much broader exposure to bioregions, particularly Indian Ocean and Pacific Basin bioregions and therefore broader exposure to a wider suite of species. The trading activities of vessels visiting CNMI are broad with the 30 day voyages sampling nine bioregions, rapidly reaching 18 bioregions with voyages of 365 days (Figure 5.14).

The inoculation likelihoods of species increase with the addition of MSC vessels (Figures 5.15, 5.16). No species were categorized as having "High" likelihood of inoculation when assessed for commercial vessels alone, with the addition of MSC vessels increasing the "High" risk species to 15 species for voyages of 1,825 days (5 years) (Table 5.4).

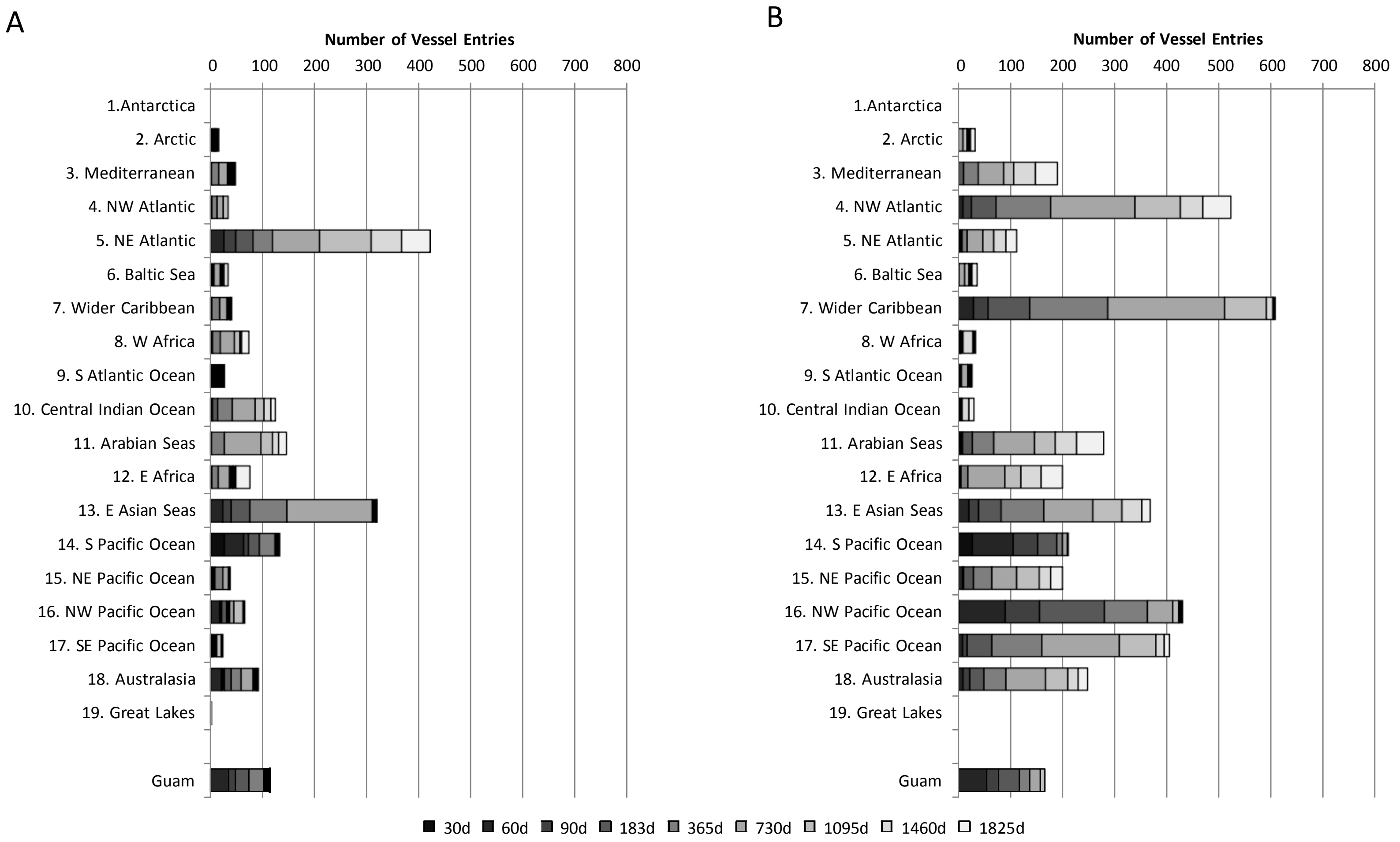

Figure 5.12. Number of A) commercial vessel (all categories) and B) MSC vessel (all categories) entries to CNMI from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries vessels (Lloyds MIU and DoD datasets). Note that vessels transiting Guam are also represented in Bioregion 14 South Pacific Ocean.

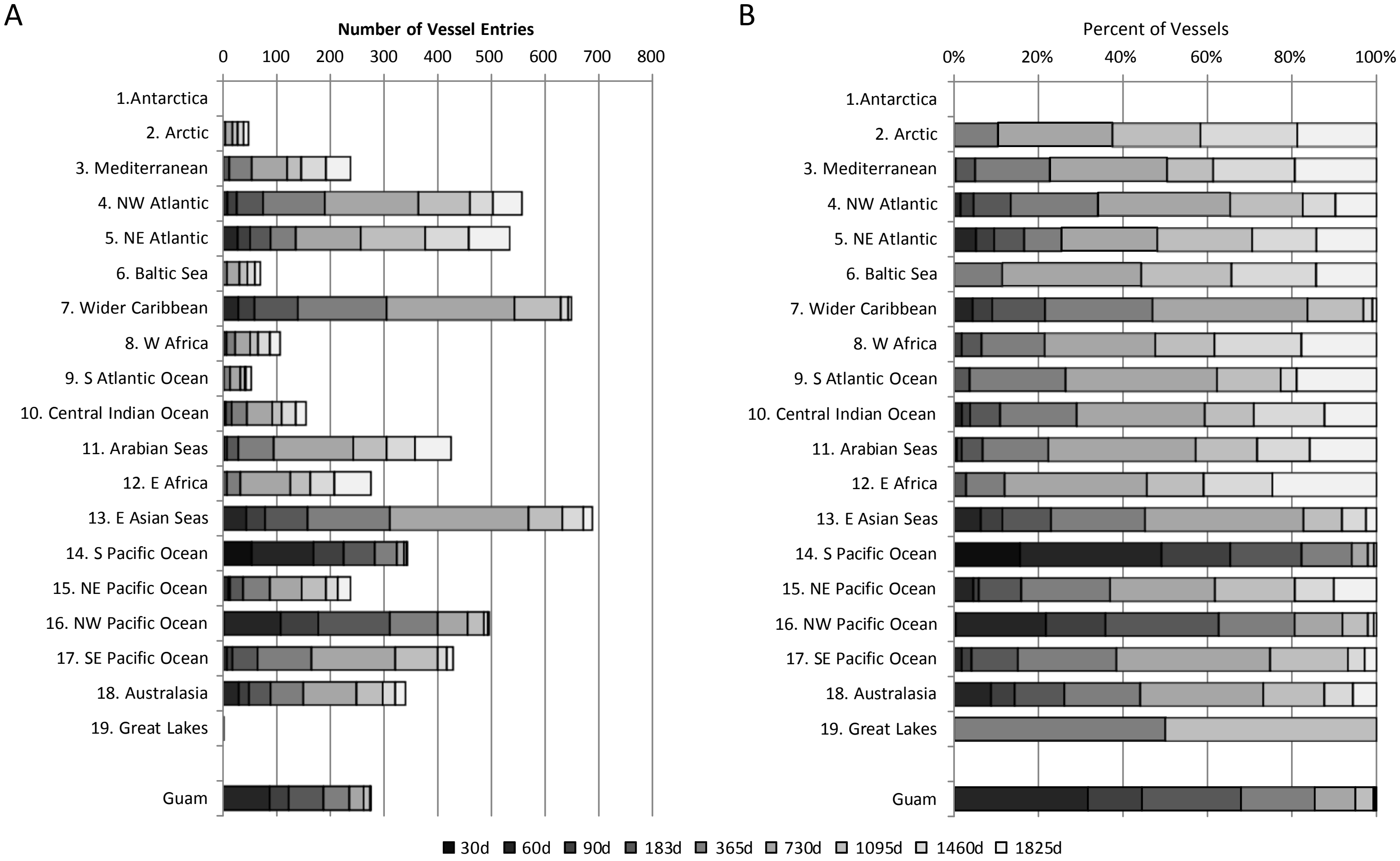

Figure 5.13. Number and percentage within a bioregion of all vessel (all categories of commercial and MSC vessels) entries to CNMI from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU and DoD datasets). Note that vessels transiting Guam are also represented in Bioregion 14 South Pacific Ocean.

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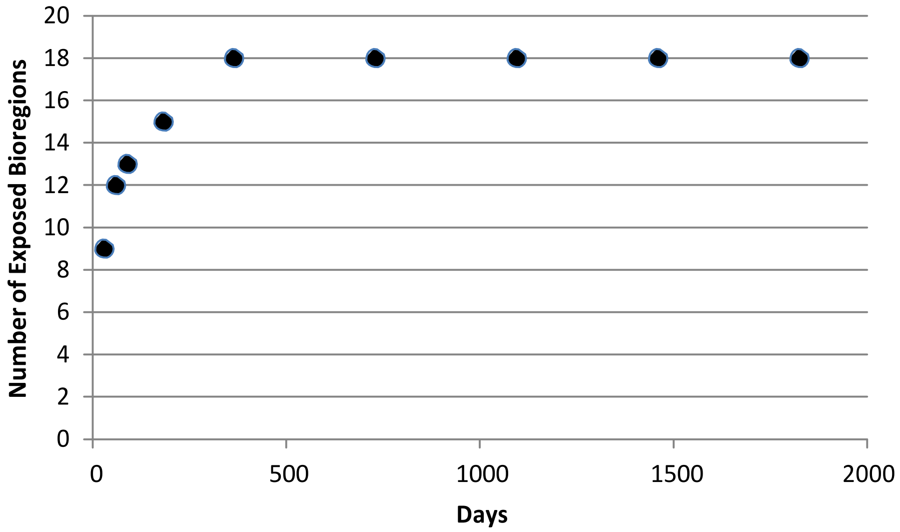

Figure 5.14. Number of bioregions visited by vessels entering the CNMI between 1999 and 2009 with increasing voyage duration (data from Lloyds MIU and DoD datasets).

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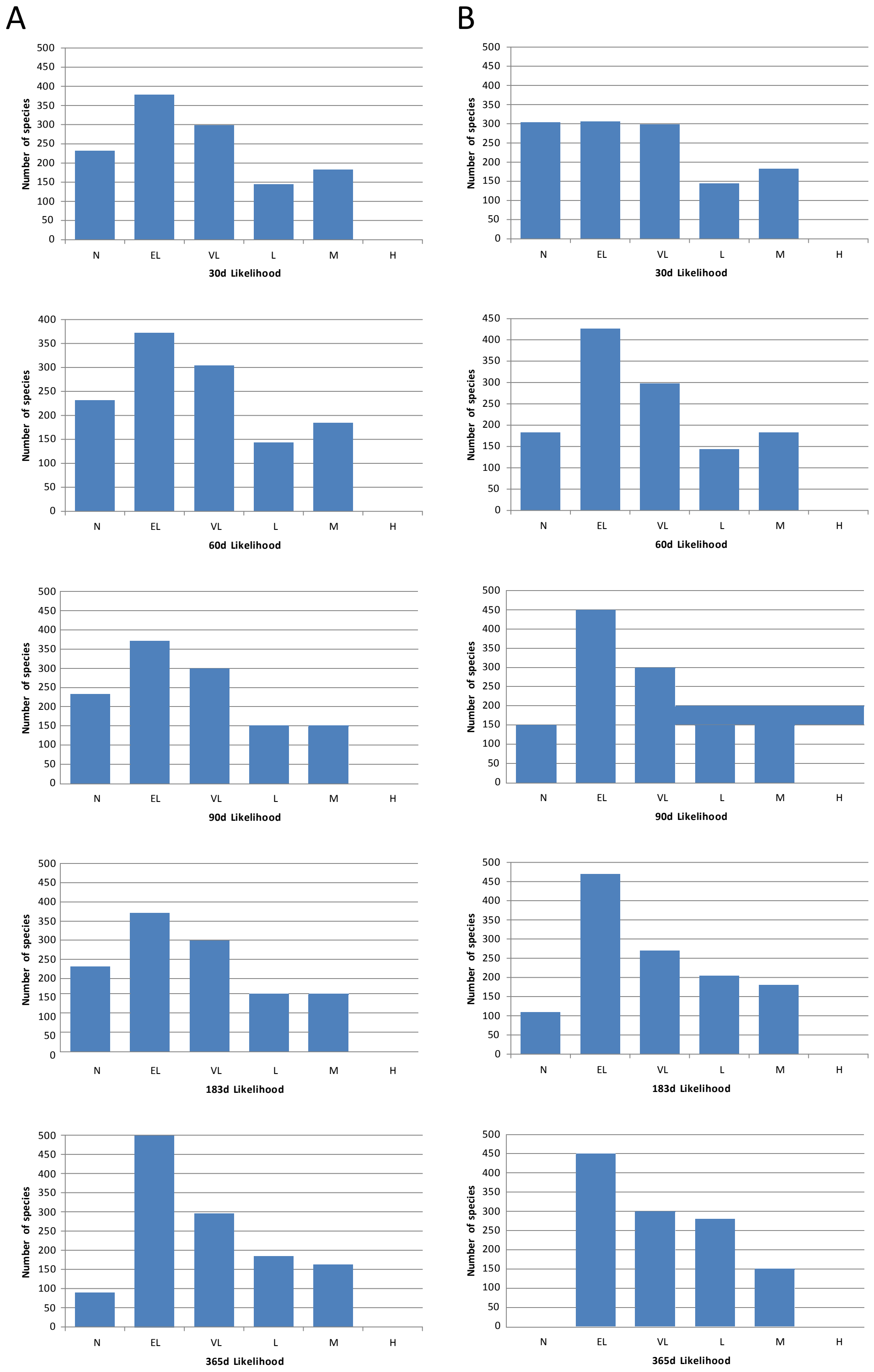

Figure 5.15. Number of species for Inoculation Likelihood Ranks to CNMI for voyage durations less than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

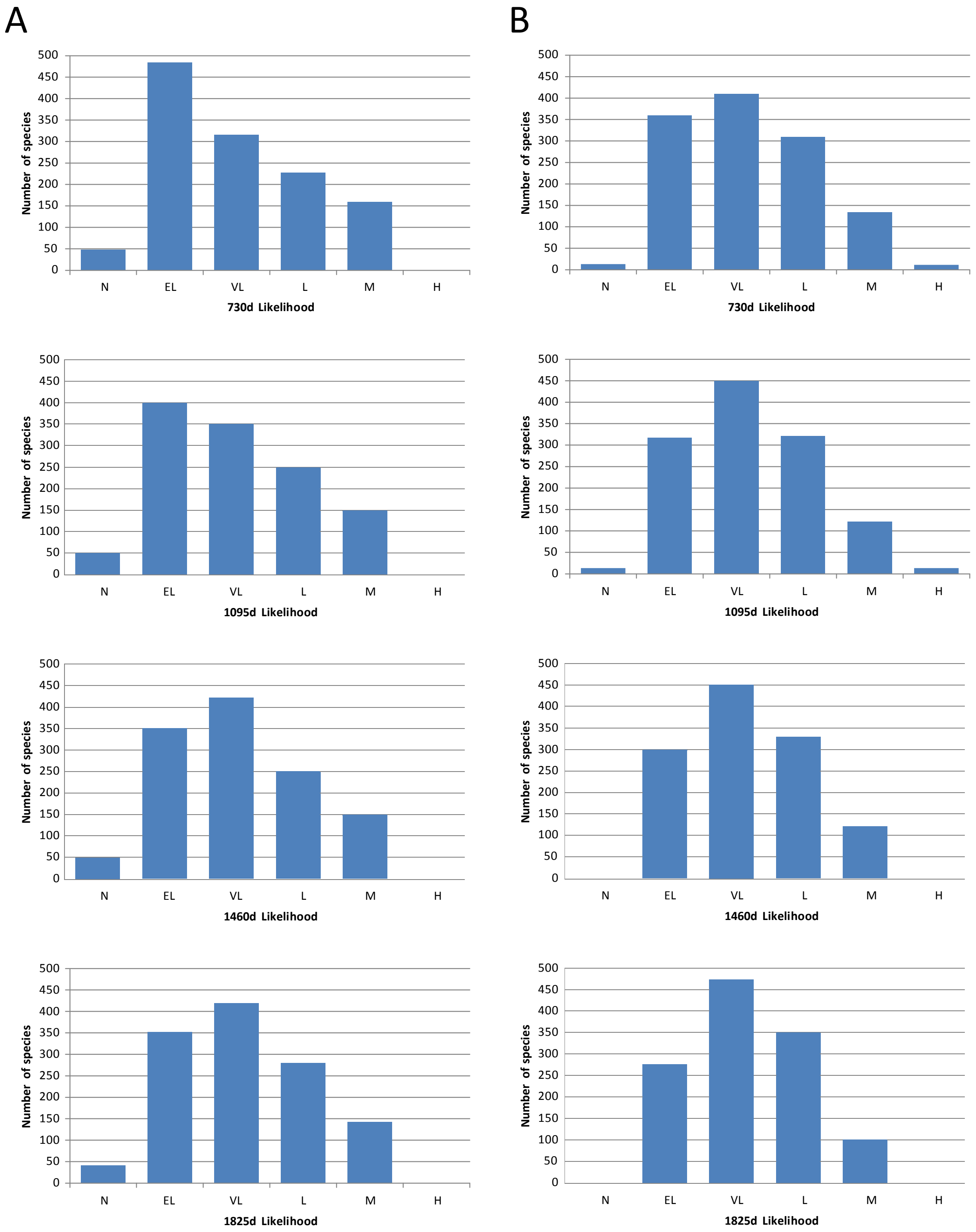

Figure 5.16. Number of species for Inoculation Likelihood Ranks to CNMI for voyage durations greater than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

Table 5.4. Biofouling species with a "High" (n=15) and "Medium" (n=116) likelihood of arrival in the CNMI associated with all vessel traffic.

Phylum	Scientific name	Likelihood
Annelida	*Alitta (Neanthes) succinea*	M
Annelida	*Dipolydora armata (=armarta)*	M
Annelida	*Eumida sanguineum*	M
Annelida	*Ficopomatus enigmaticus*	M
Annelida	*Hydroides diramphus*	M
Annelida	*Hydroides elegans*	M
Annelida	*Janua pagenstecheri*	H
Annelida	*Lysidice collaris*	M
Annelida	*Neodexiospira brasiliensis (=Janua (Dexiospira) brasiliensis)*	M
Annelida	*Pileolaria berkeleyana*	M
Annelida	*Pomatoleios kraussii*	M
Annelida	*Streblospio benedicti*	M
Chlorophyta	*Bryopsis pennata*	M
Chlorophyta	*Bryopsis plumosa*	H
Chlorophyta	*Caulerpa mexicana*	M
Chlorophyta	*Caulerpa racemosa var. lamourouxii*	M
Chlorophyta	*Chaetomorpha aerea*	H
Chlorophyta	*Chaetomorpha linum*	H
Chlorophyta	*Cladophora herpestica*	M
Chlorophyta	*Cladophora prolifera*	M
Chlorophyta	*Cladophora sericea*	M
Chlorophyta	*Cladophoropsis membranacea*	M
Chlorophyta	*Derbesia marina*	M
Chlorophyta	*Dictyosphaeria cavernosa*	M
Chlorophyta	*Neomeris annulata*	M
Chlorophyta	*Ulva clathrata (=Enteromorpha clathrata var. crinata)*	H
Chlorophyta	*Ulva flexuosa*	H
Chlorophyta	*Ulva reticulata*	M

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Table 5.4: Continued

Phylum	**Scientific name**	**Likelihood**
Chlorophyta	*Ulva rigida*	H
Chordata (Ascidiacea)	*Botrylloides perspicuum*	M
Chordata (Ascidiacea)	*Botryllus schlosseri*	M
Chordata (Ascidiacea)	*Ciona intestinalis*	H
Chordata (Ascidiacea)	*Didemnum candidum*	M
Chordata (Ascidiacea)	*Perophora multiclathrata*	M
Cnidaria	*Bougainvillia muscus*	M
Cnidaria	*Clytia hemisphaerica*	M
Cnidaria	*Cordylophora caspia*	H
Cnidaria	*Diadumene lineata*	M
Cnidaria	*Eudendrium capillare*	M
Cnidaria	*Eudendrium carneum*	M
Cnidaria	*Obelia longissima*	M
Cnidaria	*Plumularia setacea*	H
Cnidaria	*Sarsia tubulosa*	M
Cnidaria	*Tubastraea coccinea*	M
Arthropoda	*Amphibalanus amphitrite*	H
Arthropoda	*Amphibalanus reticulatus*	M
Arthropoda	*Balanus trigonus*	M
Arthropoda	*Caprella equilibra*	M
Arthropoda	*Caprella penantis*	M
Arthropoda	*Caprella scaura*	M
Arthropoda	*Carcinus maenas*	H
Arthropoda	*Dromia wilsoni*	M
Arthropoda	*Elasmopus rapax*	M
Arthropoda	*Ericthonius brasiliensis*	M
Arthropoda	*Eucrate crenata*	M
Arthropoda	*Kotoracythere inconspicua*	M
Arthropoda	*Laticorophium baconi*	M
Arthropoda	*Lepas (Anatifa) anserifera*	M

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Table 5.4: Continued

Phylum	Scientific name	Likelihood
Arthropoda	*Lepas (Anatifa) hillii*	M
Arthropoda	*Leptochela dubia*	M
Arthropoda	*Ligia exotica*	M
Arthropoda	*Menaethius monoceros*	M
Arthropoda	*Monocorophium acherusicum*	M
Arthropoda	*Monocorophium insidiosum*	M
Arthropoda	*Paracaprella pusilla*	M
Arthropoda	*Paracerceis sculpta*	M
Arthropoda	*Paradella dianae*	M
Arthropoda	*Plagusia depressa tuberculata*	M
Arthropoda	*Sphaeroma walkeri*	M
Arthropoda	*Stenothoe gallensis*	M
Arthropoda	*Stenothoe valida*	M
Arthropoda	*Synidotea laevidorsalis*	M
Dinophyta	*Prorocentrum lima*	M
Bryozoa	*Aetea anguina*	M
Bryozoa	*Aetea truncata*	M
Bryozoa	*Bowerbankia gracilis*	M
Bryozoa	*Bowerbankia imbricata*	M
Bryozoa	*Bugula dentata*	M
Bryozoa	*Bugula stolonifera*	M
Bryozoa	*Cryptosula pallasiana*	M
Bryozoa	*Hippopodina feegensis*	M
Bryozoa	*Hippothoa distans*	M
Bryozoa	*Jellyella tuberculata*	M
Bryozoa	*Scruparia ambigua*	M
Bryozoa	*Synnotum aegyptiacum*	M
Bryozoa	*Watersipora subtorquata*	M
Bryozoa	*Zoobotryon verticillatum*	M
Phoronida	*Phoronis hippocrepia*	M

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Table 5.4: Continued

Phylum	Scientific name	Likelihood
Mollusca	*Anadara granosa*	M
Mollusca	*Anteaeolidiella foulisi (=Anteaolidiella indica)*	M
Mollusca	*Caloria indica*	M
Mollusca	*Cycloscala hyalina*	M
Mollusca	*Dendrodoris fumata*	M
Mollusca	*Elysia tomentosa*	M
Mollusca	*Hiatella arctica*	M
Mollusca	*Lienardia mighelsi*	M
Mollusca	*Martesia striata*	M
Mollusca	*Musculista senhousia*	M
Mollusca	*Mytilopsis sallei*	M
Mollusca	*Perna viridis*	M
Mollusca	*Sabia conica*	M
Mollusca	*Teredo navalis*	M
Mollusca	*Thecacera pennigera*	M
Phaeophyta	*Chnoospora minima*	M
Phaeophyta	*Ectocarpus siliculosus*	M
Phaeophyta	*Hincksia mitchelliae*	H
Phaeophyta	*Padina boryana*	M
Phaeophyta	*Pylaiella littoralis*	M
Porifera	*Dysidea fragilis*	M
Porifera	*Mycale parishii (=Zygomycale parishii)*	M
Pycnogonida	*Pigrogromitus timsanus*	M
Rhodophyta	*Acanthophora spicifera*	M
Rhodophyta	*Aglaothamnion cordatum*	M
Rhodophyta	*Antithamnion hubbsii (=nipponicum, pectinatum)*	M
Rhodophyta	*Asparagopsis taxiformis*	M
Rhodophyta	*Bangia atropurpurea*	H

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Table 5.4: Continued

Phylum	Scientific name	Likelihood
Rhodophyta	*Caulacanthus ustulatus*	M
Rhodophyta	*Chroodactylon ramosum*	M
Rhodophyta	*Dasya baillouviana*	M
Rhodophyta	*Eucheuma denticulatum*	M
Rhodophyta	*Gymnothamnion elegans*	M
Rhodophyta	*Herposiphonia parca*	M
Rhodophyta	*Hildenbrandia rubra*	H
Rhodophyta	*Hypnea anastomosans (=Hypnea esperi)*	M
Rhodophyta	*Hypnea cornuta*	M
Rhodophyta	*Hypnea spinella (=Hypnea cervicornis)*	M
Rhodophyta	*Hypnea valentiae*	M
Rhodophyta	*Polysiphonia subtilissima*	M
Rhodophyta	*Sarconema filiforme*	M
Rhodophyta	*Spongoclonium caribaeum (=Pleonosporium caribaeum)*	M

5.4.2 Federated States of Micronesia

The Federated States of Micronesia (FSM) received 783 commercial vessels and 28 MSC vessel entries during the assessed period (Figures 5.17, 5.18). Approximately 15.5% of these vessels arrived directly from Guam. Commercial vessels had strong affinities with a restricted suite of Pacific bioregions (East Asian Seas-13, South Pacific-14, and Northwest Pacific-16), representing more than 62% of total trade. In contrast, few military vessels traded with FSM and were restricted to the South Pacific Ocean and NW Pacific. As a consequence, military vessels contribute little to the likelihood of species inoculations based on vessel entries alone. The trading activities are widespread initially, with 30 day voyages reaching seven bioregions, however only after 730 day voyages the maximum of 17 bioregions are reached (Figure 5.19).

The inoculation likelihoods of species do not change with the addition of military vessels (Figures 5.20 and 5.21) due to the limited number of military vessel entries. The overall result is 42 species identified as ‘High” likelihood of inoculation for voyages of 1,825 days (5 years) (Table 5.5).

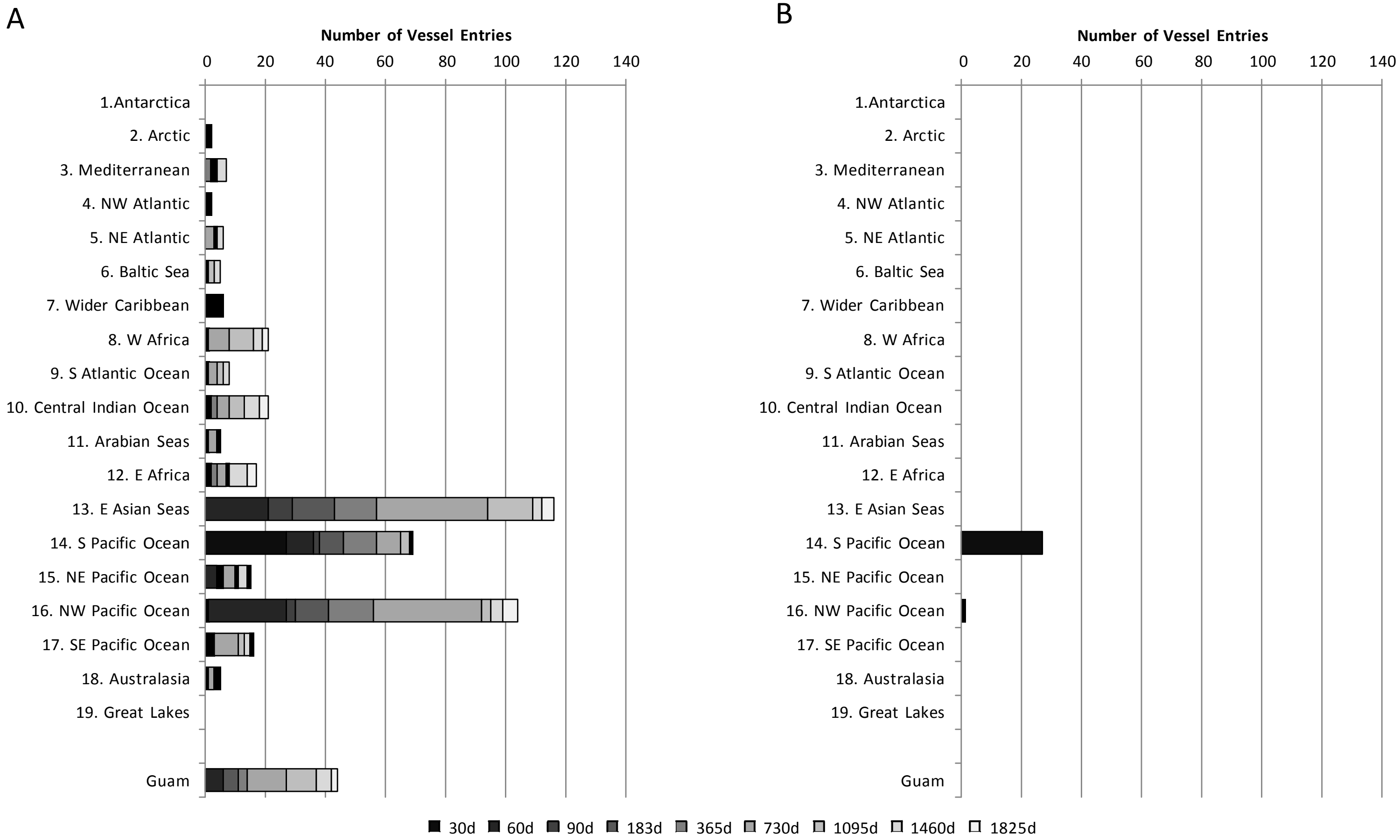

Figure 5.17. Number of A) commercial vessel (all categories) and B) MSC vessel (all categories) entries to the FSM from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU and DoD datasets). Note that vessels transiting Guam are also represented in Bioregion 14 South Pacific Ocean.

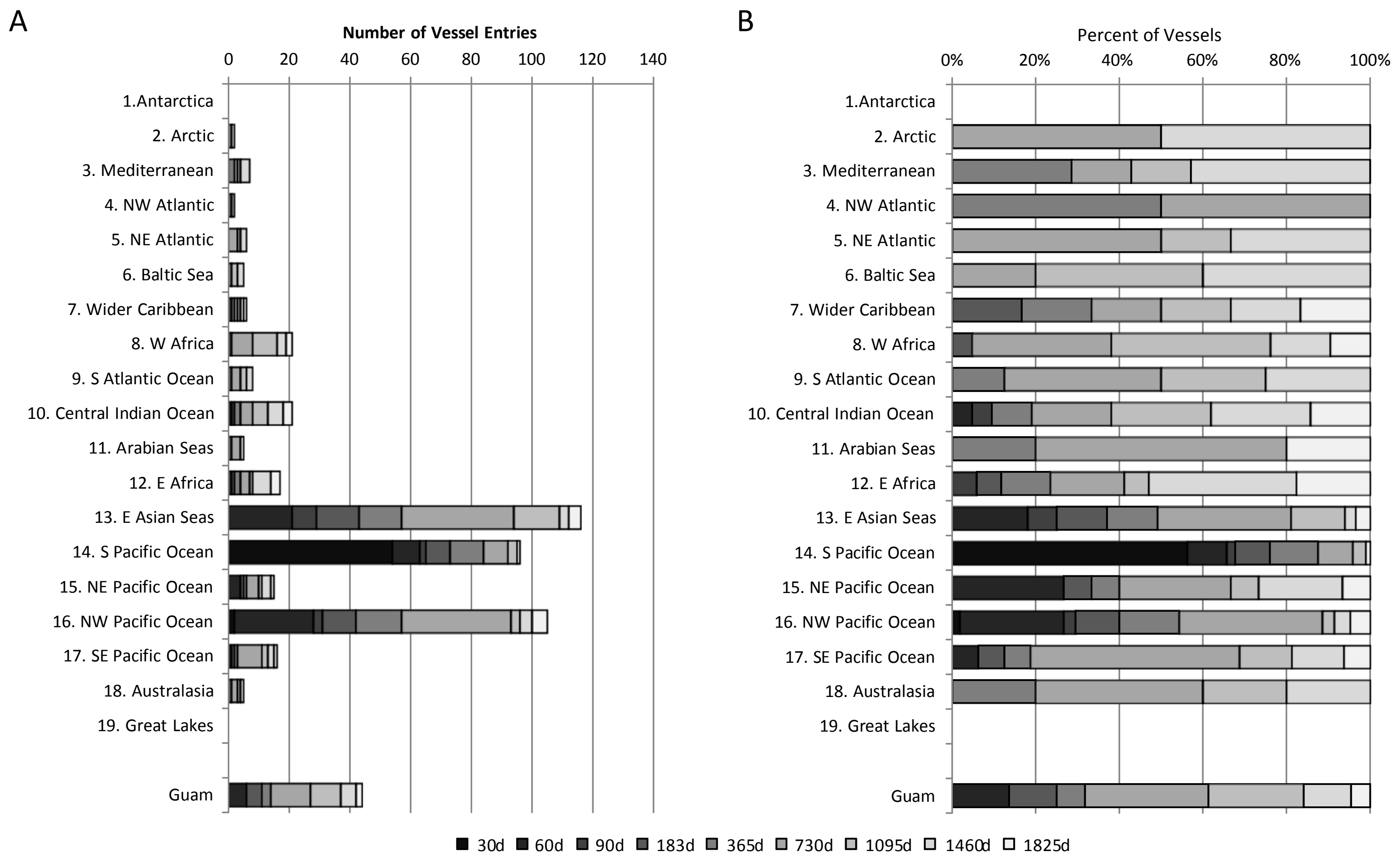

Figure 5.18. Number and percentage within a bioregion of all vessel (all categories of commercial and MSC vessels) entries to FSM from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU and DoD datasets). Note that vessels transiting Guam are also represented in Bioregion 14 South Pacific Ocean.

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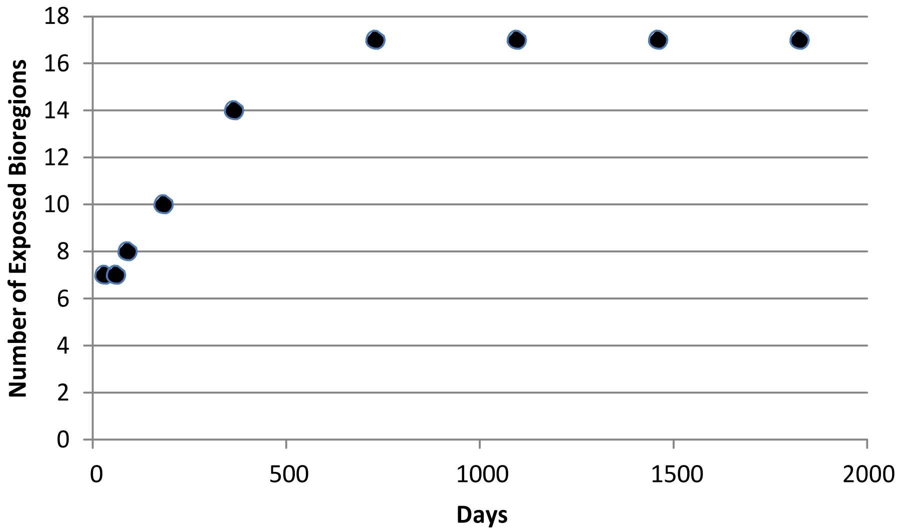

Figure 5.19: Number of bioregions visited by vessels entering FSM between 1999 and 2009 with increasing voyage duration (data from Lloyds MIU and DoD datasets).

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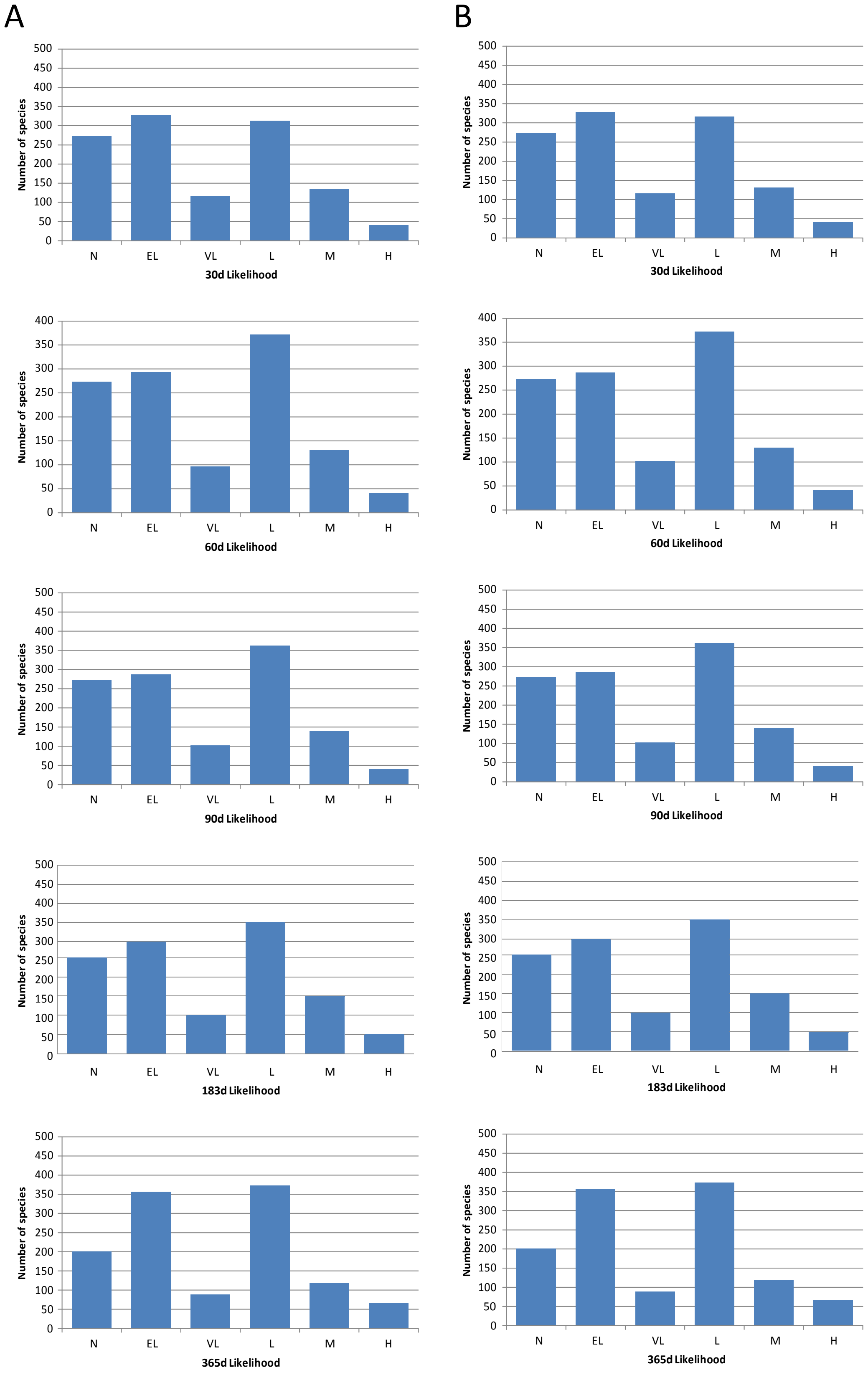

Figure 5.20. Number of species for Inoculation Likelihood Ranks to FSM for voyage durations less than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

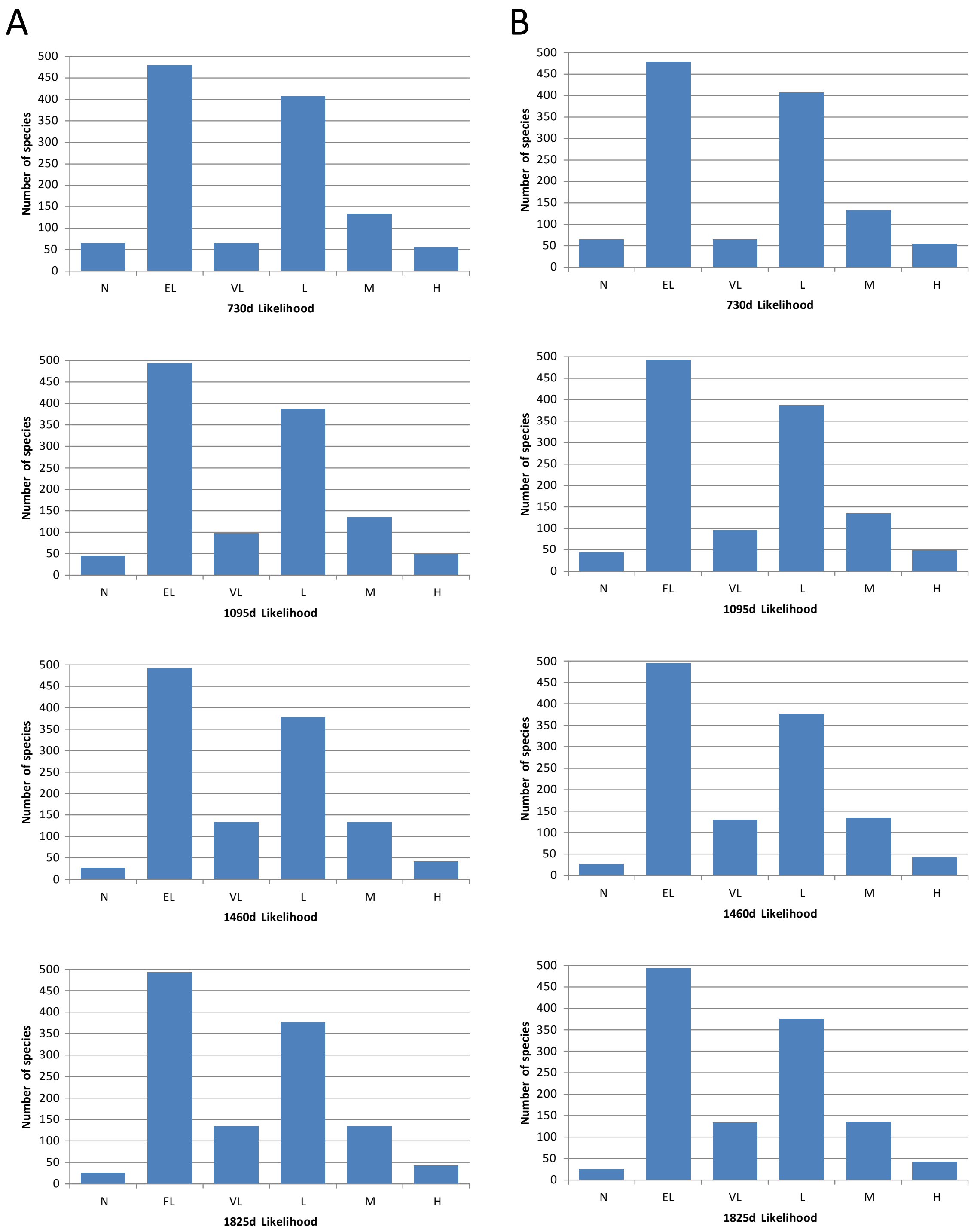

Figure 5.21. Number of species for Inoculation Likelihood Ranks to FSM for voyage durations greater than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

Table 5.5. Biofouling species with a "High" (n=42) and "Medium" (n=135) likelihood of arrival in FSM associated with all vessel traffic.

Phylum	Scientific Name	Likelihood
Annelida	*Alitta (Neanthes) succinea*	M
Annelida	*Dipolydora armata (=armarta)*	H
Annelida	*Dorvillea similis*	M
Annelida	*Eumida sanguineum*	M
Annelida	*Ficopomatus enigmaticus*	M
Annelida	*Hydroides albiceps (casual)*	M
Annelida	*Hydroides diramphus*	H
Annelida	*Hydroides elegans*	H
Annelida	*Janua pagenstecheri*	H
Annelida	*Lysidice collaris*	M
Annelida	*Myrianida pachycera*	M
Annelida	*Ophryotrocha labronica pacifica*	M
Annelida	*Pileolaria berkeleyana*	M
Annelida	*Polydora websteri*	M
Annelida	*Pomatoleios kraussii*	H
Annelida	*Pseudopolydora paucibranchiata*	M
Annelida	*Streblospio benedicti*	M
Chlorophyta	*Avrainvillea amadelpha*	M
Chlorophyta	*Bryopsis plumosa*	H
Chlorophyta	*Caulerpa racemosa var. lamourouxii*	M
Chlorophyta	*Chaetomorpha aerea*	H
Chlorophyta	*Cladophora prolifera*	M
Chlorophyta	*Codium ovale*	M
Chlorophyta	*Ulva clathrata (=Enteromorpha clathrata var. crinata)*	H
Chlorophyta	*Ulva flexuosa*	H
Chlorophyta	*Ulva pertusa*	M
Chlorophyta	*Ulva reticulata*	M
Chlorophyta	*Ulva rigida*	H
Chlorophyta	*Ulva taeniata*	M

Table 5.5: Continued

Phylum	Scientific Name	Likelihood
Chlorophyta	*Valonia fastigiata*	M
Chordata (Ascidiacea)	*Ascidia archaia*	M
Chordata (Ascidiacea)	*Botrylloides leachi*	M
Chordata (Ascidiacea)	*Botrylloides perspicuum*	M
Chordata (Ascidiacea)	*Botryllus schlosseri*	H
Chordata (Ascidiacea)	*Ciona intestinalis*	H
Chordata (Ascidiacea)	*Cnemidocarpa irene*	M
Chordata (Ascidiacea)	*Didemnum candidum*	H
Chordata (Ascidiacea)	*Microcosmus squamiger*	M
Chordata (Ascidiacea)	*Molgula ficus*	M
Chordata (Ascidiacea)	*Perophora multiclathrata*	M
Chordata (Ascidiacea)	*Polyandrocarpa zorritensis*	M
Chordata (Ascidiacea)	*Symplegma reptans*	M
Cnidaria	*Bougainvillia muscus*	M
Cnidaria	*Clytia hemisphaerica*	H
Cnidaria	*Cordylophora caspia*	H
Cnidaria	*Diadumene lineata*	H
Cnidaria	*Eudendrium capillare*	H
Cnidaria	*Eudendrium carneum*	M
Cnidaria	*Obelia longissima*	M
Cnidaria	*Plumularia setacea*	H
Cnidaria	*Sarsia tubulosa*	M
Cnidaria	*Scolionema suvaensis*	M
Cnidaria	*Sertularia tongensis (=Sertularia stechowi, S. theocarpa)*	M
Cnidaria	*Tubastraea coccinea*	H
Arthropoda	*Alpheus rapacida*	M
Arthropoda	*Amphibalanus amphitrite*	H
Arthropoda	*Amphibalanus improvisus*	M
Arthropoda	*Amphibalanus reticulatus*	H
Arthropoda	*Balanus trigonus*	H

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Table 5.5: Continued

Phylum	Scientific Name	Likelihood
Arthropoda	*Caprella danilevskii*	M
Arthropoda	*Caprella equilibra*	M
Arthropoda	*Caprella penantis*	M
Arthropoda	*Caprella scaura*	H
Arthropoda	*Carcinus maenas*	H
Arthropoda	*Conchoderma virgatum*	M
Arthropoda	*Dromia wilsoni*	M
Arthropoda	*Elasmopus rapax*	M
Arthropoda	*Ericthonius brasiliensis*	M
Arthropoda	*Eucrate crenata*	M
Arthropoda	*Glabropilumnus seminudus*	M
Arthropoda	*Gnorimosphaeroma rayi*	M
Arthropoda	*Inciscalliope derzhavini*	M
Arthropoda	*Kotoracythere inconspicua*	M
Arthropoda	*Laticorophium baconi*	H
Arthropoda	*Lepas (Anatifa) anatifera*	H
Arthropoda	*Leptochela dubia*	H
Arthropoda	*Ligia exotica*	H
Arthropoda	*Megabalanus occator*	M
Arthropoda	*Menaethius monoceros*	M
Arthropoda	*Merocryptus lambriformis*	M
Arthropoda	*Monocorophium acherusicum*	M
Arthropoda	*Monocorophium insidiosum*	M
Arthropoda	*Nanosesarma minutum*	M
Arthropoda	*Pachygrapsus crassipes*	M
Arthropoda	*Paracaprella pusilla*	H
Arthropoda	*Paracerceis sculpta*	M
Arthropoda	*Paradella dianae*	M
Arthropoda	*Plagusia depressa tuberculata*	M
Arthropoda	*Sinelobus cf. stanfordi*	M
Arthropoda	*Sphaeroma quoianum*	M

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Table 5.5: Continued

Phylum	Scientific Name	Likelihood
Arthropoda	*Sphaeroma walkeri*	H
Arthropoda	*Stenothoe gallensis*	M
Arthropoda	*Stenothoe valida*	M
Arthropoda	*Synidotea laevidorsalis*	M
Dinophyta	*Ostreopsis ovata*	M
Dinophyta	*Prorocentrum lima*	M
Bryozoa	*Aetea anguina*	M
Bryozoa	*Aetea truncata*	M
Bryozoa	*Bowerbankia gracilis*	M
Bryozoa	*Bowerbankia imbricata*	M
Bryozoa	*Bugula dentata*	M
Bryozoa	*Bugula stolonifera*	M
Bryozoa	*Caberea boryi*	M
Bryozoa	*Celleporaria brunnea*	M
Bryozoa	*Cryptosula pallasiana*	H
Bryozoa	*Hippopodina feegensis*	M
Bryozoa	*Hippothoa distans*	M
Bryozoa	*Jellyella tuberculata*	M
Bryozoa	*Scruparia ambigua*	M
Bryozoa	*Synnotum aegyptiacum*	M
Bryozoa	*Tricellaria occidentalis*	M
Bryozoa	*Watersipora arcuata*	M
Bryozoa	*Watersipora subtorquata*	H
Bryozoa	*Zoobotryon verticillatum*	M
Mollusca	*Anadara granosa (casual)*	M
Mollusca	*Anteaeolidiella foulisi (=Anteaolidiella indica)*	H
Mollusca	*Bankia bipalmulata*	M
Mollusca	*Caloria indica*	M
Mollusca	*Crepidpatella lingulata (=Crepidula lingulata)*	M

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Table 5.5: Continued

Phylum	Scientific Name	Likelihood
Mollusca	*Cycloscala hyalina*	M
Mollusca	*Dendrodoris fumata*	M
Mollusca	*Diodora ruppelli*	M
Mollusca	*Doxander vittatus*	M
Mollusca	*Elysia tomentosa*	M
Mollusca	*Hiatella arctica*	M
Mollusca	*Isognomon ephippium*	M
Mollusca	*Lienardia mighelsi*	M
Mollusca	*Martesia striata*	M
Mollusca	*Musculista senhousia*	H
Mollusca	*Mytilopsis sallei*	M
Mollusca	*Mytilus galloprovincialis*	M
Mollusca	*Nanostrea fluctigera (=Nanostrea exigua)*	M
Mollusca	*Okenia pellucida*	M
Mollusca	*Ostrea conchaphila*	M
Mollusca	*Perna viridis*	M
Mollusca	*Sabia conica*	M
Mollusca	*Strombus mutabilis*	M
Mollusca	*Syrnola cinctella*	M
Mollusca	*Teredo navalis*	H
Mollusca	*Teredora princesae*	M
Mollusca	*Thecacera pennigera*	M
Phaeophyta	*Chnoospora minima*	M
Phaeophyta	*Cutleria multifida*	M
Phaeophyta	*Dictyota flabellata*	M
Phaeophyta	*Ectocarpus siliculosus*	M
Phaeophyta	*Leathesia marina (=Leathesia difformis)*	M
Phaeophyta	*Macrocystis pyrifera*	M
Phaeophyta	*Myrionema strangulans*	M
Phaeophyta	*Nemacystus decipiens*	M
Phaeophyta	*Padina antillarum*	M

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Table 5.5: Continued

Phylum	Scientific Name	Likelihood
Phaeophyta	*Padina boryana*	M
Phaeophyta	*Pylaiella littoralis*	H
Phaeophyta	*Rugulopteryx okamurae*	M
Phoronida	*Phoronis hippocrepia*	M
Porifera	*Dysidea fragilis*	M
Porifera	*Mycale parishii (=Zygomycale parishii)*	H
Pycnogonida	*Ammothea hilgendorfi*	M
Pycnogonida	*Anoplodactylus erectus*	M
Pycnogonida	*Pigrogromitus timsanus*	M
Rhodophyta	*Acanthophora spicifera*	M
Rhodophyta	*Aglaothamnion cordatum*	H
Rhodophyta	*Antithamnion hubbsii (=nipponicum, pectinatum)*	M
Rhodophyta	*Apoglossum gregarium*	M
Rhodophyta	*Asparagopsis taxiformis*	H
Rhodophyta	*Bangia atropurpurea*	H
Rhodophyta	*Caulacanthus ustulatus*	H
Rhodophyta	*Chondria arcuata*	M
Rhodophyta	*Chroodactylon ramosum*	M
Rhodophyta	*Dasya baillouviana*	H
Rhodophyta	*Eucheuma denticulatum*	M
Rhodophyta	*Gracilaria gracilis*	M
Rhodophyta	*Hypnea cornuta*	M
Rhodophyta	*Hypnea nidifica*	M
Rhodophyta	*Laurencia brongniartii*	M
Rhodophyta	*Porphyra suborbiculata*	M
Rhodophyta	*Pterosiphonia bipinnata*	M
Rhodophyta	*Sarconema filiforme*	M

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5.4.3 Republic of the Marshall Islands

Republic of the Marshall Islands (RMI) received 540 commercial vessels and 630 MSC vessel entries during the assessed period (Figures 5.22 and 5.23). Approximately 6% of these vessels arrived directly from Guam. Commercial vessels had strong affinities with a restricted suite of Pacific Rim bioregions (East Asian Seas-13, South Pacific-14, Northeast Pacific-15, and Northwest Pacific-16), representing more than 47% of total trade. In contrast, military vessels exhibit a much broader exposure to bioregions, particularly Atlantic and Mediterranean bioregions, and therefore broader exposure to a wider suite of species. The trading activities rapidly sampled a wide variety of bioregions, with vessels arriving from 10 bioregions in 30 day voyages and reaching saturation (18 bioregions) with voyages of 365 days (Figure 5.24).

The inoculation likelihoods of species decrease with the addition of military vessels (Figures 5.25 and 5.26), in part due to the reduction of emphasis on Northeast and Northwest Pacific bioregions as trading partners. The combined result of commercial and military (MSC) traffic is 34 species identified as ‘High” likelihood of inoculation for voyages of 1,825 days (5 years) (Table 5.6).

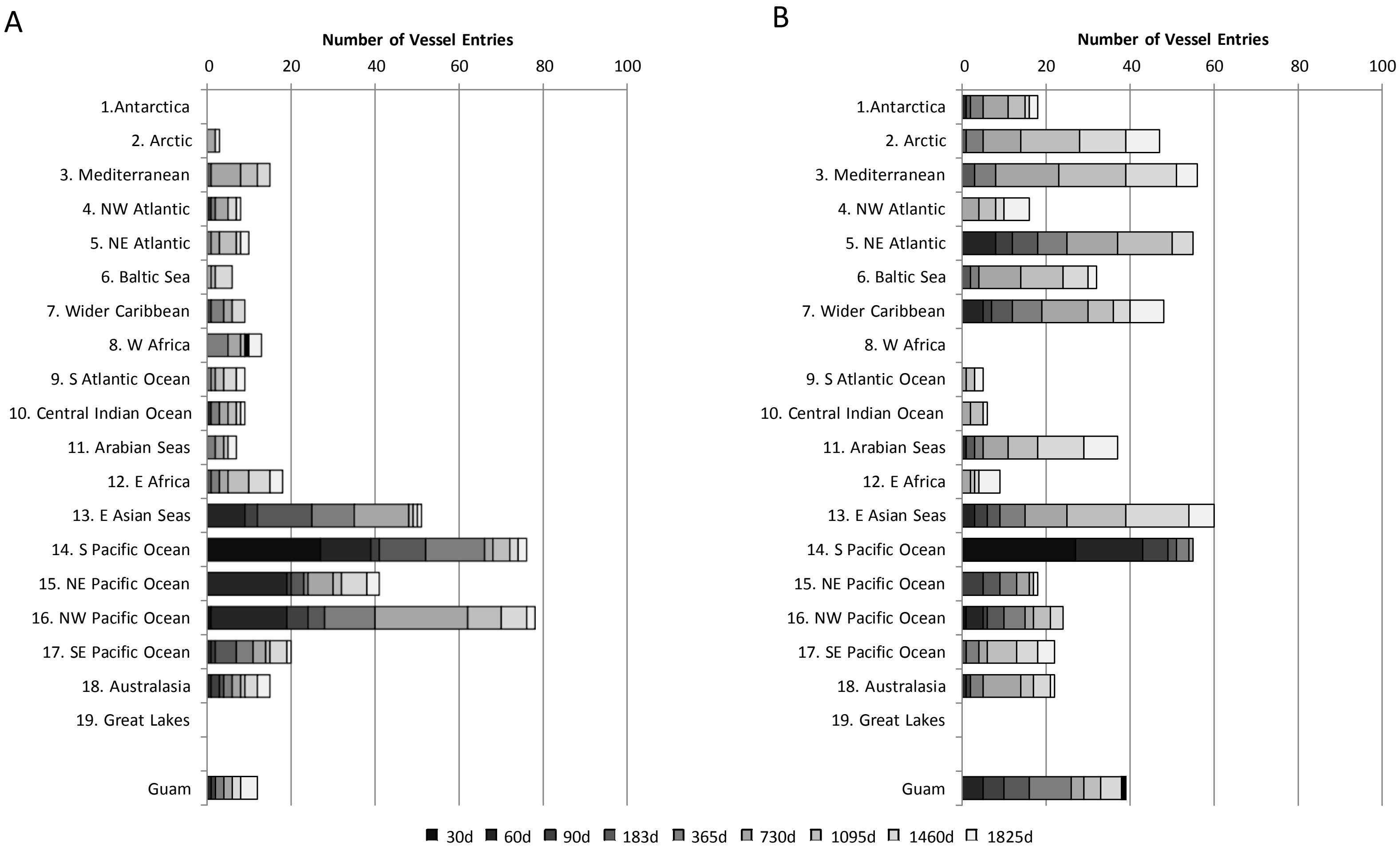

Figure 5.22. Number of A) commercial vessel (all categories) and B) MSC vessel (all categories) entries to RMI from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU and DoD datasets). Note that vessels transiting Guam are also represented in Bioregion 14 South Pacific Ocean.

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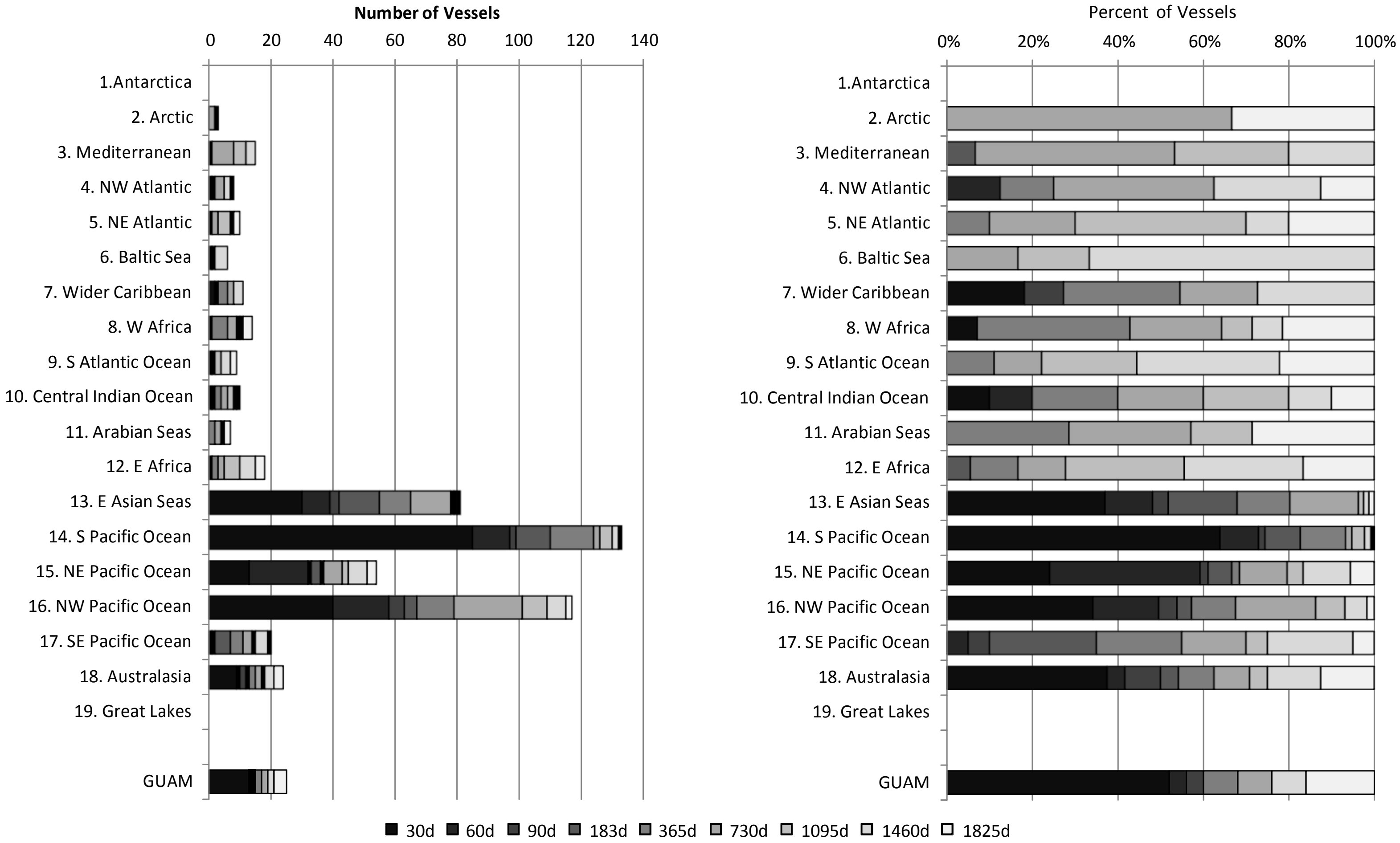

Figure 5.23. Number and percentage within a bioregion of all vessel (all categories of commercial and MSC vessels) entries to RMI from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU and DoD datasets). Note that vessels transiting Guam are also represented in Bioregion 14 South Pacific Ocean.

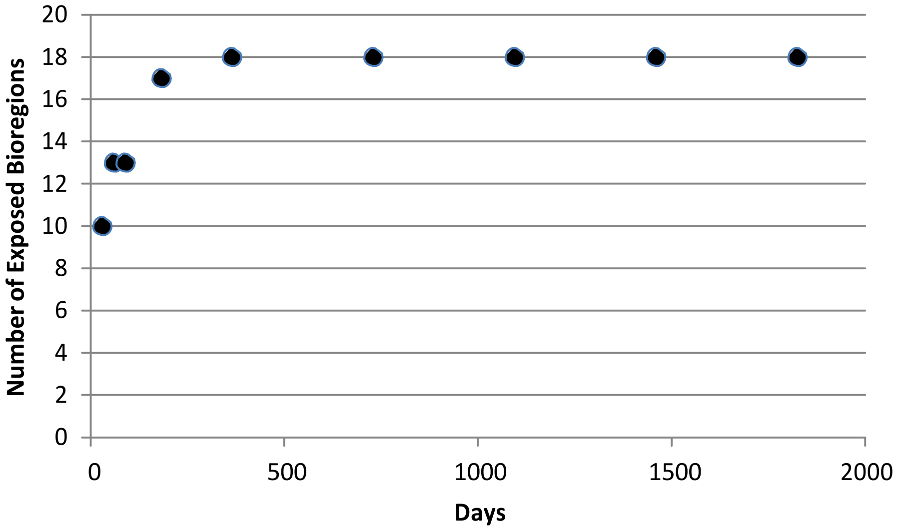

Figure 5.24. Number of bioregions visited by vessels entering RMI between 1999 and 2009 with increasing voyage duration (data from Lloyds MIU and DoD datasets).

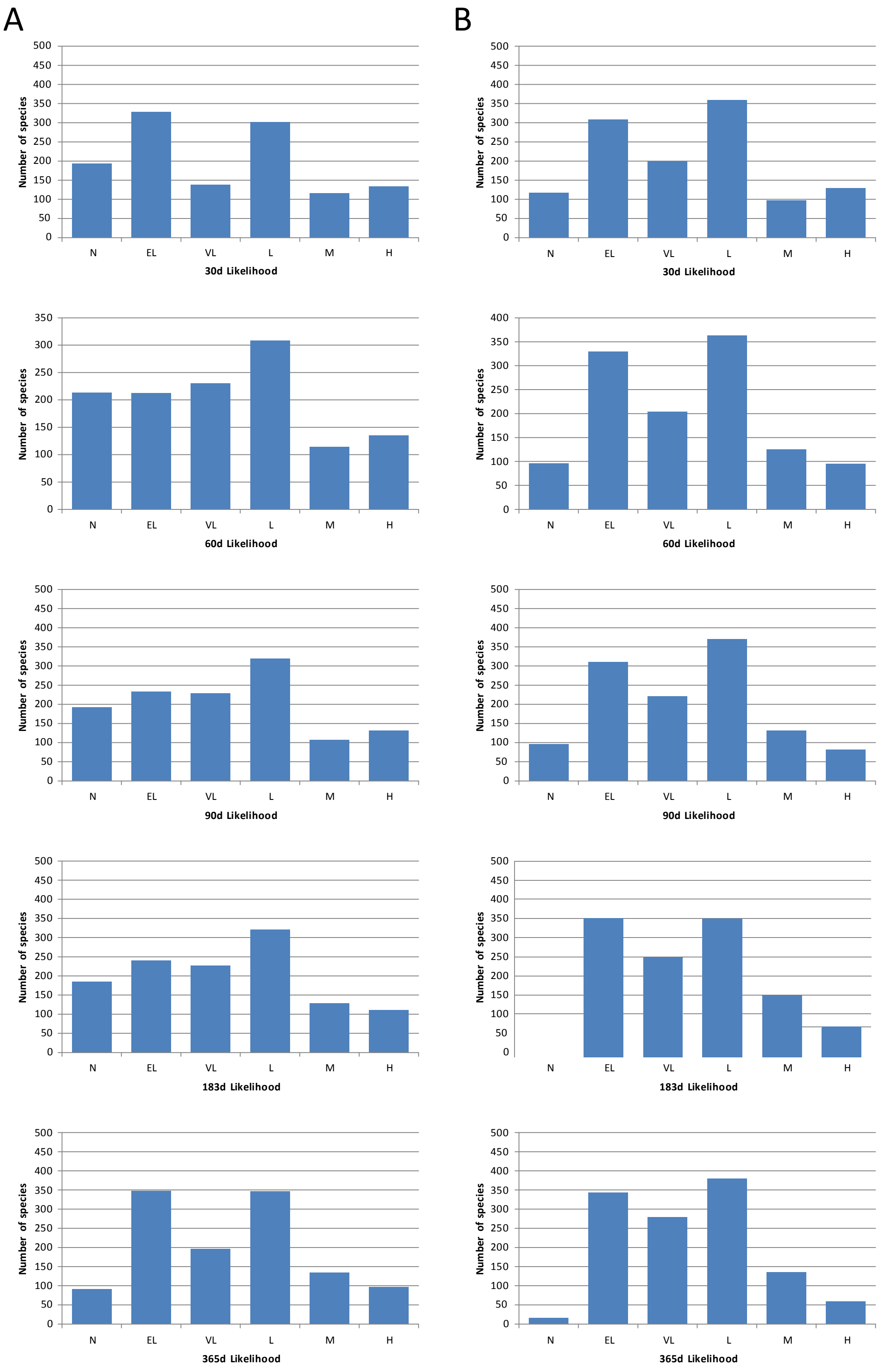

Figure 5.25. Number of species for Inoculation Likelihood Ranks to RMI for voyage durations less than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

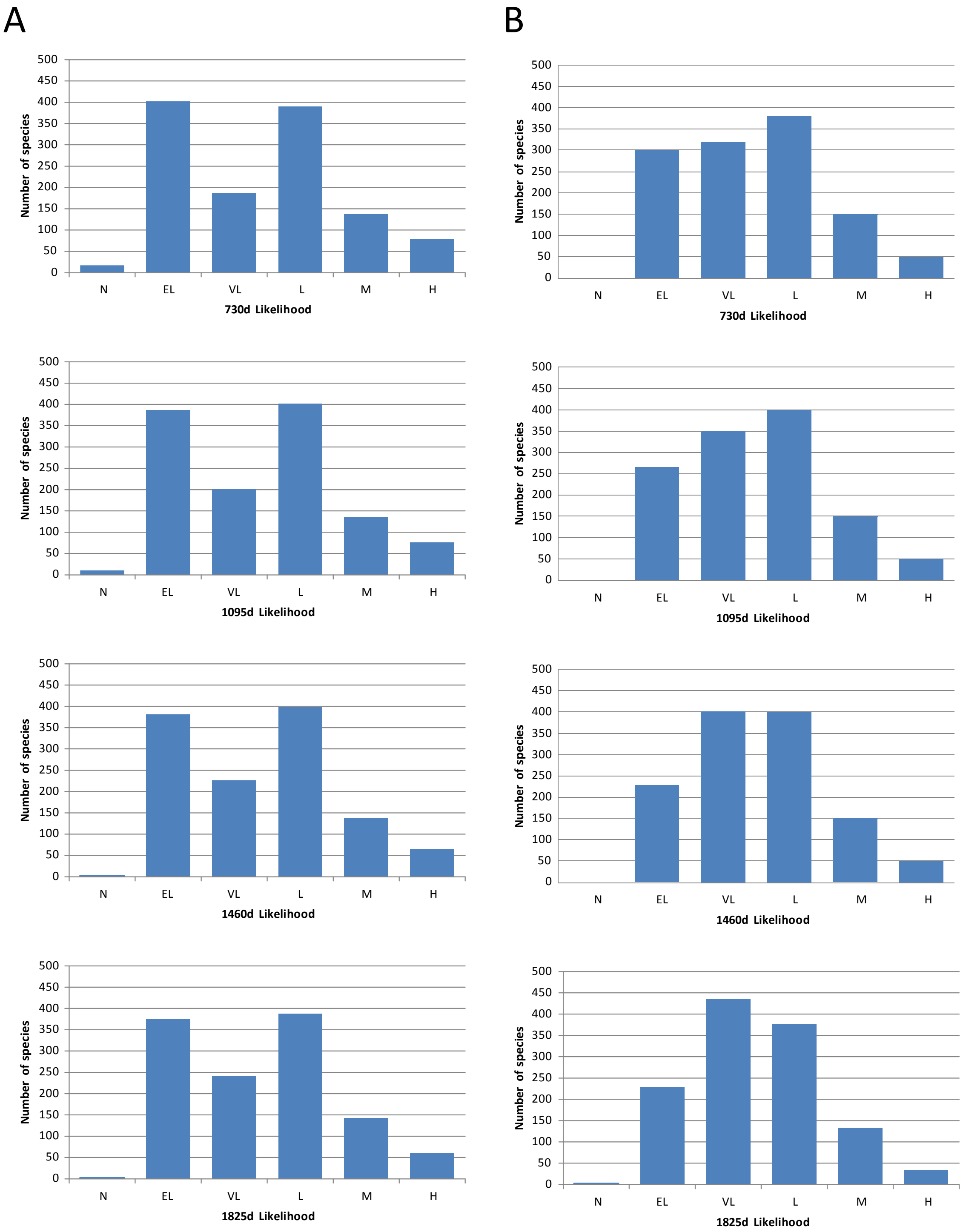

Figure 5.26. Number of species for Inoculation Likelihood Ranks to RMI for voyage durations greater than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

Table 5.6. Biofouling species with a "High" (n=34) AND "Medium" (n=133) likelihood of arrival in RMI associated with all vessel traffic.

Phylum	Scientific name	Likelihood
Annelida	*Janua pagenstecheri*	H
Annelida	*Hydroides elegans*	H
Annelida	*Hydroides diramphus*	M
Annelida	*Ficopomatus enigmaticus*	M
Annelida	*Eunice antennata*	M
Annelida	*Pileolaria berkeleyana*	M
Annelida	*Pomatoleios kraussii*	M
Annelida	*Lysidice collaris*	M
Annelida	*Neodexiospira brasiliensis (=Janua (Dexiospira) brasiliensis)*	M
Annelida	*Glycera capitata*	M
Annelida	*Heteromastus filiformis*	M
Annelida	*Hydroides albiceps*	M
Annelida	*Streblospio benedicti*	M
Annelida	*Pseudopolydora paucibranchiata*	M
Annelida	*Polydora websteri*	M
Annelida	*Alitta (Neanthes) succinea*	M
Chlorophyta	*Bryopsis plumosa*	H
Chlorophyta	*Ulva rigida*	H
Chlorophyta	*Chaetomorpha aerea*	H
Chlorophyta	*Chaetomorpha linum*	H
Chlorophyta	*Ulva clathrata (=Enteromorpha clathrata var. crinata)*	H
Chlorophyta	*Cladophora sericea*	H
Chlorophyta	*Bryopsis pennata*	H
Chlorophyta	*Neomeris annulata*	H
Chlorophyta	*Cladophora prolifera*	M
Chlorophyta	*Ulva reticulata*	M
Chlorophyta	*Ulva pertusa*	M

Table 5.6: Continued

Phylum	Scientific name	Likelihood
Chlorophyta	*Cladophora patentiramea*	M
Chlorophyta	*Ulva taeniata*	M
Chlorophyta	*Caulerpa racemosa var. lamourouxii*	M
Chlorophyta	*Codium ovale*	M
Chordata (Ascidiacea)	*Ciona intestinalis*	H
Chordata (Ascidiacea)	*Botryllus schlosseri*	H
Chordata (Ascidiacea)	*Perophora multiclathrata*	M
Chordata (Ascidiacea)	*Botrylloides leachi*	M
Chordata (Ascidiacea)	*Microcosmus squamiger*	M
Chordata (Ascidiacea)	*Polyandrocarpa zorritensis*	M
Chordata (Ascidiacea)	*Didemnum candidum*	M
Chordata (Ascidiacea)	*Botrylloides perspicuum*	M
Cnidaria	*Diadumene lineata*	M
Cnidaria	*Plumularia setacea*	H
Cnidaria	*Cordylophora caspia*	H
Cnidaria	*Eudendrium capillare*	H
Cnidaria	*Obelia longissima*	M
Cnidaria	*Bougainvillia muscus*	M
Cnidaria	*Eudendrium carneum*	M
Cnidaria	*Sarsia tubulosa*	M
Cnidaria	*Scolionema suvaensis*	M
Cnidaria	*Coryne eximia (=Sarsia eximia)*	M
Cnidaria	*Coryne pusilla*	M
Cnidaria	*Cladonema radiatum*	M
Cnidaria	*Phyllorhiza punctata*	M
Arthropoda	*Caprella scaura*	H
Arthropoda	*Monocorophium acherusicum*	M
Arthropoda	*Elasmopus rapax*	M
Arthropoda	*Stenothoe gallensis*	M
Arthropoda	*Stenothoe valida*	M

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Table 5.6: Continued

Phylum	Scientific name	Likelihood
Arthropoda	*Monocorophium insidiosum*	M
Arthropoda	*Caprella equilibra*	M
Arthropoda	*Caprella penantis*	M
Arthropoda	*Laticorophium baconi*	M
Arthropoda	*Paracaprella pusilla*	M
Arthropoda	*Ericthonius brasiliensis*	M
Arthropoda	*Caprella danilevskii*	M
Arthropoda	*Jassa marmorata*	M
Arthropoda	*Amphibalanus reticulatus*	H
Arthropoda	*Balanus trigonus*	H
Arthropoda	*Amphibalanus amphitrite*	H
Arthropoda	*Lepas (Anatifa) anserifera*	H
Arthropoda	*Amphibalanus improvisus*	M
Arthropoda	*Lepas (Anatifa) hillii*	M
Arthropoda	*Pleopis polyphemoides*	M
Arthropoda	*Carcinus maenas*	H
Arthropoda	*Eucrate crenata*	M
Arthropoda	*Menaethius monoceros*	M
Arthropoda	*Dromia wilsoni*	M
Arthropoda	*Plagusia depressa tuberculata*	M
Arthropoda	*Sphaeroma walkeri*	H
Arthropoda	*Ligia exotica*	M
Arthropoda	*Paracerceis sculpta*	M
Arthropoda	*Idotea metallica*	M
Arthropoda	*Synidotea laevidorsalis*	M
Arthropoda	*Leptochela dubia*	H
Arthropoda	*Sinelobus cf. stanfordi*	M
Dinophyta	*Prorocentrum lima*	M
Dinophyta	*Ostreopsis ovata*	M
Bryozoa	*Cryptosula pallasiana*	H
Bryozoa	*Watersipora subtorquata*	H

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Table 5.6: Continued

Phylum	Scientific name	Likelihood
Bryozoa	*Bowerbankia gracilis*	M
Bryozoa	*Bugula stolonifera*	M
Bryozoa	*Hippopodina feegensis*	M
Bryozoa	*Aetea truncata*	M
Bryozoa	*Hippothoa distans*	M
Bryozoa	*Jellyella tuberculata*	M
Bryozoa	*Synnotum aegyptiacum*	M
Bryozoa	*Bowerbankia imbricata*	M
Bryozoa	*Zoobotryon verticillatum*	M
Bryozoa	*Scruparia ambigua*	M
Bryozoa	*Bugula dentata*	M
Bryozoa	*Tricellaria occidentalis*	M
Bryozoa	*Aetea anguina*	M
Bryozoa	*Caberea boryi*	M
Mollusca	*Teredo navalis*	H
Mollusca	*Musculista senhousia*	H
Mollusca	*Hiatella arctica*	M
Mollusca	*Mytilus galloprovincialis*	M
Mollusca	*Martesia striata*	M
Mollusca	*Anadara granosa*	M
Mollusca	*Mytilopsis sallei*	M
Mollusca	*Isognomon ephippium*	M
Mollusca	*Nanostrea fluctigera (=Nanostrea exigua)*	M
Mollusca	*Perna viridis*	M
Mollusca	*Thecacera pennigera*	M
Mollusca	*Dendrodoris fumata*	M
Mollusca	*Cycloscala hyalina*	M
Mollusca	*Lienardia mighelsi*	M
Mollusca	*Sabia conica*	M
Mollusca	*Elysia tomentosa*	M
Mollusca	*Caloria indica*	M

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Table 5.6: Continued

Phylum	Scientific name	Likelihood
Mollusca	*Syrnola cinctella*	M
Mollusca	*Tenellia adspersa*	M
Mollusca	*Doxander vittatus*	M
Mollusca	*Strombus mutabilis*	M
Mollusca	*Okenia pellucida*	M
Mollusca	*Anteaeolidiella foulisi (=Anteaolidiella indica)*	M
Phaeophyta	*Pylaiella littoralis*	H
Phaeophyta	*Ectocarpus siliculosus*	M
Phaeophyta	*Myrionema strangulans*	M
Phaeophyta	*Leathesia marina (=Leathesia difformis)*	M
Phaeophyta	*Ectocarpus fasciculatus*	M
Phaeophyta	*Hincksia ovata*	M
Phaeophyta	*Cutleria multifida*	M
Phaeophyta	*Chnoospora minima*	M
Phaeophyta	*Hincksia granulosa*	M
Phaeophyta	*Punctaria latifolia*	M
Phaeophyta	*Sargassum muticum*	M
Phaeophyta	*Macrocystis pyrifera*	M
Phaeophyta	*Hincksia sandriana*	M
Phoronida	*Phoronis hippocrepia*	M
Porifera	*Mycale parishii (=Zygomycale parishii)*	M
Porifera	*Dysidea fragilis*	M
Porifera	*Halichondria panicea*	M
Pycnogonida	*Pigrogromitus timsanus*	M
Pycnogonida	*Ammothea hilgendorfi*	M
Rhodophyta	*Bangia atropurpurea*	H
Rhodophyta	*Asparagopsis taxiformis*	H
Rhodophyta	*Centroceras clavulatum*	H
Rhodophyta	*Gymnothamnion elegans*	H
Rhodophyta	*Hypnea valentiae*	H

Table 5.6: Continued

Phylum	Scientific name	Likelihood
Rhodophyta	*Dasya baillouviana*	H
Rhodophyta	*Aglaothamnion cordatum*	M
Rhodophyta	*Caulacanthus ustulatus*	M
Rhodophyta	*Hypnea anastomosans (=Hypnea esperi)*	M
Rhodophyta	*Hypnea cornuta*	M
Rhodophyta	*Chroodactylon ramosum*	M
Rhodophyta	*Antithamnion hubbsii (=nipponicum, pectinatum)*	M
Rhodophyta	*Herposiphonia parca*	M
Rhodophyta	*Sarconema filiforme*	M
Rhodophyta	*Ceramium virgatum*	M
Rhodophyta	*Gracilaria gracilis*	M
Rhodophyta	*Neosiphonia harveyi (=Polysiphonia harveyi)*	M
Rhodophyta	*Eucheuma denticulatum*	M
Rhodophyta	*Corallina officinalis*	M
Rhodophyta	*Spongoclonium caribaeum (=Pleonosporium caribaeum)*	M
Rhodophyta	*Apoglossum gregarium*	M
Rhodophyta	*Polysiphonia brodiei*	M
Rhodophyta	*Polysiphonia sertularioides*	M

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5.4.4 Republic of Palau

The Republic of Palau received 707 commercial vessels and 159 MSC vessel entries during the assessed period (Figures 5.27 and 5.28). Approximately 15% of these vessels arrived directly from Guam. Commercial vessels had strong affinities with a restricted suite of bioregions (East Asian Seas-13, Central Indian Ocean-10, South Pacific-14, and Arabian Seas-11), representing more than 46% of total trade. In contrast, military vessels exhibit a much broader, albeit minor, exposure to bioregions. The trading activities initially had a small sample of bioregions at short voyage durations (30 days = 5 bioregions, 90 days = 8 bioregions) but reached 17 bioregions with voyages of 365 days and saturation after 1,460 days (4 years) (Figure 5.29).

The inoculation likelihoods of species are not significantly affected with the addition of military vessels (Figures 5.30 and 5.31), largely due to the minor contribution military vessels make to the trading activities of Palau. The combined trading activities result in 31 species identified as ‘High” likelihood of inoculation for voyages of 1,825 days (5 years) (Table 5.7).

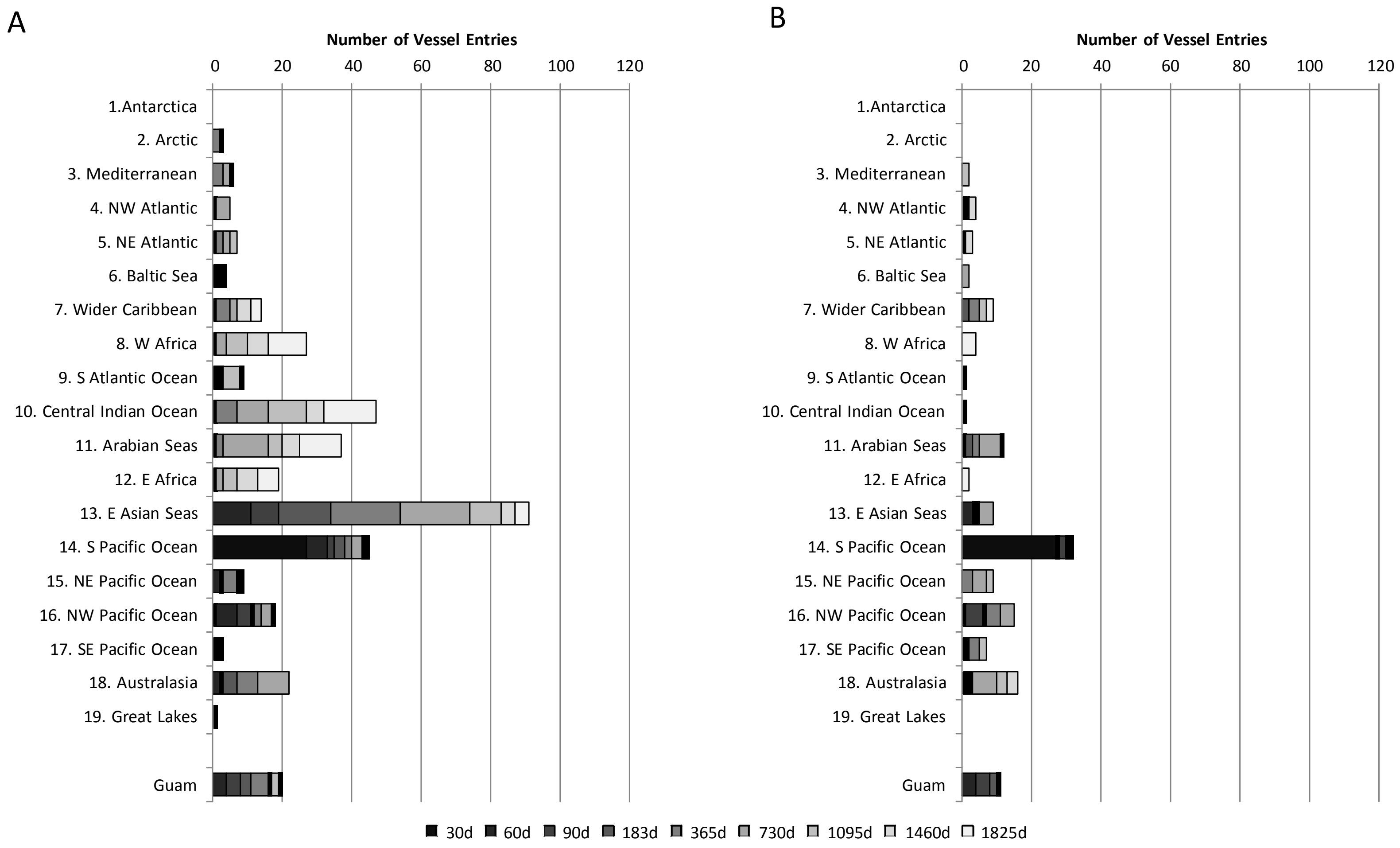

Figure 5.27. Number of A) commercial vessel (all categories) and B) MSC vessel (all categories) entries to the Republic of Palau from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU and DoD datasets). Note that vessels transiting Guam are also represented in Bioregion 14 South Pacific Ocean.

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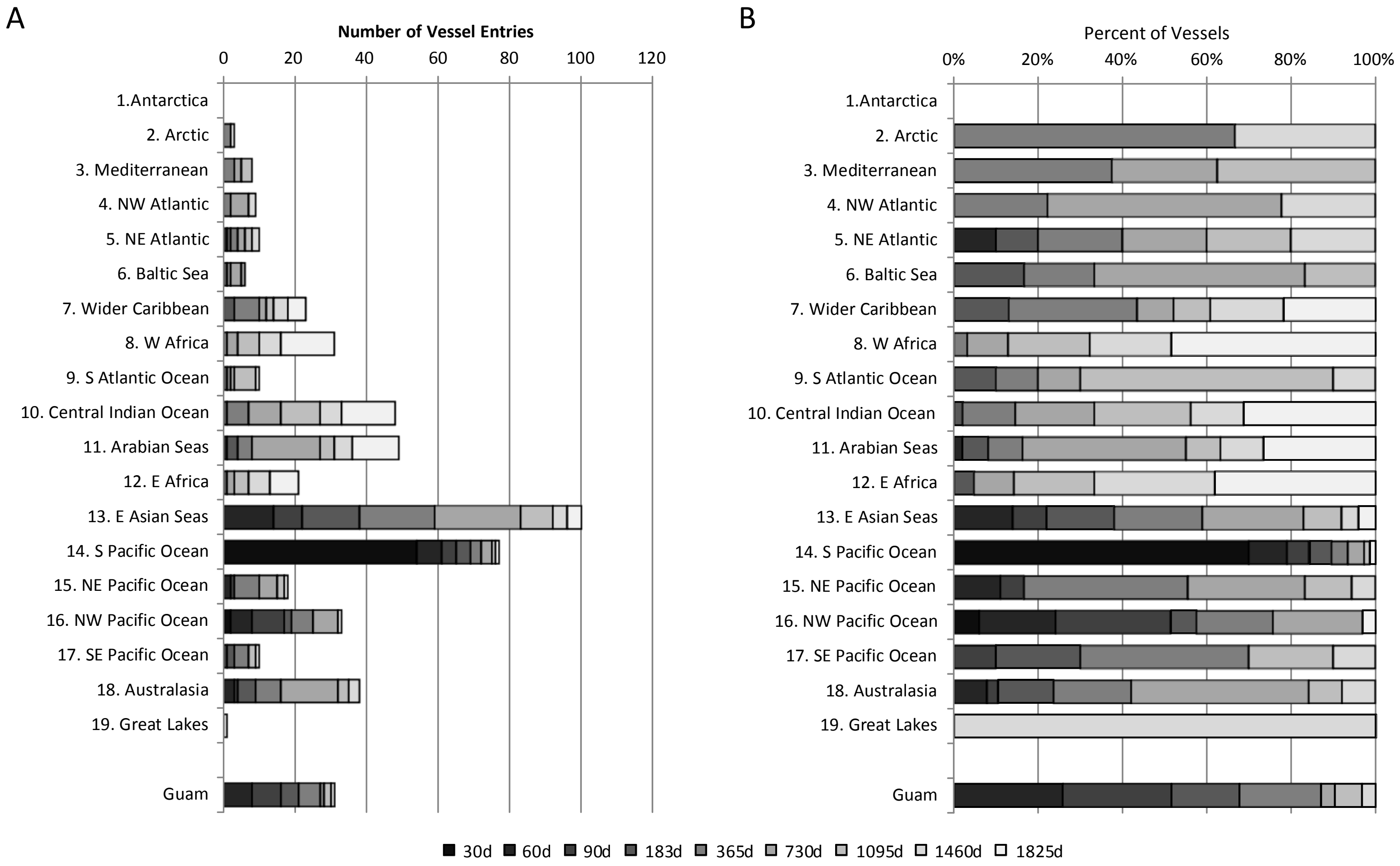

Figure 5.28. Number and percentage within a bioregion of all vessel (all categories of commercial and MSC vessels) entries to the Republic of Palau from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU and DoD datasets). Note that vessels transiting Guam are also represented in Bioregion 14 South Pacific Ocean.

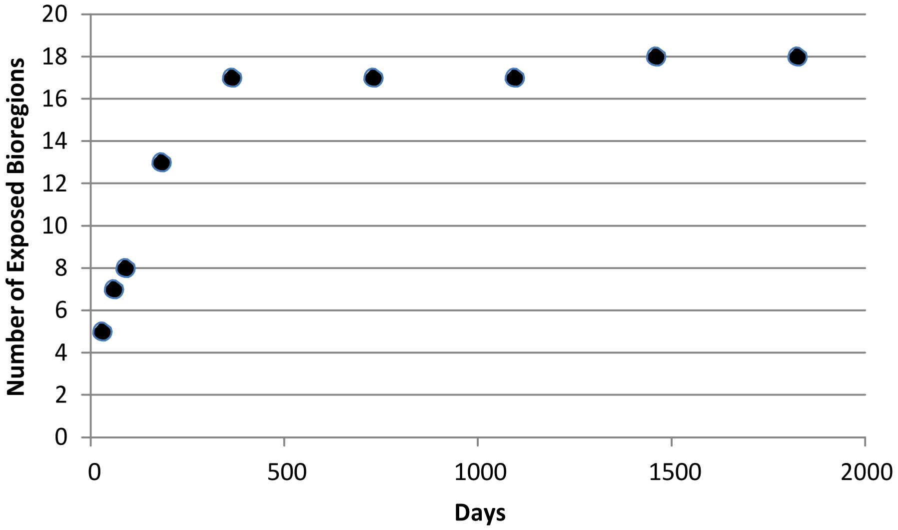

Figure 5.29. Number of bioregions visited by vessels entering the Republic of Palau between 1999 and 2009 with increasing voyage duration (data frm Lloyds MIU and DoD datasets).

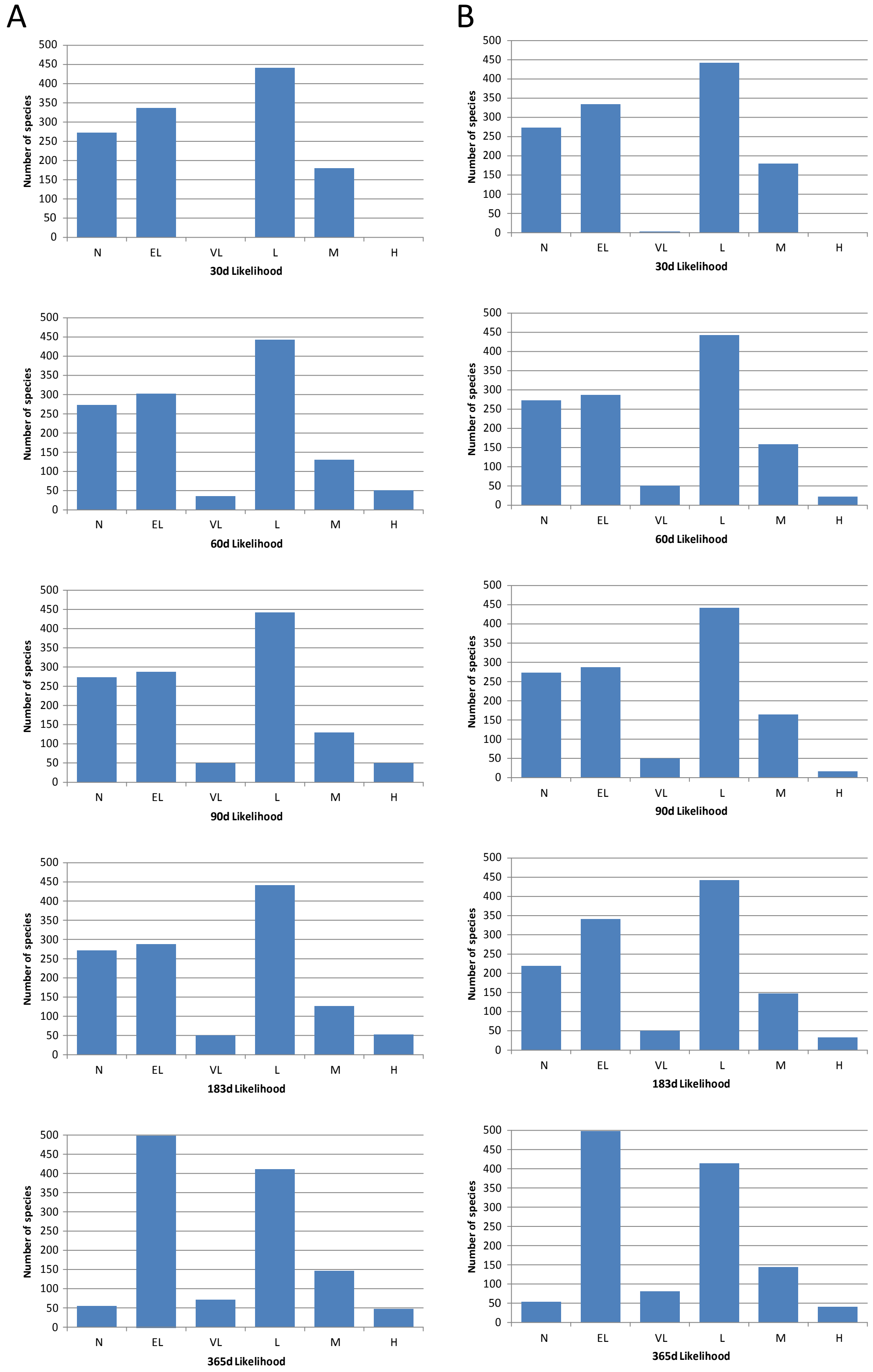

Figure 5.30. Number of species for Inoculation Likelihood Ranks to the Republic of Palau for voyage durations less than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

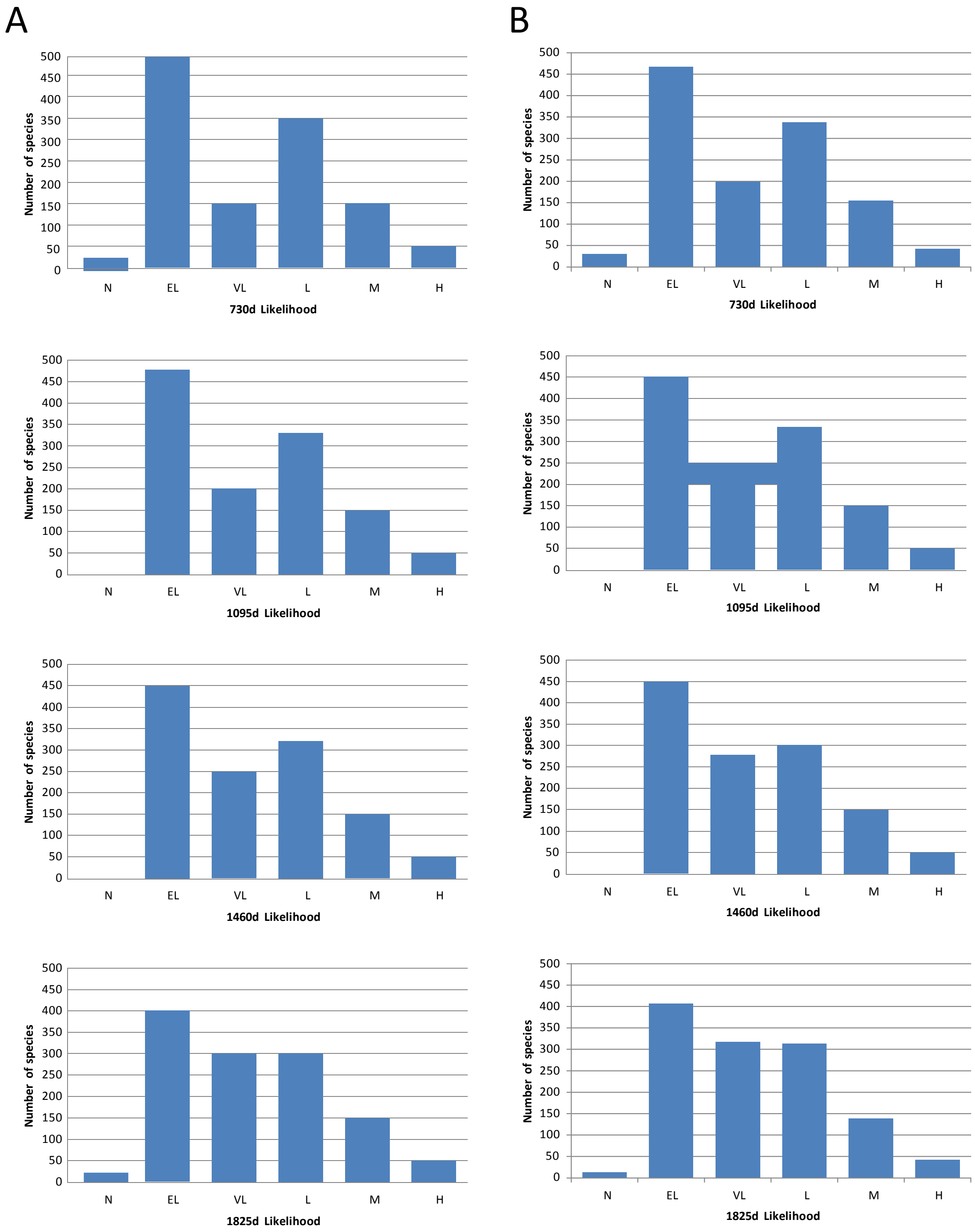

Figure 5.31. Number of species for Inoculation Likelihood Ranks to the Republic of Palau for voyage durations greater than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

Table 5.7. Biofouling species with a “High” (n=31) and “Medium” (n=108) likelihood of arrival in the Republic of Palau associated with all vessel traffic.

Phylum	Scientific name	Likelihood
Annelida	*Alitta (Neanthes) succinea*	M
Annelida	*Dipolydora armata (=armarta)*	M
Annelida	*Eumida sanguineum*	M
Annelida	*Eunice antennata*	M
Annelida	*Ficopomatus enigmaticus*	M
Annelida	*Glycera capitata*	M
Annelida	*Heteromastus filiformis*	M
Annelida	*Hydroides diramphus*	M
Annelida	*Janua pagenstecheri*	H
Annelida	*Neodexiospira brasiliensis (=Janua (Dexiospira) brasiliensis)*	M
Annelida	*Pileolaria berkeleyana*	M
Annelida	*Streblospio benedicti*	M
Chlorophyta	*Bryopsis pennata*	M
Chlorophyta	*Bryopsis plumosa*	H
Chlorophyta	*Chaetomorpha aerea*	H
Chlorophyta	*Chaetomorpha linum*	H
Chlorophyta	*Cladophora herpestica*	M
Chlorophyta	*Cladophora prolifera*	M
Chlorophyta	*Cladophora sericea*	H
Chlorophyta	*Codium fragile (=C. f. tomentosoides)*	M
Chlorophyta	*Derbesia marina*	H
Chlorophyta	*Neomeris annulata (casual)*	M
Chlorophyta	*Ulva clathrata (=Enteromorpha clathrata var. crinata)*	H
Chlorophyta	*Ulva flexuosa*	H
Chlorophyta	*Ulva pertusa*	M
Chlorophyta	*Ulva reticulata*	M
Chlorophyta	*Ulva rigida*	H
Chordata (Ascidiacea)	*Botrylloides perspicuum*	M

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Table 5.7: Continued

Phylum	Scientific name	Likelihood
Chordata (Ascidiacea)	*Botryllus schlosseri*	H
Chordata (Ascidiacea)	*Ciona intestinalis*	H
Chordata (Ascidiacea)	*Didemnum candidum*	M
Chordata (Ascidiacea)	*Molgula manhattensis*	M
Cnidaria	*Bougainvillia muscus*	M
Cnidaria	*Cladonema radiatum*	M
Cnidaria	*Clytia hemisphaerica*	H
Cnidaria	*Cordylophora caspia*	H
Cnidaria	*Coryne eximia (=Sarsia eximia)*	M
Cnidaria	*Coryne pusilla*	M
Cnidaria	*Diadumene lineata*	M
Cnidaria	*Eudendrium capillare*	H
Cnidaria	*Eudendrium carneum*	M
Cnidaria	*Gonothyraea loveni*	M
Cnidaria	*Obelia longissima*	M
Cnidaria	*Plumularia setacea*	H
Cnidaria	*Sarsia tubulosa*	M
Cnidaria	*Tubastraea coccinea*	M
Arthropoda	*Amphibalanus amphitrite*	H
Arthropoda	*Amphibalanus improvisus*	M
Arthropoda	*Amphibalanus reticulatus*	H
Arthropoda	*Balanus trigonus*	H
Arthropoda	*Caprella equilibra*	M
Arthropoda	*Caprella penantis*	M
Arthropoda	*Caprella scaura*	M
Arthropoda	*Carcinus maenas*	H
Arthropoda	*Elasmopus rapax*	M
Arthropoda	*Ericthonius brasiliensis*	M
Arthropoda	*Idotea metallica*	M
Arthropoda	*Jassa marmorata*	M
Arthropoda	*Laticorophium baconi*	M

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Table 5.7: Continued

Phylum	Scientific name	Likelihood
Arthropoda	*Lepas (Anatifa) anatifera*	H
Arthropoda	*Lepas (Anatifa) anserifera*	H
Arthropoda	*Lepas (Anatifa) hillii*	M
Arthropoda	*Leptochela dubia*	H
Arthropoda	*Ligia exotica*	M
Arthropoda	*Monocorophium acherusicum*	M
Arthropoda	*Monocorophium insidiosum*	M
Arthropoda	*Paracaprella pusilla*	M
Arthropoda	*Paracerceis sculpta*	M
Arthropoda	*Paradella dianae*	M
Arthropoda	*Pleopis polyphemoides*	M
Arthropoda	*Porcellio lamellatus lamellatus*	M
Arthropoda	*Sinelobus cf. stanfordi*	M
Arthropoda	*Sphaeroma walkeri*	M
Arthropoda	*Stenothoe gallensis*	M
Arthropoda	*Stenothoe valida*	M
Arthropoda	*Synidotea laevidorsalis*	M
Dinophyta	*Prorocentrum lima*	M
Bryozoa	*Aetea anguina*	M
Bryozoa	*Aetea truncata*	M
Bryozoa	*Bowerbankia gracilis*	M
Bryozoa	*Bowerbankia imbricata*	M
Bryozoa	*Bugula stolonifera*	M
Bryozoa	*Cryptosula pallasiana*	H
Bryozoa	*Hippopodina feegensis*	M
Bryozoa	*Hippothoa distans*	M
Bryozoa	*Jellyella tuberculata*	M
Bryozoa	*Scruparia ambigua*	M
Bryozoa	*Synnotum aegyptiacum*	M
Bryozoa	*Victorella pavida*	M
Bryozoa	*Watersipora subtorquata*	M

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Table 5.7: Continued

Phylum	Scientific name	Likelihood
Bryozoa	*Zoobotryon verticillatum*	M
Mollusca	*Anteaeolidiella foulisi (=Anteaolidiella indica)*	M
Mollusca	*Dendrodoris fumata*	M
Mollusca	*Hiatella arctica*	H
Mollusca	*Musculista senhousia*	M
Mollusca	*Mytilus galloprovincialis*	M
Mollusca	*Sabia conica*	M
Mollusca	*Tenellia adspersa*	M
Mollusca	*Teredo navalis*	H
Mollusca	*Thecacera pennigera*	M
Phaeophyta	*Cutleria multifida*	M
Phaeophyta	*Desmarestia viridis*	M
Phaeophyta	*Ectocarpus fasciculatus*	M
Phaeophyta	*Ectocarpus siliculosus*	M
Phaeophyta	*Hincksia granulosa*	M
Phaeophyta	*Hincksia mitchelliae*	H
Phaeophyta	*Hincksia ovata*	M
Phaeophyta	*Hincksia sandriana*	M
Phaeophyta	*Leathesia marina (=Leathesia difformis)*	M
Phaeophyta	*Myrionema strangulans*	M
Phaeophyta	*Pylaiella littoralis*	H
Phaeophyta	*Punctaria latifolia*	M
Phoronida	*Phoronis hippocrepia*	M
Porifera	*Dysidea fragilis*	M
Porifera	*Halichondria panicea*	M
Porifera	*Mycale parishii (=Zygomycale parishii)*	M
Pycnogonida	*Ammothea hilgendorfi*	M
Pycnogonida	*Pigrogromitus timsanus*	M
Rhodophyta	*Aglaothamnion cordatum*	M

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Table 5.7: Continued

Phylum	Scientific name	Likelihood
Rhodophyta	*Antithamnion hubbsii (=nipponicum, pectinatum)*	M
Rhodophyta	*Asparagopsis taxiformis*	H
Rhodophyta	*Bangia atropurpurea*	H
Rhodophyta	*Caulacanthus ustulatus*	M
Rhodophyta	*Centroceras clavulatum*	H
Rhodophyta	*Ceramium virgatum*	M
Rhodophyta	*Chroodactylon ramosum*	M
Rhodophyta	*Corallina officinalis*	M
Rhodophyta	*Dasya baillouviana*	M
Rhodophyta	*Gracilaria gracilis*	M
Rhodophyta	*Gymnothamnion elegans*	M
Rhodophyta	*Hildenbrandia rubra*	H
Rhodophyta	*Hypnea anastomosans (=Hypnea esperi)*	M
Rhodophyta	*Hypnea cornuta*	M
Rhodophyta	*Hypnea spinella (=Hypnea cervicornis)*	M
Rhodophyta	*Hypnea valentiae*	M
Rhodophyta	*Neosiphonia harveyi (=Polysiphonia harveyi)*	M
Rhodophyta	*Polysiphonia brodiei*	M
Rhodophyta	*Polysiphonia sertularioides*	M
Rhodophyta	*Polysiphonia subtilissima*	M

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5.4.5 United States Minor Islands

The United States Minor Islands (UMI) received 58 commercial vessels and 762 MSC vessel entries during the assessed period (Figures 5.32 and 5.33). Approximately 7% of these vessels arrived directly from Guam. Commercial vessels were of insufficient number to ascertain string trade affinities other than relationships within the South Pacific. In contrast, military vessels exhibit a much broader exposure to bioregions, particularly throughout the Atlantic, Mediterranean and Pacific basins, and therefore broader exposure to a wider suite of species. The trading activities slowly sampled bioregions, with only five bioregions being visited for 30 day voyage windows and only reaching saturation (18 bioregions) after 1,460 days (4 years) (Figure 5.34).

The inoculation likelihoods of species should only be considered for all vessels (commercial and military) due to the inability to assess on the basis of insufficient numbers of commercial vessel entries (Figures 5.35 and 5.36). Military vessels therefore significantly increase the risk of species entry. This results in 31 species identified as ‘High” likelihood of inoculation for voyages of 1,825 days (5 years) (Table 5.8).

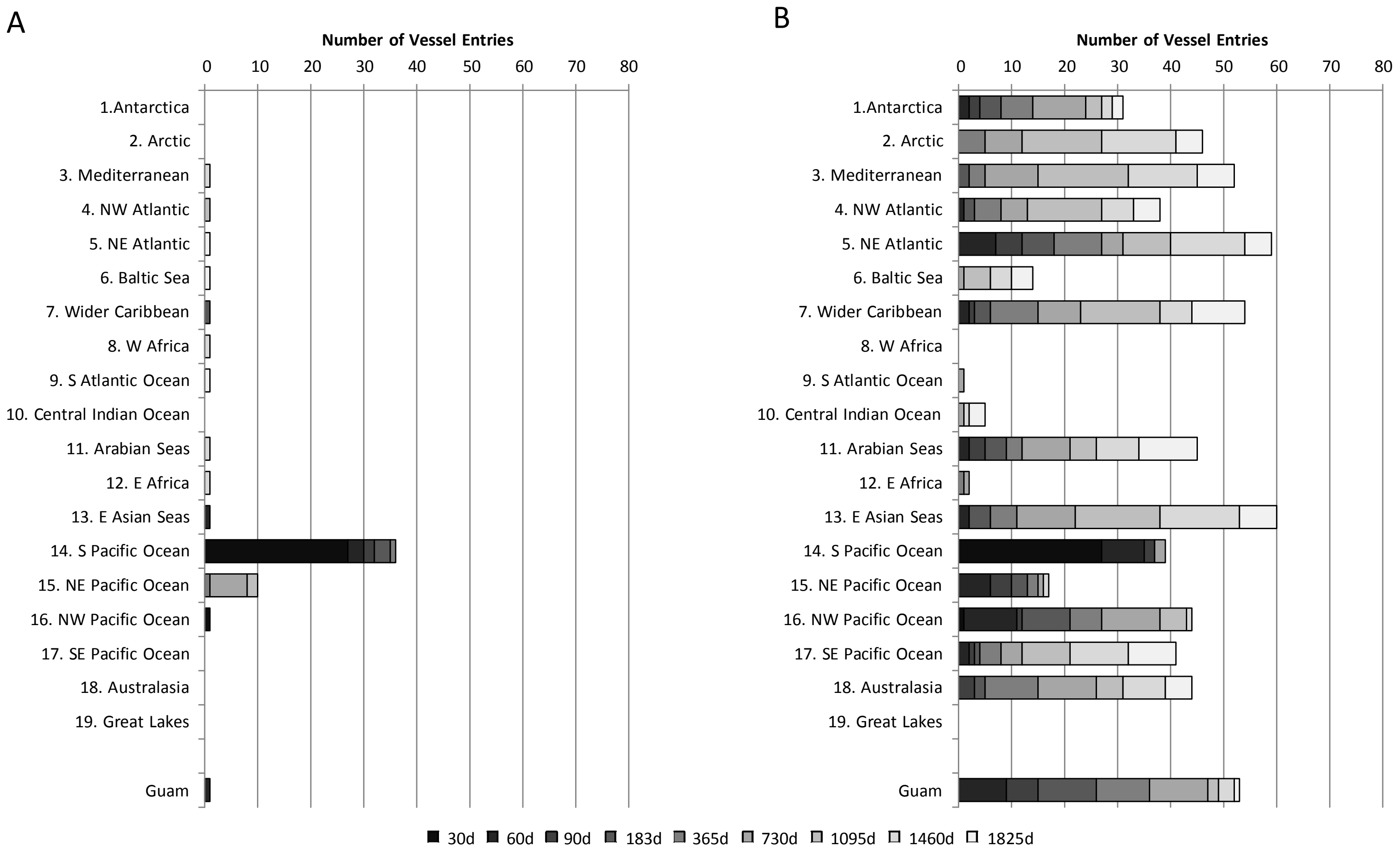

Figure 5.32. Number of A) commercial vessel (all categories) and B) MSC vessel (all categories) entries to UMI from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU and DoD datasets). Note that vessels transiting Guam are also represented in Bioregion 14 South Pacific Ocean.

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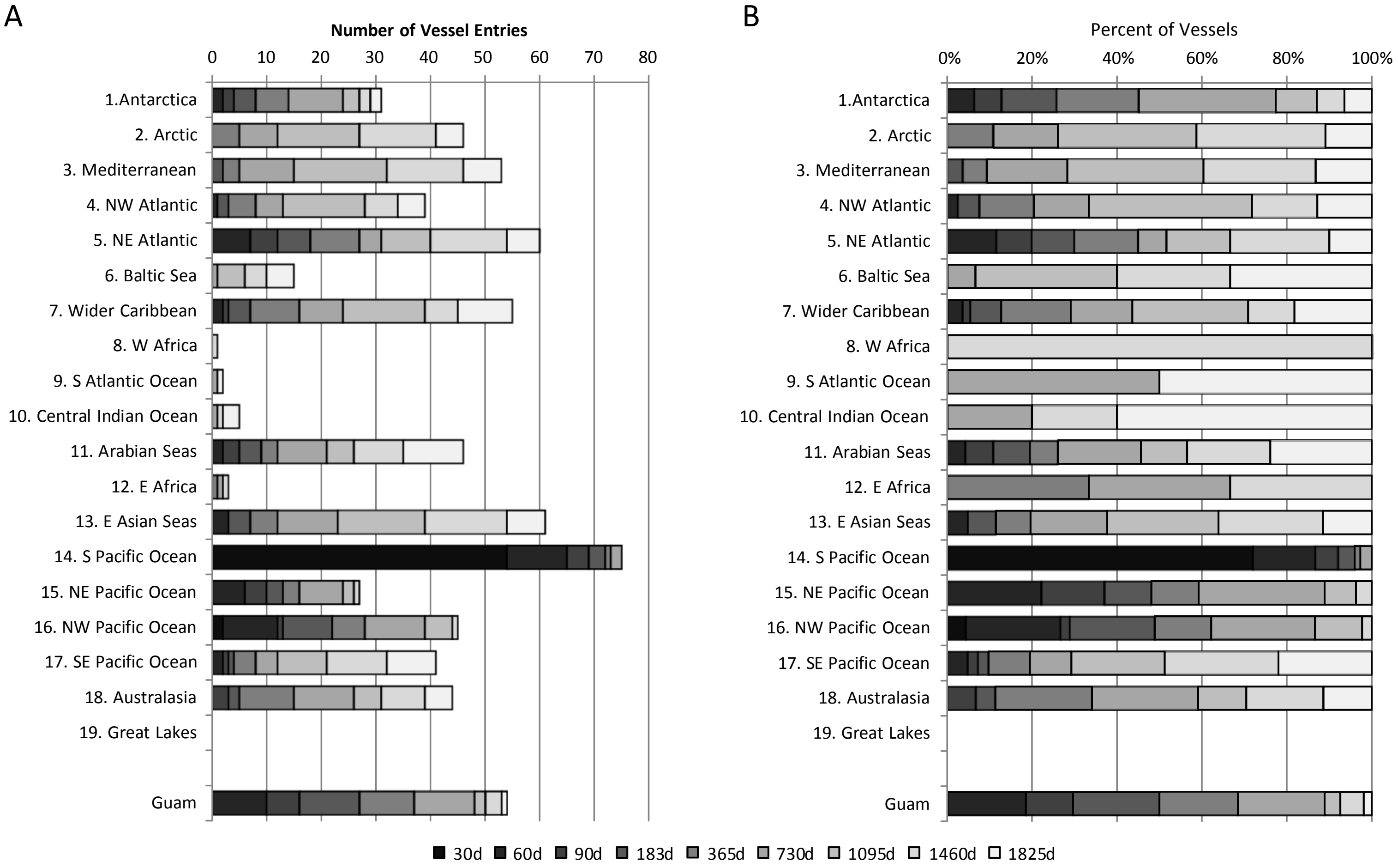

Figure 5.33. Number and percentage within a bioregion of all vessel (all categories of commercial and MSC vessels) entries to UMI from 1999 to 2009 which had traded with specific bioregions for voyages of 30d, 60d, 90d, 183d, 365d (1yr), 730d (2yrs), 1095d (3yrs), 1460d (4yrs), or 1825d (5yrs) during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU and DoD datasets). Note that vessels transiting Guam are also represented in Bioregion 14 South Pacific Ocean.

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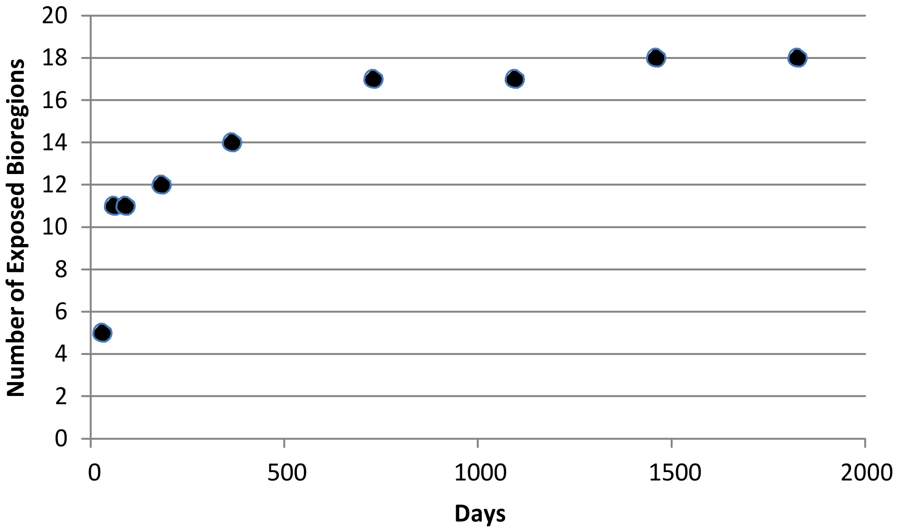

Figure 5.34. Number of bioregions visited by vessels entering the UMI between 1999 and 2009 with increasing voyage duration (data from Lloyds MIU and DOD datasets).

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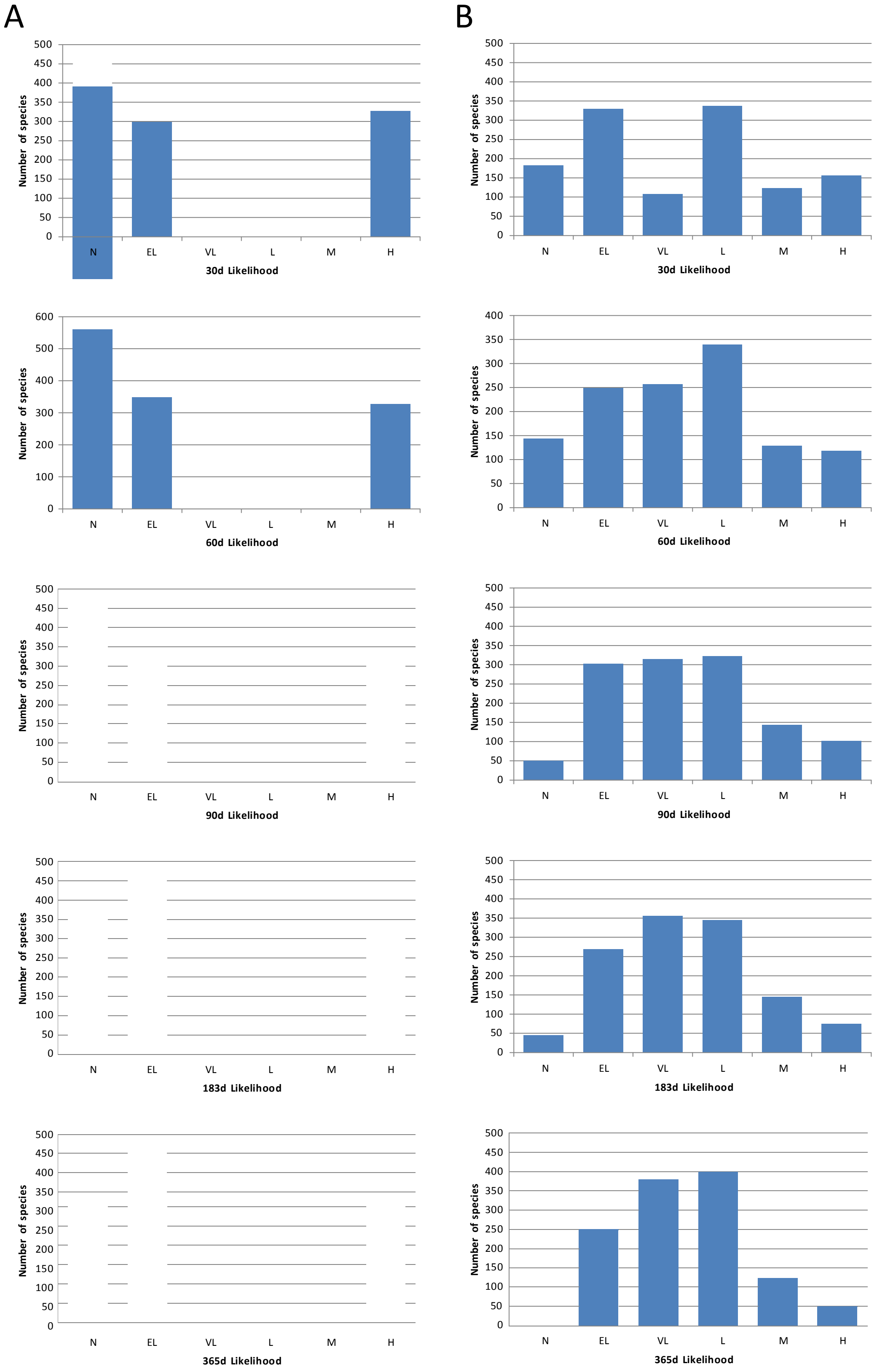

Figure 5.35. Number of species for Inoculation Likelihood Ranks to UMI for voyage durations less than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

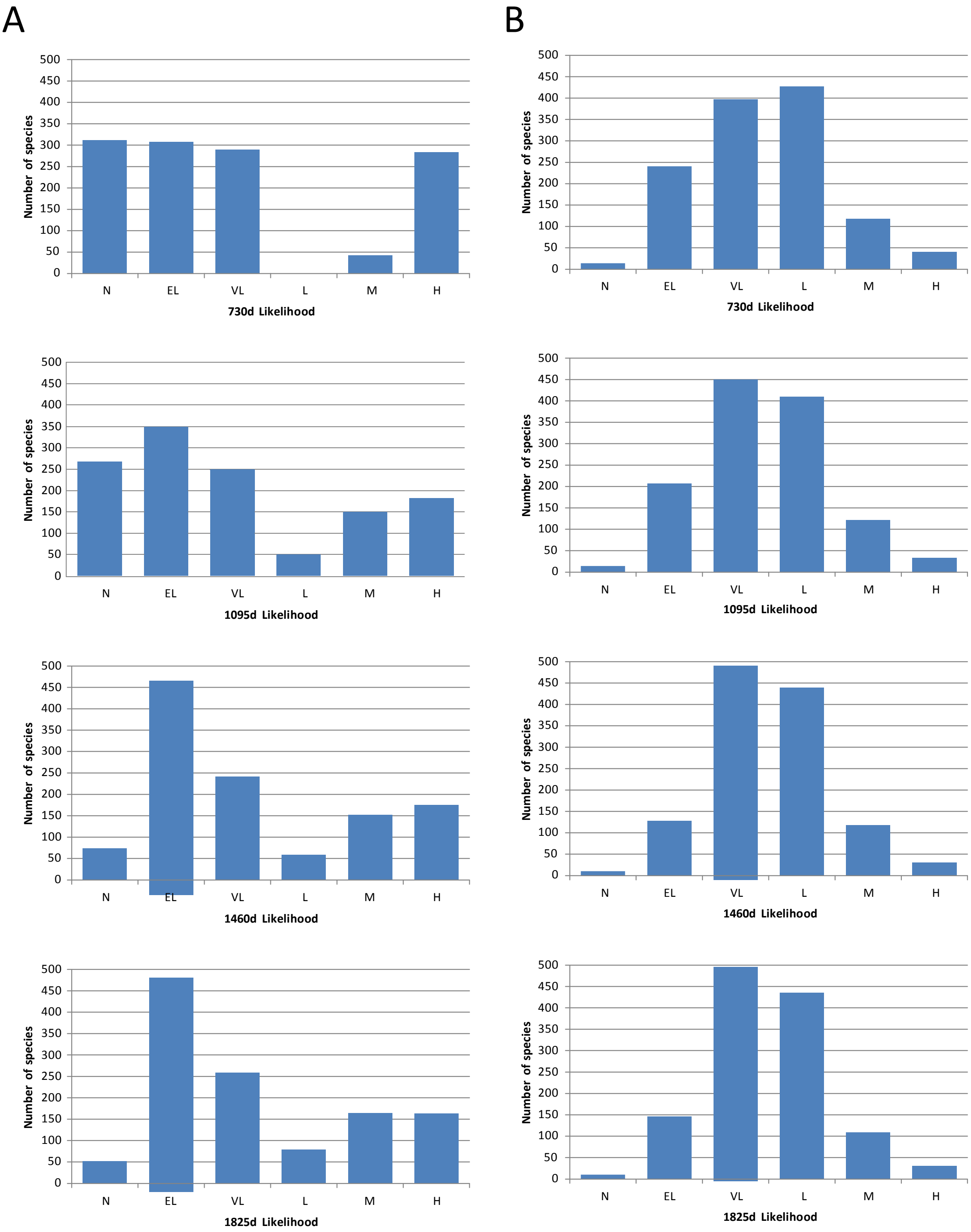

Figure 5.36. Number of species for Inoculation Likelihood Ranks to UMI for voyage durations greater than 365 days (1 year). A) commercial vessels alone, B) commercial and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

Table 5.8. Biofouling species with a “High” (n=31) and “Medium” (n=108) likelihood of arrival in the UMI associated with all vessel traffic.

Phylum	Scientific name	Likelihood
Annelida	*Alitta (Neanthes) succinea*	M
Annelida	*Dipolydora armata (=armarta)*	M
Annelida	*Eumida sanguineum*	M
Annelida	*Eunice antennata*	M
Annelida	*Ficopomatus enigmaticus*	M
Annelida	*Glycera capitata*	M
Annelida	*Heteromastus filiformis*	M
Annelida	*Hydroides diramphus*	M
Annelida	*Janua pagenstecheri*	H
Annelida	*Neodexiospira brasiliensis (=Janua (Dexiospira) brasiliensis)*	M
Annelida	*Pileolaria berkeleyana*	M
Annelida	*Streblospio benedicti*	M
Chlorophyta	*Bryopsis pennata*	M
Chlorophyta	*Bryopsis plumosa*	H
Chlorophyta	*Chaetomorpha aerea*	H
Chlorophyta	*Chaetomorpha linum*	H
Chlorophyta	*Cladophora herpestica*	M
Chlorophyta	*Cladophora prolifera*	M
Chlorophyta	*Cladophora sericea*	H
Chlorophyta	*Codium fragile (=C. f. tomentosoides)*	M
Chlorophyta	*Derbesia marina*	H
Chlorophyta	*Neomeris annulata*	M
Chlorophyta	*Ulva clathrata (=Enteromorpha clathrata var. crinata)*	H
Chlorophyta	*Ulva flexuosa*	H
Chlorophyta	*Ulva pertusa*	M
Chlorophyta	*Ulva reticulata*	M
Chlorophyta	*Ulva rigida*	H
Chordata (Ascidiacea)	*Botrylloides perspicuum*	M

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Table 5.8: Continued

Phylum	***Scientific name***	**Likelihood**
Chordata (Ascidiacea)	*Botrylloides perspicuum*	M
Chordata (Ascidiacea)	*Botryllus schlosseri*	H
Chordata (Ascidiacea)	*Ciona intestinalis*	H
Chordata (Ascidiacea)	*Didemnum candidum*	M
Chordata (Ascidiacea)	*Molgula manhattensis*	M
Cnidaria	*Bougainvillia muscus*	M
Cnidaria	*Cladonema radiatum*	M
Cnidaria	*Clytia hemisphaerica*	H
Cnidaria	*Cordylophora caspia*	H
Cnidaria	*Coryne eximia (=Sarsia eximia)*	M
Cnidaria	*Coryne pusilla*	M
Cnidaria	*Diadumene lineata*	M
Cnidaria	*Eudendrium capillare*	H
Cnidaria	*Eudendrium carneum*	M
Cnidaria	*Gonothyraea loveni*	M
Cnidaria	*Obelia longissima*	M
Cnidaria	*Plumularia setacea*	H
Cnidaria	*Sarsia tubulosa*	M
Cnidaria	*Tubastraea coccinea*	M
Arthropoda	*Amphibalanus amphitrite*	H
Arthropoda	*Amphibalanus improvisus*	M
Arthropoda	*Amphibalanus reticulatus*	H
Arthropoda	*Balanus trigonus*	H
Arthropoda	*Caprella equilibra*	M
Arthropoda	*Caprella penantis*	M
Arthropoda	*Caprella scaura*	M
Arthropoda	*Carcinus maenas*	H
Arthropoda	*Elasmopus rapax*	M
Arthropoda	*Ericthonius brasiliensis*	M
Arthropoda	*Idotea metallica*	M
Arthropoda	*Jassa marmorata*	M

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Table 5.8: Continued

Phylum	*Scientific name*	Likelihood
Arthropoda	*Laticorophium baconi*	M
Arthropoda	*Lepas (Anatifa) anatifera*	H
Arthropoda	*Lepas (Anatifa) anserifera*	H
Arthropoda	*Lepas (Anatifa) hillii*	M
Arthropoda	*Leptochela dubia*	H
Arthropoda	*Ligia exotica*	M
Arthropoda	*Monocorophium acherusicum*	M
Arthropoda	*Monocorophium insidiosum*	M
Arthropoda	*Paracaprella pusilla*	M
Arthropoda	*Paracerceis sculpta*	M
Arthropoda	*Paradella dianae*	M
Arthropoda	*Pleopis polyphemoides*	M
Arthropoda	*Porcellio lamellatus lamellatus*	M
Arthropoda	*Sinelobus cf. stanfordi*	M
Arthropoda	*Sphaeroma walkeri*	M
Arthropoda	*Stenothoe gallensis*	M
Arthropoda	*Stenothoe valida*	M
Arthropoda	*Synidotea laevidorsalis*	M
Dinophyta	*Prorocentrum lima*	M
Bryozoa	*Aetea anguina*	M
Bryozoa	*Aetea truncata*	M
Bryozoa	*Bowerbankia gracilis*	M
Bryozoa	*Bowerbankia imbricata*	M
Bryozoa	*Bugula stolonifera*	M
Bryozoa	*Cryptosula pallasiana*	H
Bryozoa	*Hippopodina feegensis*	M
Bryozoa	*Hippothoa distans*	M
Bryozoa	*Jellyella tuberculata*	M
Bryozoa	*Scruparia ambigua*	M
Bryozoa	*Synnotum aegyptiacum*	M
Bryozoa	*Victorella pavida*	M

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Table 5.8: Continued

Phylum	***Scientific name***	**Likelihood**
Bryozoa	*Watersipora subtorquata*	M
Bryozoa	*Zoobotryon verticillatum*	M
Mollusca	*Anteaeolidiella foulisi (=Anteaolidiella indica)*	M
Mollusca	*Dendrodoris fumata*	M
Mollusca	*Hiatella arctica*	H
Mollusca	*Musculista senhousia*	M
Mollusca	*Mytilus galloprovincialis*	M
Mollusca	*Sabia conica*	M
Mollusca	*Tenellia adspersa*	M
Mollusca	*Teredo navalis*	H
Mollusca	*Thecacera pennigera*	M
Phaeophyta	*Cutleria multifida*	M
Phaeophyta	*Desmarestia viridis*	M
Phaeophyta	*Ectocarpus fasciculatus*	M
Phaeophyta	*Ectocarpus siliculosus*	M
Phaeophyta	*Hincksia granulosa*	M
Phaeophyta	*Hincksia mitchelliae*	H
Phaeophyta	*Hincksia ovata*	M
Phaeophyta	*Hincksia sandriana*	M
Phaeophyta	*Leathesia marina (=Leathesia difformis)*	M
Phaeophyta	*Myrionema strangulans*	M
Phaeophyta	*Pylaiella littoralis*	H
Phaeophyta	*Punctaria latifolia*	M
Phoronida	*Phoronis hippocrepia*	M
Porifera	*Dysidea fragilis*	M
Porifera	*Halichondria panicea*	M
Porifera	*Mycale parishii (=Zygomycale parishii)*	M
Pycnogonida	*Ammothea hilgendorfi*	M
Pycnogonida	*Pigrogromitus timsanus*	M
Rhodophyta	*Aglaothamnion cordatum*	M

Table 5.8: Continued

Phylum	***Scientific name***	**Likelihood**
Rhodophyta	*Antithamnion hubbsii (=nipponicum, pectinatum)*	M
Rhodophyta	*Asparagopsis taxiformis*	H
Rhodophyta	*Bangia atropurpurea*	H
Rhodophyta	*Caulacanthus ustulatus*	M
Rhodophyta	*Centroceras clavulatum*	H
Rhodophyta	*Ceramium virgatum*	M
Rhodophyta	*Chroodactylon ramosum*	M
Rhodophyta	*Corallina officinalis*	M
Rhodophyta	*Dasya baillouviana*	M
Rhodophyta	*Gracilaria gracilis*	M
Rhodophyta	*Gymnothamnion elegans*	M
Rhodophyta	*Hildenbrandia rubra*	H
Rhodophyta	*Hypnea anastomosans (=Hypnea esperi)*	M
Rhodophyta	*Hypnea cornuta*	M
Rhodophyta	*Hypnea spinella (=Hypnea cervicornis)*	M
Rhodophyta	*Hypnea valentiae*	M
Rhodophyta	*Neosiphonia harveyi (=Polysiphonia harveyi)*	M
Rhodophyta	*Polysiphonia brodiei*	M
Rhodophyta	*Polysiphonia sertularioides*	M
Rhodophyta	*Polysiphonia subtilissima*	M

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5.4.6 State of Hawai’i

Hawai’i received 6,380 vessel entries of which 6,030 were commercial vessel entries, 318 were fishing vessel entries, and 54 were MSC vessel entries during the five year period (Figures 5.37). It should be noted that this was only half of the 10-year period for which data were available for Micronesia. It should also be noted that data were only available LPOC, and data for cumulative voyage histories were not available unlike analyses for Micronesia, hence presentation of a single panel for HI (Figure 5.37). Slightly more than 1% of these vessels arrived directly from Guam. Commercial vessels had strong affinities the Northeastern Pacific (15) and the Northwestern Pacific (16) bioregions, with a decreased trade across a wider number of bioregions. The Northeastern Pacific and Northwestern Pacific bioregions represent more than 81% of commercial vessel trade. MSC vessels have a similar level of exposure to bioregions as commercial vessels, with 78% of vessel entries derived from the Northeastern Pacific and Northwestern Pacific bioregions. Fishing vessels primarily arrive from Northwestern Pacific and the South Pacific (14) bioregions, representing 88% of all fishing vessel entries.

LPOC arrivals to Hawai’i during the evaluation period arrived from 15 of the 18 bioregions, with commercial vessels trading across all 15 bioregions, Fishing vessels with 7 bioregions and MSC vessels with 8 bioregions.

The inoculation likelihoods of species only slightly increase with the addition of MSC vessels for biofouling related risk (Figure 5.38). More than 160 species were categorized as having “High” likelihood of inoculation by biofouling for all vessel categories. In total, 317 species are ranked as “High” (167) or “Medium” (150) likelihood of inoculation (Table 5.9), with MSC vessels having no effect in the likelihoods of inoculation.

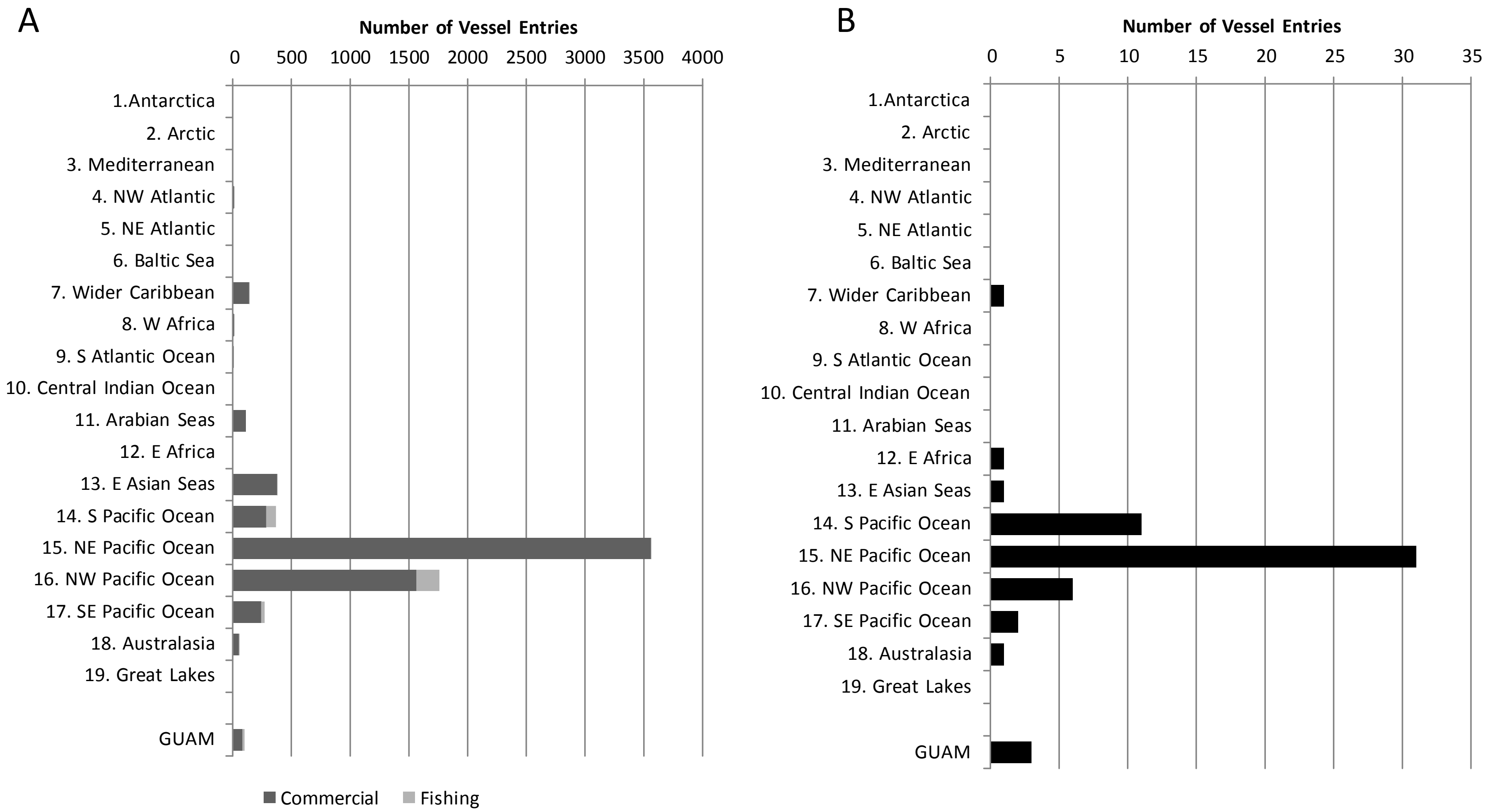

Figure 5.37. A) Number of commercial and fishing vessel and B) MSC vessel entries to HI from 2006-2011 that had traded with specific bioregions Last Port of Call during the evaluation period. Note that vessels may have multiple entries (Lloyds MIU and DoD datasets). Note that vessels arriving from Guam are also represented in Bioregion 14 South Pacific Ocean.

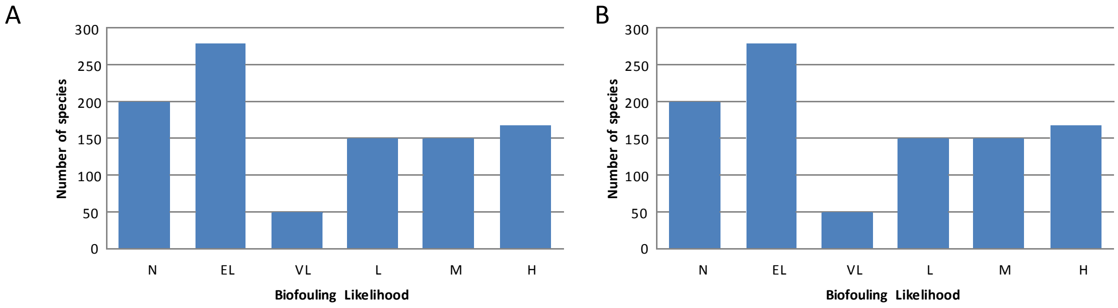

Figure 5.38. Number of Species for Biofouling related Inoculation Likelihood Ranks to HI based on LPOC arrivals. A) commercial vessels and fishing alone, B) commercial, fishing and MSC vessels. Where N = negligible, EL = extremely low; VL = very low, L = low, M = moderate, and H = high. Data from Lloyds MIU and DoD datasets.

Table 5.9. Biofouling species with a "High" (n=167) and "Medium" (n=150) likelihood of arrival in HI associated with all vessel traffic.

Phylum	Scientific name	Likelihood
Annelida	*Amaeana sp. A*	M
Annelida	*Amblyosyllis sp. A*	M
Annelida	*Boccardiella ligerica*	M
Annelida	*Branchiomma bairdi*	M
Annelida	*Ceratonereis mirabilis*	M
Annelida	*Crucigera websteri*	M
Annelida	*Dipolydora giardi*	M
Annelida	*Dipolydora socialis*	H
Annelida	*Dispio uncinata*	H
Annelida	*Eteone tchangsii*	H
Annelida	*Euchone limnicola*	M
Annelida	*Eunice antennata*	H
Annelida	*Geminosyllis ohma*	H
Annelida	*Glycera capitata*	H
Annelida	*Hesionides arenaria*	M
Annelida	*Heteromastus filiformis*	H

Table 5.9. Continued

Phylum	Scientific name	Likelihood
Annelida	*Hobsonia floridana*	M
Annelida	*Hydroides albiceps+B148*	M
Annelida	*Limnodrilus monothecus*	M
Annelida	*Lumbricillus lineatus*	M
Annelida	*Marenzelleria viridis*	M
Annelida	*Marphysa disjuncta*	H
Annelida	*Neodexiospira brasiliensis (=Janua (Dexiospira) brasiliensis)*	H
Annelida	*Nicolea sp. A*	M
Annelida	*Ophryotrocha diadema*	M
Annelida	*Paranais frici*	M
Annelida	*Polydora cornuta*	H
Annelida	*Polydora hoplura*	M
Annelida	*Polydora limicola*	H
Annelida	*Prionospio pygmaea (=Apoprionospio pygmaea)*	M
Annelida	*Pseudopolydora kempi*	H
Annelida	*Pseudopolydora paucibranchiata*	H
Annelida	*Pseudopotamilla occelata*	H
Annelida	*Sigambra tentaculata (=Ancistrosyllis tentaculata)*	H
Annelida	*Syllis bella*	M
Annelida	*Tubificoides apectinatus*	M
Annelida	*Tubificoides benedii*	M
Annelida	*Tubificoides brownae*	M
Annelida	*Tubificoides diazi*	M
Annelida	*Tubificoides pseudogaster*	M
Annelida	*Tubificoides wasselli*	M
Annelida	*Typosyllis nipponica*	H

Table 5.9. Continued

Phylum	Scientific name	Likelihood
Ascidiacea	*Ascidia sp. A (SF Bay)*	M
Ascidiacea	*Ascidia zara*	H
Ascidiacea	*Botrylloides perspicuum*	H
Ascidiacea	*Botrylloides violaceus (=Botryllus aurantius)*	H
Ascidiacea	*Botryllus planus*	M
Ascidiacea	*Botryllus schlosseri*	H
Ascidiacea	*Botryllus sp. A (SF Bay)*	M
Ascidiacea	*Ciona savignyi*	H
Ascidiacea	*Didemnum vexillum (=Didemnum lahillei)*	H
Ascidiacea	*Molgula ficus*	H
Ascidiacea	*Molgula manhattensis*	H
Ascidiacea	*Perophora japonica*	H
Ascidiacea	*Styela clava*	H
Ascidiacea	*Styela plicata*	H
Ascidiacea	*Trididemnum orbiculatum*	M
Chlorophyta	*Bryopsis plumosa*	H
Chlorophyta	*Bryopsis sp. A*	M
Chlorophyta	*Caulerpa filiformis*	M
Chlorophyta	*Caulerpa taxifolia (aquarium strain)*	H
Chlorophyta	*Chaetomorpha linum*	H
Chlorophyta	*Cladophora prolifera*	H
Chlorophyta	*Codium fragile (=C. f. tomentosoides)*	H
Chlorophyta	*Derbesia marina*	H
Chlorophyta	*Pilinella californica*	M
Chlorophyta	*Ulva californica*	M
Chlorophyta	*Ulva pertusa*	H
Chlorophyta	*Ulva stenophylla*	M
Cnidaria	*Amphinema dinema*	M
Cnidaria	*Amphinema sp.*	M

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Table 5.9. Continued

Phylum	Scientific name	Likelihood
Cnidaria	*Aurelia sp.*	H
Cnidaria	*Bimeria vestita*	M
Cnidaria	*Blackfordia virginica*	H
Cnidaria	*Bunodeopsis sp.*	M
Cnidaria	*Cladonema pacificum (=uchidai)*	H
Cnidaria	*Clava multicornis*	M
Cnidaria	*Corymorpha bigelowi (=Euphysora bigelowi)*	H
Cnidaria	*Corymorpha sp.*	M
Cnidaria	*Coryne eximia (=Sarsia eximia)*	H
Cnidaria	*Coryne japonica (=Sarsia japonica)*	H
Cnidaria	*Diadumene cincta*	M
Cnidaria	*Eudendrium carneum*	H
Cnidaria	*Garveia franciscana*	M
Cnidaria	*Gonionemus vertens*	H
Cnidaria	*Gonothyraea clarki*	M
Cnidaria	*Gonothyraea loveni*	H
Cnidaria	*Halitholus pauper*	H
Cnidaria	*Hartlaubella gelatinosa*	H
Cnidaria	*Laomedea calciolifera*	H
Cnidaria	*Lensia challengeri*	M
Cnidaria	*Maeotias marginata*	H
Cnidaria	*Metridium senile*	H
Cnidaria	*Mitrocomium cirratum (=Campalecium medusiferum)*	M
Cnidaria	*Moerisia sp.*	M
Cnidaria	*Nematostella vectensis*	M
Cnidaria	*Obelia longissima*	H
Cnidaria	*Octotiara russelli*	M
Cnidaria	*Pinauay (Ectopleura) larynx*	H

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Table 5.9. Continued

Phylum	Scientific name	Likelihood
Cnidaria	*Pinauay crocea*	M
Cnidaria	*Rathkea octopunctata*	H
Cnidaria	*Stomolophus meleagris*	M
Cnidaria	*Tubularia indivisa (=Pinauay (Ectopleura) indivisa)*	H
Arthropoda	*Abludomelita rylovae*	H
Arthropoda	*Ampelisca abdita*	M
Arthropoda	*Amphibalanus albicostatus*	H
Arthropoda	*Amphibalanus improvisus*	H
Arthropoda	*Amphibalanus subalbidus*	M
Arthropoda	*Ampithoe longimana*	M
Arthropoda	*Ampithoe valida*	H
Arthropoda	*Aoroides secunda*	H
Arthropoda	*Aspidoconcha limnoriae*	M
Arthropoda	*Balanus glandula*	H
Arthropoda	*Balanus uliginosus*	M
Arthropoda	*Briarosaccus callosus*	H
Arthropoda	*Caprella californica*	H
Arthropoda	*Caprella drepanochir*	H
Arthropoda	*Caprella mutica*	H
Arthropoda	*Caprella simia*	H
Arthropoda	*Chelura terebrans*	H
Arthropoda	*Cirolana harfordi*	M
Arthropoda	*Concavus concavus species group (=Balanus concavus)*	M
Arthropoda	*Conchoderma auritum*	M
Arthropoda	*Corophium alienense*	M
Arthropoda	*Corophium heteroceratum*	H
Arthropoda	*Dynoides dentisinus*	H
Arthropoda	*Elminius kingii*	M

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Table 5.9. Continued

Phylum	Scientific name	Likelihood
Arthropoda	*Eobrolgus spinosus*	M
Arthropoda	*Eochelidium miraculum*	H
Arthropoda	*Eochelidium sp.*	M
Arthropoda	*Eurylana arcuata*	H
Arthropoda	*Fistulobalanus dentivarians*	M
Arthropoda	*Gammarus daiberi*	M
Arthropoda	*Iais californica*	M
Arthropoda	*Ianiropsis serricaudis*	H
Arthropoda	*Idotea metallica*	H
Arthropoda	*Jassa marmorata*	H
Arthropoda	*Jassa morinoi*	H
Arthropoda	*Jassa slatteryi*	H
Arthropoda	*Lepas (Anatifa) hillii*	H
Arthropoda	*Limnoria quadripunctata*	M
Arthropoda	*Megabalanus coccopoma*	H
Arthropoda	*Melita nitida*	M
Arthropoda	*Microdeutopus gryllotalpa*	M
Arthropoda	*Monocorophium uenoi*	H
Arthropoda	*Mytilicola orientalis*	H
Arthropoda	*Palaemon macrodactylus*	H
Arthropoda	*Paracorophium lucasi*	M
Arthropoda	*Paradexamine sp.*	M
Arthropoda	*Paranthura japonica*	H
Arthropoda	*Percnon gibbesi*	M
Arthropoda	*Petrolisthes armatus*	H
Arthropoda	*Pleopis polyphemoides*	H
Arthropoda	*Pseudomyicola ostreae*	H
Arthropoda	*Pseudosphaeroma campbellensis*	M
Arthropoda	*Pyromaia tuberculata*	H
Arthropoda	*Redkea californica*	M

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Table 5.9. Continued

Phylum	Scientific name	Likelihood
Arthropoda	*Rhithropanopeus harrisii*	H
Arthropoda	*Sinelobus cf. stanfordi*	H
Arthropoda	*Synidotea laevidorsalis*	H
Arthropoda	*Tetraclita japonica (=Tetraclita squamosa japonica)*	M
Arthropoda	*Uromunna sp. (=Munna reynoldsi)*	M
Bryozoa	*Aeverrillia armata*	M
Bryozoa	*Alcyonidium polyoum*	M
Bryozoa	*Anguinella palmata*	M
Bryozoa	*Aspidelectra melolontha*	M
Bryozoa	*Bugula californica*	H
Bryozoa	*Bugula flabellata*	M
Bryozoa	*Bugula sp. 1 (Puget Sound)*	M
Bryozoa	*Bugula sp. 2 (Puget Sound)*	M
Bryozoa	*Celleporella hyalina*	M
Bryozoa	*Conidoprhys pilisuctor*	M
Bryozoa	*Conopeum tenuissimum*	M
Bryozoa	*Einhornia crustulenta (=Electra crustulenta)*	H
Bryozoa	*Hippothoa divaricata*	M
Bryozoa	*Jellyella tuberculata*	H
Bryozoa	*Nolella stipata*	M
Bryozoa	*Pherusella brevituba (casual)*	M
Bryozoa	*Schizoporella japonica (=unicornis)*	H
Bryozoa	*Scruparia ambigua*	H
Bryozoa	*Scrupocellaria bertholettii*	M
Bryozoa	*Tricellaria inopinata*	H
Bryozoa	*Tricellaria occidentalis*	H
Bryozoa	*Victorella pavida*	H
Entoprocta	*Barentsia benedeni*	H

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Table 5.9. Continued

Phylum	Scientific name	Likelihood
Mollusca	*Anadara kagoshimensis (=Anadara inaequivalvis, =Scapharca inaequivalvis)*	M
Mollusca	*Assiminea parasitologia*	H
Mollusca	*Babakina festiva*	H
Mollusca	*Bankia cieba*	M
Mollusca	*Bankia destructa*	M
Mollusca	*Bankia gouldi*	M
Mollusca	*Boonea cincta*	M
Mollusca	*Catriona rickettsi*	M
Mollusca	*Cenchritus muricatus (=Tectarius muricatus)*	M
Mollusca	*Chromodoris annulata*	M
Mollusca	*Crepidula convexa*	M
Mollusca	*Crepidula fornicata*	M
Mollusca	*Crepidula plana*	M
Mollusca	*Cuthona columbiana*	H
Mollusca	*Eubranchus inabai*	M
Mollusca	*Eubranchus misakiensis*	H
Mollusca	*Geukensia demissa*	M
Mollusca	*Glossodoris sedna*	M
Mollusca	*Guildforia yoka*	H
Mollusca	*Hopkinsia (Okenia) plana*	H
Mollusca	*Hypselodoris infurcata*	M
Mollusca	*Ischadium recurvum*	M
Mollusca	*Ividella navisa*	M
Mollusca	*Littorina littorea*	M
Mollusca	*Meretrix lusoria*	H
Mollusca	*Musculista senhousia*	H
Mollusca	*Myosotella myosotis (=Phytia myosotis)*	M
Mollusca	*Mytilopsis adamsi*	H

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Table 5.9. Continued

Phylum	Scientific name	Likelihood
Mollusca	*Mytilus edulis*	M
Mollusca	*Nassarius fraterculus*	H
Mollusca	*Ostrea edulis*	H
Mollusca	*Ostrea puelchana (=Ostrea chilensis)*	M
Mollusca	*Polycera hedgpethi*	H
Mollusca	*Rapana venosa (=thomasiana)*	H
Mollusca	*Sakuraeolis enosimensis*	H
Mollusca	*Stiliger fuscovitattus*	M
Mollusca	*Tenellia adspersa*	H
Mollusca	*Teredo navalis*	H
Mollusca	*Xenostrobus securis*	H
Nematoda	*Angiostrongylus cantonensis*	M
Nemertea	*Lineus ruber*	M
Osteichthyes	*Acanthogobius flavimanus*	H
Osteichthyes	*Gobiosoma nudum*	M
Osteichthyes	*Stathmonotus stahli*	M
Osteichthyes	*Tridentiger trigonocephalus*	H
Phaeophyta	*Acrothrix gracilis*	H
Phaeophyta	*Chnoospora minima*	H
Phaeophyta	*Chorda filum*	H
Phaeophyta	*Cladostephus spongiosus*	M
Phaeophyta	*Colpomenia durvillei*	H
Phaeophyta	*Colpomenia peregrina*	H
Phaeophyta	*Cutleria cylindrica*	H
Phaeophyta	*Desmarestia viridis*	H
Phaeophyta	*Ectocarpus fasciculatus*	H
Phaeophyta	*Ectocarpus siliculosus*	H
Phaeophyta	*Endarachne binghamiae*	H
Phaeophyta	*Fucus evanescens*	H
Phaeophyta	*Fucus spiralis*	M

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Table 5.9. Continued

Phylum	Scientific name	Likelihood
Phaeophyta	*Hincksia granulosa*	H
Phaeophyta	*Hincksia ovata*	H
Phaeophyta	*Hincksia sandriana*	H
Phaeophyta	*Leathesia marina (=Leathesia difformis)*	H
Phaeophyta	*Macrocystis pyrifera*	H
Phaeophyta	*Melanosiphon intestinalis*	H
Phaeophyta	*Microspongium globosum*	H
Phaeophyta	*Myrionema strangulans*	H
Phaeophyta	*Punctaria latifolia*	H
Phaeophyta	*Punctaria tenuissima*	M
Phaeophyta	*Rugulopteryx okamurae*	H
Phaeophyta	*Sargassum filicinum*	H
Phaeophyta	*Sargassum muticum*	H
Phaeophyta	*Scytosiphon dotyi*	H
Phaeophyta	*Undaria pinnatifida*	H
Platyhelminthes	*Leptoplana limnoriae*	M
Platyhelminthes	*Pseudostylochus ostreophagus*	H
Porifera	*Chalinula loosanoffi (=Haliclona loosanoffi)*	M
Porifera	*Chalinula nematifera*	M
Porifera	*Clathria prolifera (=Microciona prolifera)*	M
Porifera	*Cliona celata*	M
Porifera	*Cliona thoosina*	M
Porifera	*Halichondria bowerbanki*	M
Porifera	*Halichondria panicea*	H
Porifera	*Lissodendoryx isodictyalis*	M
Porifera	*Prosuberites sp.*	M
Porifera	*Stelleta clarella*	M
Protozoa	*Bonamia ostreae*	M

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Table 5.9. Continued

Phylum	Scientific name	Likelihood
Protozoa	*Boveria teredinis*	M
Protozoa	*Cothurnia limnoriae*	M
Protozoa	*Haplosporidium costale*	H
Protozoa	*Lagenophrys cochinensos*	M
Protozoa	*Lankesteria ascidiae*	M
Protozoa	*Orchitophyra stellarum*	H
Protozoa	*Trochammina hadai*	H
Raphidophyta	*Heterosigma akashiwo (=Olisthodiscus luteus)*	H
Rhodophyta	*Acrochaetium pacificum (=Audouinella pacificum)*	H
Rhodophyta	*Agardhiella subulata*	H
Rhodophyta	*Aglaothamnion tenuissimum (=Callithamnion byssoides)*	M
Rhodophyta	*Anotrichium furcellatum*	H
Rhodophyta	*Antithamnion densum*	H
Rhodophyta	*Antithamnionella elegans*	H
Rhodophyta	*Antithamnionella spirographidis*	H
Rhodophyta	*Antithamnionella sublittoralis*	M
Rhodophyta	*Asparagopsis armata*	M
Rhodophyta	*Audouinella simplex*	M
Rhodophyta	*Caulacanthus ustulatus*	H
Rhodophyta	*Centroceras clavulatum*	H
Rhodophyta	*Ceramium kondoi*	H
Rhodophyta	*Ceramium sinicola*	M
Rhodophyta	*Ceramium virgatum*	H
Rhodophyta	*Gelidium vagum*	H
Rhodophyta	*Goniotrichiopsis sublittoralis*	M
Rhodophyta	*Gracilaria gracilis*	M
Rhodophyta	*Gracilaria vermiculophylla*	M

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Table 5.9. Continued

Phylum	Scientific name	Likelihood
Rhodophyta	*Grateloupia doryphora*	H
Rhodophyta	*Grateloupia lanceolata*	H
Rhodophyta	*Gymnogongrus crenulatus*	M
Rhodophyta	*Haraldiophyllum nottii*	M
Rhodophyta	*Hildenbrandia occidentalis*	M
Rhodophyta	*Hildenbrandia rubra*	H
Rhodophyta	*Hypnea anastomosans (=Hypnea esperi)*	H
Rhodophyta	*Hypnea spicifera*	M
Rhodophyta	*Mastocarpus papillatus*	M
Rhodophyta	*Neosiphonia harveyi (=Polysiphonia harveyi)*	H
Rhodophyta	*Pikea californica*	H
Rhodophyta	*Polysiphonia brodiei*	H
Rhodophyta	*Polysiphonia denudata*	M
Rhodophyta	*Polysiphonia paniculata*	M
Rhodophyta	*Polysiphonia senticulosa*	H
Rhodophyta	*Porphyra suborbiculata*	H
Rhodophyta	*Prionitis lyallii*	M
Rhodophyta	*Rhodophysema georgei*	H
Rhodophyta	*Schizymenia pacifica*	H

5.5 Summary of Spread from Guam to other jurisdictions of Micronesia and Hawai'i

The jurisdictions of Micronesia are variously exposed to the global suite of non-native marine and estuarine species through commercial and MSC vessel traffic, as discussed above. This exposure has been used to identify the suites of species with "High" likelihoods of arrival. MSC vessels demonstrably increase the exposure of various jurisdictions of Micronesia to novel bioregions, and therefore suites of non-native marine and estuarine species (Table 5.10). For example, MSC vessels increased the exposure of Guam to the Arabian Seas by 2.85 times, which would mean that species found in the Arabian Seas would have a 2.85 times greater likelihood of arrival in Guam when MSC vessels are counted. In contrast, the MSC vessels have no detectable effect on Hawai'i.

A comparison of "High" and "Medium" likelihood of inoculation species identified for various jurisdictions of Micronesia with those identified for Guam (Table 5.11) indicates a significant overlap. A total of 270 species are identified as having "High" or "Medium" likelihoods of arrival in at least one location in Micronesia, with 56 (21%) identified for a single Micronesian jurisdiction, 24 of which were restricted to Guam. Only four species determined to be of “High” likelihood in another jurisdiction of Micronesia were not identified as a “High” likelihood for Guam. This suggests that similar factors influencing arrival to Guam are acting in other jurisdictions of Micronesia, rather than a formal “hub and spoke” model, as has been previously suggested.

Table 5.10. Increase in exposure to IUCN Bioregions (and Guam) for the jurisdictions of Micronesia and Hawai’i

attributed to MSC vessels (1.00 = no increase).

	Guam	CNMI	FSM	RMI	Palau	UMI	HI
1. Antarctica	65.00	-	-	-	-	-	-
2. Arctic	4.03	3.00	1.00	16.67	1.00	-	-
3. Mediterranean	3.25	4.96	1.00	4.73	1.33	53.00	1.00
4. NW Atlantic	3.81	16.38	1.00	3.00	1.80	39.00	1.00
5. NE Atlantic	1.78	1.27	1.00	6.50	1.43	60.00	-
6. Baltic Sea	1.77	2.06	1.00	6.33	1.50	15.00	1.00
7. Wider Caribbean	4.42	15.83	1.00	6.33	1.64	55.00	1.00
8. W Africa	1.31	1.45	1.00	1.00	1.15	1.00	1.00
9. S Atlantic Ocean	1.36	1.96	1.00	1.56	1.11	2.00	1.00
10. Central Indian Ocean	1.12	1.24	1.00	1.67	1.02	-	1.00
11. Arabian Seas	2.85	2.91	1.00	6.29	1.32	46.00	1.00
12. E Africa	2.08	3.63	1.00	1.50	1.11	3.00	1.00
13. E Asian Seas	1.60	2.15	1.00	2.18	1.10	61.00	1.00
14. S Pacific Ocean	1.68	2.59	1.39	1.72	1.71	2.08	1.00
15. NE Pacific Ocean	4.50	6.26	1.00	1.44	2.00	2.70	1.00
16. NW Pacific Ocean	2.93	7.52	1.01	1.31	1.83	45.00	1.00
17. SE Pacific Ocean	5.36	17.88	1.00	2.10	3.33	-	1.00
18. Australasia	3.17	3.69	1.00	2.47	1.73	-	1.00
19. Great Lakes	1.00	1.00	-	-	1.00	-	1.00
20. Guam	N/A	2.44	1.00	4.25	1.55	54.00	1.00

In contrast, the pattern for Hawai’i is substantially different from Micronesia with 318 species identified as having “High” or “Medium” likelihoods of arrival, of which 158 are unique to Hawai’i, with only 9 species ranked as “High” in both Guam and Hawai’i. This infers that invasion risk to Hawai’i is driven by factors independent of Guam or other jurisdictions of Micronesia.

Table 5.11. Comparison of "High" and "Medium" likelihood of inoculation species in all jurisdictions of Micronesia and Hawai'i.

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Annelida	*Alitta (Neanthes) succinea*	M	M	M	M	M	M	
Annelida	*Alitta (Neanthes) succinea*						M	
Annelida	*Amaeana sp. A*							M
Annelida	*Amblyosyllis sp. A*							M
Annelida	*Boccardiella ligerica*							M
Annelida	*Branchiomma bairdi*							M
Annelida	*Ceratonereis mirabilis*							M
Annelida	*Crucigera websteri*							M
Annelida	*Dipolydora armata (=armarta)*	H	M	H		M	M	
Annelida	*Dipolydora giardi*							M
Annelida	*Dipolydora socialis*							H
Annelida	*Dispio uncinata*							H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Annelida	*Dorvillea similis*			M				
Annelida	*Eteone tchangsii*							H
Annelida	*Euchone limnicola*							M
Annelida	*Eumida sanguineum*	M	M	M		M	M	
Annelida	*Eunice antennata*							H
Annelida	*Eunice antennata*	H						
Annelida	*Eunice antennata*				M			
Annelida	*Eunice antennata*					M		
Annelida	*Eunice antennata*						M	
Annelida	*Ficopomatus enigmaticus*	H	M	M	M	M	M	
Annelida	*Ficopomatus uschakovi*	M						
Annelida	*Geminosyllis ohma*							H
Annelida	*Glycera capitata*	M			M	M	M	H
Annelida	*Hesionides arenaria*							M
Annelida	*Heteromastus filiformis*	M			M	M	M	H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Annelida	*Hobsonia floridana*							M
Annelida	*Hydroides albiceps*	M		M				M
Annelida	*Hydroides albiceps*				M			
Annelida	*Hydroides diramphus*	H	M	H	M	M	M	
Annelida	*Hydroides elegans*	H	M	H	H			
Annelida	*Janua pagenstecheri*	H	H	H	H	H	H	
Annelida	*Limnodrilus monothecus*							M
Annelida	*Lumbricillus lineatus*							M
Annelida	*Lysidice collaris*	M	M	M	M			
Annelida	*Marenzelleria viridis*							M
Annelida	*Marphysa disjuncta*							H
Annelida	*Myrianida pachycera*	M		M				

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Annelida	*Neodexiospira brasiliensis (=Janua (Dexiospira) brasiliensis)*	M	M		M	M	M	H
Annelida	*Nicolea sp. A*							M
Annelida	*Ophryotrocha diadema*							M
Annelida	*Ophryotrocha labronica pacifica*			M				
Annelida	*Paranais frici*							M
Annelida	*Pileolaria berkeleyana*	M	M	M	M	M	M	
Annelida	*Polydora cornuta*	M						H
Annelida	*Polydora hoplura*							M
Annelida	*Polydora limicola*							H
Annelida	*Polydora websteri*	M		M	M			

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Annelida	*Pomatoleios kraussii*	M	M	H	M			
Annelida	*Prionospio pygmaea (=Apoprionospio pygmaea)*							M
Annelida	*Pseudopolydora kempi*							H
Annelida	*Pseudopolydora paucibranchiata*	M		M	M			
Annelida	*Pseudopolydora paucibranchiata*							H
Annelida	*Pseudopotamilla occelata*							H
Annelida	*Sigambra tentaculata (=Ancistrosyllis tentaculata)*							H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Annelida	*Streblospio benedicti*	M	M	M	M	M	M	
Annelida	*Syllis bella*							M
Annelida	*Tubificoides apectinatus*							M
Annelida	*Tubificoides benedii*							M
Annelida	*Tubificoides brownae*							M
Annelida	*Tubificoides diazi*							M
Annelida	*Tubificoides pseudogaster*							M
Annelida	*Tubificoides wasselli*							M
Annelida	*Typosyllis nipponica*							H
Chlorophyta	*Avrainvillea amadelpha*	M		M				
Chlorophyta	*Bryopsis pennata*	H	M		H		M	

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Table 5.11. Continued

Phylum	**Scientific name**	**Guam**	**CNMI**	**FSM**	**RMI**	**Palau**	**UMI**	**HI**
Chlorophyta	*Bryopsis plumosa*	H	H	H	H			H
Chlorophyta	*Bryopsis plumosa*						H	
Chlorophyta	*Bryopsis sp. A*							M
Chlorophyta	*Caulerpa filiformis*							M
Chlorophyta	*Caulerpa mexicana*	M	M					
Chlorophyta	*Caulerpa racemosa var. lamourouxii*	M	M	M	M			
Chlorophyta	*Caulerpa taxifolia (aquarium strain)*							H
Chlorophyta	*Chaetomorpha aerea*	H	H	H	H		H	
Chlorophyta	*Chaetomorpha linum*	H	H		H		H	H
Chlorophyta	*Cladophora herpestica*	M	M				M	
Chlorophyta	*Cladophora patentiramea*	M			M			

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Chlorophyta	*Cladophora prolifera*	M	M	M	M		M	H
Chlorophyta	*Cladophora sericea*	H	M		H		H	
Chlorophyta	*Cladophoropsis membranacea*	M	M					
Chlorophyta	*Codium fragile (=C. f. tomentosoides)*						M	H
Chlorophyta	*Codium ovale*	M		M	M			
Chlorophyta	*Derbesia marina*	H	M				H	H
Chlorophyta	*Dictyosphaeria cavernosa*	M	M					
Chlorophyta	*Neomeris annulata*	H	M		H		M	
Chlorophyta	*Pilinella californica*							M
Chlorophyta	*Ulva californica*							M
Chlorophyta	*Ulva clathrata (=Enteromorpha clathrata var. crinata)*	H	H	H	H		H	

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Chlorophyta	*Ulva flexuosa*	H	H	H			H	
Chlorophyta	*Ulva pertusa*	M		M	M		M	H
Chlorophyta	*Ulva reticulata*	M	M	M	M		M	
Chlorophyta	*Ulva rigida*	H	H	H	H		H	
Chlorophyta	*Ulva stenophylla*							M
Chlorophyta	*Ulva taeniata*	M		M	M			
Chlorophyta	*Valonia fastigiata*	M		M				
Chlorophyta	*Bryopsis pennata*					M		
Chlorophyta	*Bryopsis plumosa*					H		
Chlorophyta	*Chaetomorpha aerea*					H		
Chlorophyta	*Chaetomorpha linum*					H		
Chlorophyta	*Cladophora herpestica*					M		
Chlorophyta	*Cladophora prolifera*					M		
Chlorophyta	*Cladophora sericea*					H		

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Chlorophyta	*Codium fragile (=C. f. tomentosoides)*					M		
Chlorophyta	*Derbesia marina*					H		
Chlorophyta	*Neomeris annulata (casual)*					M		
Chlorophyta	*Ulva clathrata (=Enteromorpha clathrata var. crinata)*					H		
Chlorophyta	*Ulva flexuosa*					H		
Chlorophyta	*Ulva pertusa*					M		
Chlorophyta	*Ulva reticulata*					M		
Chlorophyta	*Ulva rigida*					H		
Chordata (Ascidiacea)	*Ascidia archaia*			M				
Chordata (Ascidiacea)	*Ascidia sp. A (SF Bay)*							M

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Chordata (Ascidiacea)	*Ascidia zara*							H
Chordata (Ascidiacea)	*Botrylloides leachi*			M	M			
Chordata (Ascidiacea)	*Botrylloides perspicuum*		M	M	M	M	M	H
Chordata (Ascidiacea)	*Botrylloides violaceus (=Botryllus aurantius)*							H
Chordata (Ascidiacea)	*Botryllus planus*							M
Chordata (Ascidiacea)	*Botryllus schlosseri*		M	H	H	H	H	H
Chordata (Ascidiacea)	*Botryllus sp. A (SF Bay)*							M
Chordata (Ascidiacea)	*Ciona intestinalis*		H	H	H	H	H	

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Chordata (Ascidiacea)	*Ciona savignyi*							H
Chordata (Ascidiacea)	*Cnemidocarpa irene*			M				
Chordata (Ascidiacea)	*Didemnum candidum*		M	H	M	M	M	
Chordata (Ascidiacea)	*Didemnum vexillum (=Didemnum lahillei)*							H
Chordata (Ascidiacea)	*Microcosmus squamiger*			M	M			
Chordata (Ascidiacea)	*Molgula ficus*							H
Chordata (Ascidiacea)	*Molgula ficus*			M				
Chordata (Ascidiacea)	*Molgula manhattensis*					M	M	H
Chordata (Ascidiacea)	*Perophora japonica*		M	M	M			H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Chordata (Ascidiacea)	*Polyandrocarpa zorritensis*			M	M			
Chordata (Ascidiacea)	*Styela clava*							H
Chordata (Ascidiacea)	*Styela plicata*							H
Chordata (Ascidiacea)	*Symplegma reptans*			M				
Chordata (Ascidiacea)	*Trididemnum orbiculatum*							M
Chordata (Ascidieacea)	*Ascidia archaia*	M						
Chordata (Ascidieacea)	*Botrylloides leachi*	M						
Chordata (Ascidieacea)	*Botrylloides perspicuum*	M						
Chordata (Ascidieacea)	*Botryllus schlosseri*	H						

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Chordata (Ascidieacea)	*Ciona intestinalis*	H						
Chordata (Ascidieacea)	*Cnemidocarpa irene*	M						
Chordata (Ascidieacea)	*Didemnum candidum*	H						
Chordata (Ascidieacea)	*Microcosmus squamiger*	M						
Chordata (Ascidieacea)	*Perophora multiclathrata*	M						
Chordata (Ascidieacea)	*Polyandrocarpa zorritensis*	M						
Chordata (Ascidieacea)	*Styela plicata*	M						
Chordata (Ascidieacea)	*Symplegma reptans*	M						
Cnidaria	*Amphinema dinema*							M
Cnidaria	*Amphinema sp.*							M
Cnidaria	*Aurelia sp.*							H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Cnidaria	*Bimeria vestita*							M
Cnidaria	*Blackfordia virginica*							H
Cnidaria	*Blackfordia virginica*	M						
Cnidaria	*Bougainvillia muscus*	H	M	M	M	M	M	
Cnidaria	*Bunodeopsis sp.*							M
Cnidaria	*Cladonema pacificum (=uchidai)*							H
Cnidaria	*Cladonema radiatum*	M			M	M	M	
Cnidaria	*Clava multicornis*							M
Cnidaria	*Clytia hemisphaerica*	H	M	H		H	H	
Cnidaria	*Cordylophora caspia*	H	H	H	H	H	H	

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Cnidaria	*Corymorpha bigelowi (=Euphysora bigelowi)*							H
Cnidaria	*Corymorpha sp.*							M
Cnidaria	*Coryne eximia (=Sarsia eximia)*	M			M	M	M	
Cnidaria	*Coryne eximia (=Sarsia eximia)*							H
Cnidaria	*Coryne japonica (=Sarsia japonica)*							H
Cnidaria	*Coryne pusilla*	M			M	M	M	
Cnidaria	*Diadumene cincta*							M
Cnidaria	*Diadumene lineata*	H	M	H	M	M	M	
Cnidaria	*Eucheilota paradoxica*	M						
Cnidaria	*Eudendrium capillare*	H	M	H	H	H	H	

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Cnidaria	*Eudendrium carneum*	M	M	M	M	M	M	H
Cnidaria	*Garveia franciscana*							M
Cnidaria	*Gonionemus vertens*							H
Cnidaria	*Gonothyraea clarki*							M
Cnidaria	*Gonothyraea loveni*	M				M	M	H
Cnidaria	*Halitholus pauper*							H
Cnidaria	*Hartlaubella gelatinosa*							H
Cnidaria	*Laomedea calciolifera*							H
Cnidaria	*Lensia challengeri*							M
Cnidaria	*Maeotias marginata*							H
Cnidaria	*Metridium senile*							H
Cnidaria	*Mitrocomium cirratum (=Campalecium medusiferum)*							M

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Cnidaria	*Moerisia sp.*							M
Cnidaria	*Nematostella vectensis*							M
Cnidaria	*Obelia longissima*	M	M	M	M	M	M	H
Cnidaria	*Octotiara russelli*							M
Cnidaria	*Phyllorhiza punctata*	M						
Cnidaria	*Phyllorhiza punctata*				M			
Cnidaria	*Pinauay (Ectopleura) larynx*							H
Cnidaria	*Pinauay crocea*							M
Cnidaria	*Plumularia setacea*	H	H	H	H	H	H	
Cnidaria	*Rathkea octopunctata*							H
Cnidaria	*Sarsia tubulosa*	M	M	M	M	M	M	
Cnidaria	*Scolionema suvaensis*	M		M	M			

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Cnidaria	*Sertularia tongensis (=Sertularia stechowi, S. theocarpa)*	M		M				
Cnidaria	*Stomolophus meleagris*							M
Cnidaria	*Tubastraea coccinea*	H	M	H		M	M	
Cnidaria	*Tubularia indivisa (=Pinauay (Ectopleura) indivisa)*							H
Arthropoda	*Abludomelita rylovae*							H
Arthropoda	*Alpheus rapacida*	M		M				
Arthropoda	*Ampelisca abdita*							M
Arthropoda	*Amphibalanus albicostatus*							H

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Arthropoda	*Amphibalanus amphitrite*	H	H	H	H	H	H	
Arthropoda	*Amphibalanus improvisus*	M		M	M	M	M	H
Arthropoda	*Amphibalanus reticulatus*	H	M	H	H	H	H	
Arthropoda	*Amphibalanus subalbidus*							M
Arthropoda	*Ampithoe longimana*							M
Arthropoda	*Ampithoe valida*							H
Arthropoda	*Aoroides secunda*							H
Arthropoda	*Aspidoconcha limnoriae*							M
Arthropoda	*Balanus glandula*							H
Arthropoda	*Balanus trigonus*	H	M	H	H	H	H	
Arthropoda	*Balanus uliginosus*							M
Arthropoda	*Briarosaccus callosus*							H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Arthropoda	*Caprella californica*							H
Arthropoda	*Caprella danilevskii*	M		M	M			
Arthropoda	*Caprella drepanochir*							H
Arthropoda	*Caprella equilibra*	H	M	M	M	M	M	
Arthropoda	*Caprella mutica*							H
Arthropoda	*Caprella penantis*	H	M	M	M	M	M	
Arthropoda	*Caprella scaura*	H	M	H	H	M	M	H
Arthropoda	*Caprella simia*							H
Arthropoda	*Carcinus maenas*	H	H	H	H	H	H	
Arthropoda	*Chelura terebrans*	M						H
Arthropoda	*Cirolana harfordi*							M
Arthropoda	*Concavus concavus species group (=Balanus concavus)*							M
Arthropoda	*Conchoderma auritum*							M

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Arthropoda	*Conchoderma virgatum*	M		M				
Arthropoda	*Corophium alienense*							M
Arthropoda	*Corophium heteroceratum*							H
Arthropoda	*Dromia wilsoni*	M	M	M	M			
Arthropoda	*Dynoides dentisinus*							H
Arthropoda	*Elasmopus rapax*	H	M	M	M	M	M	
Arthropoda	*Elminius kingii*							M
Arthropoda	*Eobrolgus spinosus*							M
Arthropoda	*Eochelidium miraculum*							H
Arthropoda	*Eochelidium sp.*							M
Arthropoda	*Ericthonius brasiliensis*	H	M	M	M	M	M	
Arthropoda	*Eucrate crenata*	M	M	M	M			
Arthropoda	*Eurylana arcuata*							H

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Arthropoda	*Fistulobalanus dentivarians*							M
Arthropoda	*Gammarus daiberi*							M
Arthropoda	*Glabropilumnus seminudus*			M				
Arthropoda	*Gnorimosphaeroma rayi*			M				
Arthropoda	*Iais californica*							M
Arthropoda	*Ianiropsis serricaudis*							H
Arthropoda	*Idotea metallica*	M			M	M	M	H
Arthropoda	*Inciscalliope derzhavini*			M				
Arthropoda	*Jassa marmorata*	M			M	M	M	H
Arthropoda	*Jassa morinoi*							H
Arthropoda	*Jassa slatteryi*							H
Arthropoda	*Kotoracythere inconspicua*	M	M	M				

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Arthropoda	*Laticorophium baconi*	H	M	H	M	M	M	
Arthropoda	*Lepas (Anatifa) anatifera*	H		H		H	H	
Arthropoda	*Lepas (Anatifa) anserifera*	H	M		H	H	H	
Arthropoda	*Lepas (Anatifa) hillii*	M	M		M	M	M	H
Arthropoda	*Leptochela dubia*	H	M	H	H	H	H	
Arthropoda	*Ligia exotica*	H	M	H	M	M	M	
Arthropoda	*Limnoria quadripunctata*							M
Arthropoda	*Megabalanus coccopoma*							H
Arthropoda	*Megabalanus occator*	M		M				
Arthropoda	*Melita nitida*							M
Arthropoda	*Menaethius monoceros*	M	M	M	M			

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Arthropoda	*Merocryptus lambriformis*	M		M				
Arthropoda	*Microdeutopus gryllotalpa*							M
Arthropoda	*Monocorophium acherusicum*	H	M	M	M	M	M	
Arthropoda	*Monocorophium insidiosum*	H	M	M	M	M	M	
Arthropoda	*Monocorophium uenoi*							H
Arthropoda	*Mytilicola orientalis*							H
Arthropoda	*Nanosesarma minutum*	M		M				
Arthropoda	*Pachygrapsus crassipes*			M				
Arthropoda	*Palaemon macrodactylus*							H
Arthropoda	*Paracaprella pusilla*	H	M	H	M	M	M	

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Arthropoda	*Paracerceis sculpta*	M	M	M	M	M	M	
Arthropoda	*Paracorophium lucasi*							M
Arthropoda	*Paradella dianae*	M	M	M		M	M	
Arthropoda	*Paradexamine sp.*							M
Arthropoda	*Paranthura japonica*							H
Arthropoda	*Percnon gibbesi*							M
Arthropoda	*Petrolisthes armatus*							H
Arthropoda	*Plagusia depressa tuberculata*	M	M	M	M			
Arthropoda	*Pleopis polyphemoides*				M	M	M	H
Arthropoda	*Porcellio lamellatus lamellatus*	M				M	M	
Arthropoda	*Pseudomyicola ostreae*							H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Arthropoda	*Pseudosphaeroma campbellensis*							M
Arthropoda	*Pyromaia tuberculata*							H
Arthropoda	*Redkea californica*							M
Arthropoda	*Rhithropanopeus harrisii*							H
Arthropoda	*Sinelobus cf. stanfordi*	M		M	M	M	M	H
Arthropoda	*Sphaeroma quoianum*	M		M				
Arthropoda	*Sphaeroma walkeri*	H	M	H	H	M	M	
Arthropoda	*Stenothoe gallensis*	H	M	M	M	M	M	
Arthropoda	*Stenothoe valida*	H	M	M	M	M	M	
Arthropoda	*Synidotea laevidorsalis*	M	M	M	M	M	M	H
Arthropoda	*Tetraclita japonica (=Tetraclita squamosa japonica)*							M

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Arthropoda	*Uromunna sp. (=Munna reynoldsi)*							M
Dinophyta	*Ostreopsis ovata*	M		M	M			
Dinophyta	*Prorocentrum lima*	H	M	M	M	M	M	
Echinodermata	*Protoreaster nodosus*	M						
Bryozoa	*Aetea anguina*	M	M	M	M	M	M	
Bryozoa	*Aetea truncata*	M	M	M	M	M	M	
Bryozoa	*Aeverrillia armata*							M
Bryozoa	*Alcyonidium polyoum*							M
Bryozoa	*Anguinella palmata*							M
Bryozoa	*Aspidelectra melolontha*							M
Bryozoa	*Bowerbankia gracilis*	H	M	M	M	M	M	
Bryozoa	*Bowerbankia imbricata*	M	M	M	M	M	M	
Bryozoa	*Bugula californica*							H

Table 5.11. Continued

Phylum	**Scientific name**	**Guam**	**CNMI**	**FSM**	**RMI**	**Palau**	**UMI**	**HI**
Bryozoa	*Bugula dentata*	M	M	M	M			
Bryozoa	*Bugula flabellata*							M
Bryozoa	*Bugula sp. 1 (Puget Sound)*							M
Bryozoa	*Bugula sp. 2 (Puget Sound)*							M
Bryozoa	*Bugula stolonifera*	H	M	M	M	M	M	
Bryozoa	*Caberea boryi*	M		M	M			
Bryozoa	*Celleporaria brunnea*	M		M				
Bryozoa	*Celleporella hyalina*							M
Bryozoa	*Conidoprhys pilisuctor*							M
Bryozoa	*Conopeum tenuissimum*							M

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Bryozoa	*Cryptosula pallasiana*	H	M	H	H	H	H	
Bryozoa	*Einhornia crustulenta (=Electra crustulenta)*							H
Bryozoa	*Hippopodina feegensis*	M	M	M	M	M	M	
Bryozoa	*Hippothoa distans*	M	M	M	M	M	M	
Bryozoa	*Hippothoa divaricata*							M
Bryozoa	*Jellyella tuberculata*	H	M	M	M	M	M	H
Bryozoa	*Nolella stipata*							M
Bryozoa	*Pherusella brevituba (casual)*							M
Bryozoa	*Schizoporella japonica (=unicornis)*							H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Bryozoa	*Scruparia ambigua*	M	M	M	M	M	M	H
Bryozoa	*Scrupocellaria bertholettii*							M
Bryozoa	*Synnotum aegyptiacum*	M	M	M	M	M	M	
Bryozoa	*Tricellaria inopinata*							H
Bryozoa	*Tricellaria occidentalis*	M		M	M			H
Bryozoa	*Victorella pavida*	M				M	M	H
Bryozoa	*Watersipora arcuata*	M		M				
Bryozoa	*Watersipora subtorquata*	H	M	H	H	M	M	
Bryozoa	*Zoobotryon verticillatum*	M	M	M	M	M	M	
Entoprocta	*Barentsia benedeni*							H
Mollusca	*Anadara granosa*	M	M	M	M			

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Mollusca	*Anadara kagoshimensis (=Anadara inaequivalvis, =Scapharca inaequivalvis)*							M
Mollusca	*Anteaeolidiella foulisi (=Anteaolidiella indica)*	H	M	H	M	M	M	
Mollusca	*Assiminea parasitologia*							H
Mollusca	*Babakina festiva*							H
Mollusca	*Bankia bipalmulata*	M						
Mollusca	*Bankia bipalmulata*			M				
Mollusca	*Bankia cieba*							M
Mollusca	*Bankia destructa*							M
Mollusca	*Bankia gouldi*							M
Mollusca	*Boonea cincta*							M

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Mollusca	*Caloria indica*	M						
Mollusca	*Caloria indica*		M					
Mollusca	*Caloria indica*			M				
Mollusca	*Caloria indica*				M			
Mollusca	*Catriona rickettsi*							M
Mollusca	*Cenchritus muricatus (=Tectarius muricatus)*							M
Mollusca	*Chromodoris annulata*							M
Mollusca	*Crepidpatella lingulata (=Crepidula lingulata)*			M				
Mollusca	*Crepidula convexa*							M
Mollusca	*Crepidula fornicata*							M
Mollusca	*Crepidula plana*							M

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Mollusca	*Cuthona columbiana*							H
Mollusca	*Cycloscala hyalina*	M	M	M	M			
Mollusca	*Dendrodoris fumata*	M	M	M	M	M	M	
Mollusca	*Diodora ruppelli*	M		M				
Mollusca	*Doxander vittatus*	M		M	M			
Mollusca	*Elysia tomentosa*	M	M	M	M			
Mollusca	*Eubranchus inabai*							M
Mollusca	*Eubranchus misakiensis*							H
Mollusca	*Geukensia demissa*							M
Mollusca	*Glossodoris sedna*							M
Mollusca	*Guildforia yoka*							H
Mollusca	*Hiatella arctica*	H	M	M	M	H	H	
Mollusca	*Hopkinsia (Okenia) plana*							H
Mollusca	*Hypselodoris infucata*	M						M

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Mollusca	*Ischadium recurvum*							M
Mollusca	*Isognomon ephippium*	M		M	M			
Mollusca	*Ividella navisa*							M
Mollusca	*Lienardia mighelsi*	M	M	M	M			
Mollusca	*Littorina littorea*							M
Mollusca	*Martesia striata*	M	M	M	M			
Mollusca	*Meretrix lusoria*							H
Mollusca	*Musculista senhousia*	H	M	H	H	M	M	H
Mollusca	*Myosotella myosotis (=Phytia myosotis)*							M
Mollusca	*Mytilopsis adamsi*							H
Mollusca	*Mytilopsis sallei*	M	M	M	M			
Mollusca	*Mytilus edulis*							M
Mollusca	*Mytilus galloprovincialis*	M		M	M	M	M	

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Mollusca	*Nanostrea fluctigera (=Nanostrea exigua)*	M		M	M			
Mollusca	*Nassarius fraterculus*							H
Mollusca	*Okenia pellucida*	M		M	M			
Mollusca	*Ostrea conchaphila*			M				
Mollusca	*Ostrea edulis*							H
Mollusca	*Ostrea puelchana (=Ostrea chilensis)*							M
Mollusca	*Perna viridis*	M	M	M	M			
Mollusca	*Polycera hedgpethi*							H
Mollusca	*Rapana venosa (=thomasiana)*							H
Mollusca	*Sabia conica*	M	M	M	M	M	M	
Mollusca	*Sakuraeolis enosimensis*							H

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Mollusca	*Stiliger fuscovitattus*							M
Mollusca	*Strombus mutabilis*	M		M	M			
Mollusca	*Syrnola cinctella*	M		M	M			
Mollusca	*Tenellia adspersa*	M			M	M	M	H
Mollusca	*Teredo clappi*	M						
Mollusca	*Teredo navalis*	H	M	H	H	H	H	
Mollusca	*Teredo navalis*							H
Mollusca	*Teredora princesae*	M		M				
Mollusca	*Thecacera pennigera*	H	M	M	M	M	M	
Mollusca	*Xenostrobus securis*							H
Nematoda	*Angiostrongylus cantonensis*							M
Nemertea	*Lineus ruber*							M
Osteichthyes	*Acanthogobius flavimanus*							H
Osteichthyes	*Gobiosoma nudum*							M
Osteichthyes	*Stathmonotus stahli*							M

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Osteichthyes	*Tridentiger trigonocephalus*							H
Phaeophyta	*Acrothrix gracilis*							H
Phaeophyta	*Chnoospora minima*	M	M	M	M			H
Phaeophyta	*Chorda filum*							H
Phaeophyta	*Cladostephus spongiosus*							M
Phaeophyta	*Colpomenia durvillei*							H
Phaeophyta	*Colpomenia peregrina*							H
Phaeophyta	*Cutleria cylindrica*							H
Phaeophyta	*Cutleria multifida*	M		M	M	M	M	
Phaeophyta	*Desmarestia viridis*					M	M	H
Phaeophyta	*Dictyota flabellata*			M				
Phaeophyta	*Ectocarpus fasciculatus*	M			M	M	M	H
Phaeophyta	*Ectocarpus siliculosus*	M	M	M	M	M	M	H

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Phaeophyta	*Endarachne binghamiae*							H
Phaeophyta	*Fucus evanescens*							H
Phaeophyta	*Fucus spiralis*							M
Phaeophyta	*Hincksia granulosa*	M			M	M	M	H
Phaeophyta	*Hincksia mitchelliae*	H	H			H	H	
Phaeophyta	*Hincksia ovata*	M			M	M	M	H
Phaeophyta	*Hincksia sandriana*	M			M	M	M	H
Phaeophyta	*Leathesia marina (=Leathesia difformis)*	M		M	M	M	M	H
Phaeophyta	*Macrocystis pyrifera*	M		M	M			H
Phaeophyta	*Melanosiphon intestinalis*							H
Phaeophyta	*Microspongium globosum*							H

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Phaeophyta	*Myrionema strangulans*	M		M	M	M	M	H
Phaeophyta	*Nemacystus decipiens*	M		M				
Phaeophyta	*Padina antillarum*	M		M				
Phaeophyta	*Padina boryana*	M	M	M				
Phaeophyta	*Phoronis hippocrepia*		M					
Phaeophyta	*Pylaiella littoralis*	H	M	H	H	H	H	
Phaeophyta	*Punctaria latifolia*	M			M	M	M	
Phaeophyta	*Punctaria latifolia*							H
Phaeophyta	*Punctaria tenuissima*							M
Phaeophyta	*Rugulopteryx okamurae*	M		M				H
Phaeophyta	*Sargassum filicinum*							H
Phaeophyta	*Sargassum muticum*				M			H
Phaeophyta	*Scytosiphon dotyi*							H
Phaeophyta	*Undaria pinnatifida*							H

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Phoronida	*Phoronis hippocrepia*	M		M	M	M	M	
Platyhelminthes	*Leptoplana limnoriae*							M
Platyhelminthes	*Pseudostylochus ostreophagus*							H
Porifera	*Chalinula loosanoffi (=Haliclona loosanoffi)*							M
Porifera	*Chalinula nematifera*							M
Porifera	*Clathria prolifera (=Microciona prolifera)*							M
Porifera	*Cliona celata*							M
Porifera	*Cliona thoosina*							M
Porifera	*Dysidea fragilis*	M	M	M	M	M	M	

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Porifera	*Halichondria bowerbanki*							M
Porifera	*Halichondria panicea*	M			M	M	M	H
Porifera	*Lissodendoryx isodictyalis*							M
Porifera	*Mycale parishii (=Zygomycale parishii)*	H	M	H	M	M	M	
Porifera	*Prosuberites sp.*							M
Porifera	*Stelleta clarella*							M
Protozoa	*Bonamia ostreae*							M
Protozoa	*Boveria teredinis*							M
Protozoa	*Cothurnia limnoriae*							M
Protozoa	*Haplosporidium costale*							H
Protozoa	*Lagenophrys cochinensos*							M

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Protozoa	*Lankesteria ascidiae*							M
Protozoa	*Orchitophyra stellarum*							H
Protozoa	*Trochammina hadai*							H
Pycnogonida	*Ammothea hilgendorfi*	M		M	M	M	M	
Pycnogonida	*Anoplodactylus erectus*			M				
Pycnogonida	*Pigrogromitus timsanus*	H	M	M	M	M	M	
Raphidophyta	*Heterosigma akashiwo (=Olisthodiscus luteus)*							H
Rhodophyta	*Acrochaetium pacificum (=Audouinella pacificum)*							H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Rhodophyta	*Acanthophora spicifera*	M	M	M				
Rhodophyta	*Agardhiella subulata*	M						H
Rhodophyta	*Aglaothamnion cordatum*	H	M	H	M	M	M	
Rhodophyta	*Aglaothamnion tenuissimum (=Callithamnion byssoides)*							M
Rhodophyta	*Anotrichium furcellatum*							H
Rhodophyta	*Antithamnion densum*							H
Rhodophyta	*Antithamnion hubbsii (=nipponicum, pectinatum)*	M	M	M	M	M	M	

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Rhodophyta	*Antithamnionella elegans*							H
Rhodophyta	*Antithamnionella spirographidis*							H
Rhodophyta	*Antithamnionella sublittoralis*							M
Rhodophyta	*Apoglossum gregarium*	M		M	M			
Rhodophyta	*Asparagopsis armata*							M
Rhodophyta	*Asparagopsis taxiformis*	H	M	H	H	H	H	
Rhodophyta	*Audouinella simplex*							M
Rhodophyta	*Bangia atropurpurea*	H	H	H	H	H	H	
Rhodophyta	*Caulacanthus ustulatus*	H	M	H	M	M	M	H
Rhodophyta	*Centroceras clavulatum*	H	M		H	H	H	H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Rhodophyta	*Ceramium kondoi*							H
Rhodophyta	*Ceramium sinicola*							M
Rhodophyta	*Ceramium virgatum*	M			M	M	M	H
Rhodophyta	*Chondria arcuata*	M		M				
Rhodophyta	*Chroodactylon ramosum*	M	M	M	M	M	M	
Rhodophyta	*Corallina officinalis*	M			M	M	M	
Rhodophyta	*Dasya baillouviana*	H	M	H	H	M	M	
Rhodophyta	*Eucheuma denticulatum*	M	M	M	M			
Rhodophyta	*Gelidium vagum*							H
Rhodophyta	*Goniotrichiopsis sublittoralis*							M
Rhodophyta	*Gracilaria gracilis*	M		M	M	M	M	M
Rhodophyta	*Gracilaria vermiculophylla*							M
Rhodophyta	*Grateloupia doryphora*							H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Rhodophyta	*Grateloupia lanceolata*							H
Rhodophyta	*Grateloupia subpectinata (=Grateloupia filicina var luxurians)*	M						
Rhodophyta	*Gymnogongrus crenulatus*							M
Rhodophyta	*Gymnothamnion elegans*	H	M		H	M	M	
Rhodophyta	*Haraldiophyllum nottii*	M	M					M
Rhodophyta	*Herposiphonia parca*				M			
Rhodophyta	*Hildenbrandia occidentalis*							M
Rhodophyta	*Hildenbrandia rubra*	H	H			H	H	H

Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Rhodophyta	*Hypnea anastomosans (=Hypnea esperi)*	M	M		M	M	M	H
Rhodophyta	*Hypnea cornuta*	H	M	M	M	M	M	
Rhodophyta	*Hypnea nidifica*	M		M				
Rhodophyta	*Hypnea spicifera*							M
Rhodophyta	*Hypnea spinella (=Hypnea cervicornis)*	H	M			M	M	
Rhodophyta	*Hypnea valentiae*	H	M		H	M	M	
Rhodophyta	*Kappaphycus striatum*	M						
Rhodophyta	*Laurencia brongniartii*	M		M				
Rhodophyta	*Laurencia okamurae*	M						
Rhodophyta	*Mastocarpus papillatus*							M

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Rhodophyta	*Neosiphonia harveyi (=Polysiphonia harveyi)*	M			M	M	M	H
Rhodophyta	*Pikea californica*							H
Rhodophyta	*Polysiphonia brodiei*	M			M	M	M	H
Rhodophyta	*Polysiphonia denudata*							M
Rhodophyta	*Polysiphonia paniculata*							M
Rhodophyta	*Polysiphonia senticulosa*							H
Rhodophyta	*Polysiphonia sertularioides*	M			M	M	M	
Rhodophyta	*Polysiphonia subtilissima*	M	M			M	M	
Rhodophyta	*Porphyra suborbiculata*	M		M				H

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Table 5.11. Continued

Phylum	Scientific name	Guam	CNMI	FSM	RMI	Palau	UMI	HI
Rhodophyta	*Prionitis lyallii*							M
Rhodophyta	*Pterosiphonia bipinnata*	M		M				
Rhodophyta	*Rhodophysema georgei*							H
Rhodophyta	*Sarconema filiforme*	M	M	M	M			
Rhodophyta	*Schizymenia pacifica*							H
Rhodophyta	*Spongoclonium caribaeum (=Pleonosporium caribaeum)*	M	M		M			
Rhodophyta	*Symphyocladia marchantioides*	M						

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5.6 Discussion and Conclusions

This study clearly demonstrates that a number of non-native species associated with biofouling represent a risk to Micronesia. Out of the global suite of 2,365 marine species identified with a recognized invasion history, 136 were considered native to Micronesia and 109 species have been previously introduced to Guam (but may or may not also be present in one or more of the other jurisdictions of Micronesia), leaving 2,120 species from our database with an invasion history that represent a novel risk of invasion to Guam (Table 5.1). Of these 2,120 species, 1,241 were deemed to have some likely association with biofouling of vessels. Micronesia has a relatively poor taxonomic knowledge base despite high endemicity and high levels of interest, and has not invested in significant evaluations of its current state of marine introductions, although Guam has had investigation of its non-native marine biota through literature and museum collection evaluations and a baseline survey of Apra Harbor (Paulay et al 2002). In contrast, the knowledge base for biological introductions is perhaps greatest in Guam relative to the other jurisdictions of Micronesia (but see Campbell et al 2007).

In order to advance the understanding of risk exposure it is imperative that a greater knowledge base is developed. Targeted field surveys are especially critical to determine the current levels of introductions, particularly in high risk areas (e.g., ports, marinas, aquaculture facilities) using a consistent suite of protocols and a shared taxonomic dataset. At a more fundamental level, studies on the alpha taxonomy of species with potential for invasiveness need to be undertaken, in order to better understand the diversity, ecology, and current geographic ranges of invasive species. A DNA barcoding study would help provide an indication of the unaccounted ‘cryptic’ species-level diversity present in the Micronesian region.

For the biofouling species assessed in this report, an evaluation of transport pressure was based on global distribution of the species (in native, cryptogenic and introduced bioregions). This enabled identification of the number of arriving vessels into Micronesia that **could have transported** the species to Micronesian waters. This required a number of critical assumptions:

- that a species presence in a bioregion represents an established population **throughout** the bioregion,
- that all vessel categories are equally able to transport all species and
- that all trade routes from bioregions to Micronesia are equally ‘stressful’.

These assumptions represent conservative approaches to the information available. The ability to discern a non-native marine species presence in overseas ports has been demonstrated to be problematic (e.g., Hayes and Hewitt 1998, 2000; Hewitt and Hayes 2001, 2002; Barry et al. 2008). While there have been numerous efforts to provide up-to-date information on invasions into various global regions (see review by Campbell et al. 2007), the information is typically out- of-date by the time it is in the peer reviewed literature. Assuming that a report for a species in a bioregion represents an established population in that bioregion allows a risk manager to use the information in making an assessment. Similarly, assuming that a species is spread throughout the bioregion, when it may have only been reported from one location, may assist in addressing the significant lag time between incursion, detection and reporting. During this period, which can encompass more than a decade, the opportunity for the species to have spread through natural and human- mediated means creates the high likelihood that nearby regions and ports will have been infected. It is worth noting though that assuming a species is spread through a region based on detections in one or several places within that region may be an erroneous conclusion and when considering how best to increase biosecurity for Micronesia and Hawaii, such assumptions should not be readily applied.

Differences among vessel categories (types) can clearly influence inoculation pressure elsewhere (e.g., Carlton 1985, 2001; Carlton and Hodder 1995; Coutts 1999; Wonham et al. 2000; Floerl 2002; Coutts and Dodgshun 2007; Piola et al. 2008). Vessel behaviors differ significantly both individually and across vessel categories. These behavioral differences include, but are not limited to, vessel speed, time spent in port, and maintenance history.

An evaluation of vessel speed based on the Lloyds MIU dataset indicated that at the gross scale of vessel categories used here, no clear differentiation could be discerned. Clearly, some vessel types move at much slower speeds than others, and recent reports suggest that these slower moving and sedentary vessels, including barges, dredges, drilling rigs and floating production, storage and offloading units (FPSOs), may harbor larger quantities and diversity of species than other vessels (e.g., Coutts 2002; Floerl 2002; Floerl and Inglis 2005; Davidson et al. 2009; Coutts et al. 2009, 2010a, b). The relationship, however, between a vessel's maximum, or even mean, speed (representing sheer forces) and the successful transport of species to new regions remains unclear.

The presence of hydrodynamically protected areas on a vessel's hull, such as sea-chests, rudders, and propeller shafts (e.g., Gollasch 2002; Hayes 2002; Coutts et al. 2003; Coutts and Taylor 2004; Hayes et al. 2004b; Coutts and Dodgshun 2007) nevertheless suggests that speed alone will not preclude a species presence on a vessel but may significantly reduce the abundance of a species. Coutts (1999) evaluated commercial (merchant) vessels entering Bell Bay in Tasmania, Australia and found that speed was a good correlate of species abundance and a moderatecorrelate for diversity. However, this study concentrated on the uniform areas of the hull surface and did not explore niche or protected areas of a ship's hull.

A time in port analysis was not undertaken in this study due to the limitations on data availability, particularly for military vessels. In previous studies (Hewitt et al. 2009e, 2010) differences between time spent in port for the various vessel categories provided a clear indication of differences in opportunity for species to settle on the vessel (assumed to correlate with time in port). This factor was used in previous studies as a multiplier of vessel visits from a bioregion to account for the increased likelihood that a species would be transported. However, the accumulation of biofouling in a small area of a vessel is unlikely to be a linear process. Indeed the accumulation of species onto settlement panels often follows an exponential increase in diversity as the habitat, increases in complexity (Sutherland and Karlson 1978). At some point however, an asymptote (a leveling off) of the species accumulation is expected to occur in the local patch, or more broadly once the community accumulates the entire species pool from a bioregion (Rosenzweig 2001). How rapidly the community is assembled varies widely across regions and time of year (Sutherland and Karlson 1978; Lewis 2002; Lewis et al. 2004; Dunstan and Johnson 2006).

As voyage duration increases, the number of bioregions visited by vessels entering Guam was found to encompass 12 bioregions after 30 days, reaching saturation (all 18 bioregions) after 183 days. Taking into account the expected operational cycle of vessels between dry-docking and antifouling paint applications, coupled with the restrictions placed on in-water cleaning in many jurisdictions, most vessels will be expected to have significant communities of species drawn from a wide suite of bioregions. Based on the assessment of voyage duration, multiple bioregions are visited by half of the vessels travelling for periods of less than one year. This in turn increases the opportunity for species from disparate regions to attach to the hull and also increases the total opportunity for individual species to be transported.

A number of vessel characteristics could not be evaluated and did not contribute to the final evaluation. As noted above, vessel speed did not appear to differentiate between vessel categories but varied widely within several categories. The implications that hydrodynamically protected areas may continue to harbor communities of biofouling associated species make this variable unlikely to fully eliminate any species from a vessel. Similarly, antifouling paint has been deemed to provide prophylactic protection, however the incomplete and often inappropriate applications of antifouling paints are unlikely to result in the complete elimination of a species from a vessel. While antifouling paint history coupled with more generic hull husbandry information could potentially provide significant information on the likely state of biofouling, this information could not be obtained at the scale required, and therefore could not be included in this assessment.

Biosecurity risk is typically derived from assessing both the arrival likelihood and the species consequence (impact). In this evaluation, a species' successful inoculation has been deemed to have an unacceptable consequence in keeping with a quarantine endpoint. A quarantine consideration, where the arrival of a new species is deemed to represent an unacceptable impact, is frequently employed where the desire is to prevent new invasions. In this report, the desire was to identify the species most likely to be introduced without differentiation with regard to the potential impacts they might cause. Consequently, the predictions made in this report necessarily relied on the most probable arrivals into Guam and subsequent transfer to other jurisdictions of Micronesia.

This assessment has concentrated on the likelihood of transport and inoculation, however not all species will have the physiological tolerances to establish and survive the environmental conditions found in nearshore waters of Micronesia. Establishment represents the survival and development of a self-sustaining population once a species has been inoculated into a new (receiving) environment (e.g., Occipinti-Ambrogi and Galil 2004). The likelihood of establishment has been theorized to relate to characteristics of the invading species (and its inoculation) as well as characteristics of the receiving environment (e.g., Carlton 1985; Lodge 1993; Ruiz et al. 2000; Hewitt and Huxel 2002; Lockwood et al. 2007).

Species characteristics which influence establishment likelihood include the physiological tolerance to the new (receiving) environment sufficient for reproduction to occur and all life history stages to survive. These are typically based on empirical evaluations of species' tolerances to a suite of environmental factors, such as temperature, salinity, light, dissolved oxygen, however these empirical evaluations have been carried out for a relatively small number of species (e.g., Hayes and Hewitt 1998, 2000; Campbell 2009).

Given these constraints, a second method of estimating probable survival in a new region is to match the environmental characteristics of the donor region where a species is known to exist, with a recipient region – environmental matching (e.g., Hilliard and Raaymakers 1997; Kilroy et al. 2008; see also Hewitt and Hayes 2001, 2002). As Barry et al. (2008) suggest, evidence to support the utility of environmental matching in the marine environment is limited, largely due to the inappropriate selection of environmental characteristics and scale by various authors. The ability for environmental matching to provide realistic risk evaluations becomes increasingly limited as nonsensical or irrelevant environmental factors are included in the analysis (Barry et al. 2008).

One of the greatest errors in environmental matching assessments is the inappropriate use of scale. As Hewitt and Hayes (2002) demonstrate, environmental matching is meant to create a surrogate measure for the species of concern's tolerances. This is done by selecting a location where a species is known to exist (the donor location), and using the range of environmental values to compare with a potential recipient location. If the donor location is restricted to a port, rather than the entire province or bioregion in which the species resides, then an artificial limit to the range of environmental values will be derived. To illustrate this, Hewitt and Hayes (2002) demonstrated that the temperature ranges of the Port of Sydney and the Port of Hobart do not overlap and hence, based on a simple environmental match, species would not be expected to survive in both. Regardless, Sydney and Hobart reside within a single large scale province and share many species. For example, when their temperature ranges are compared with the temperature tolerances of the non-native seastar, *Asterias amurensis*, they both fall well within the range of its survival (Hewitt and Hayes 2002).

Non-native marine species have been shown to fully realize their fundamental niche (*sensu* Hutchinson 1957), suggesting that their physiological tolerances are conservatively represented by the wide ranging environmental conditions in their native distribution (e.g., salinities and water temperatures). In a previous evaluation (Campbell and Hewitt 2011), the known temperature tolerances of several non-native marine species in Australian waters were compared with the sea surface temperature maxima and minima (over a ten year period) for their native provinces (Figure 5.37A). The environmental range of temperatures in a species' native provinces conservatively describes the temperature tolerances of the species in most cases, suggesting that the environmental ranges of provinces can be used as conservative surrogates of species' tolerances.

As a consequence, the environmental overlaps of different provinces may indicate the likelihood of species' survival in various regions. Significant provincial overlap occurs from the Arctic to the Antarctic along the eastern Pacific basin (Figure 5.37B), suggesting that many species could survive within a wide range of provinces across the eastern basin, and that their restricted distributions may be constrained more by other factors (e.g., transport opportunity, receiving community resistance including predation and competition) than significant physiological 'resistance'. The northern and southern distribution of the large brown kelp, *Macrocystis integrifolia* is a case in point (Graham et al. 2007).

Undertaking an assessment of the physiological constraints of the risk species identified here would require a significant effort and result in a large amount of remaining unknowns, given existing data limitations for many marine and estuarine species. Similarly, developing an understanding of the environmental constraints of Guam and other Micronesian environments to challenge species is beyond the scope of the current assessment.

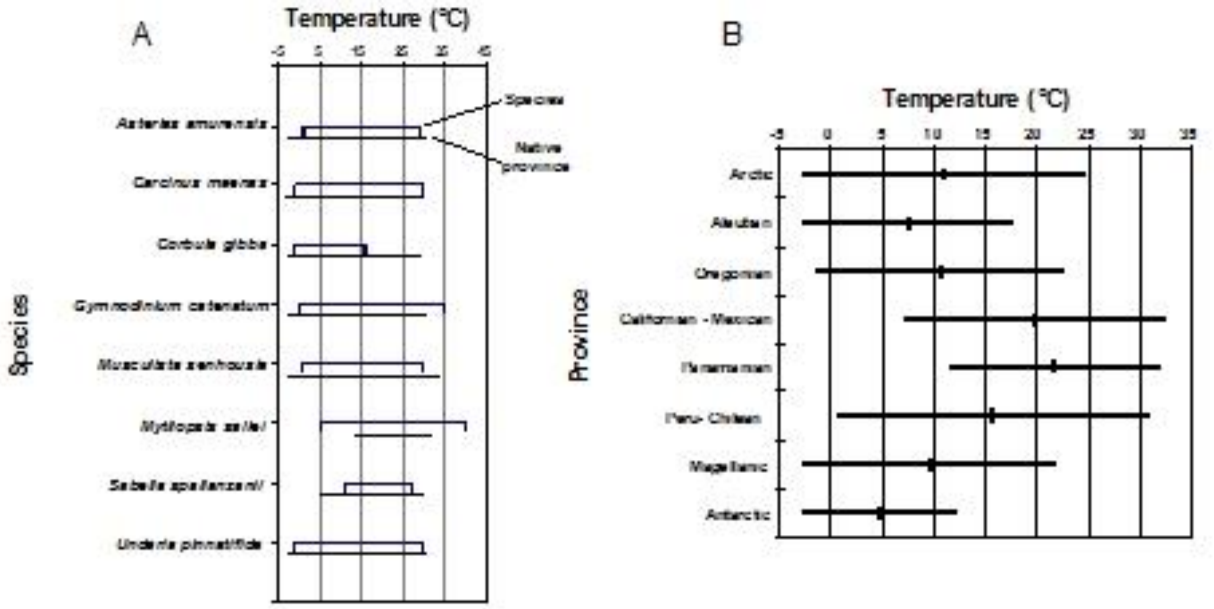

Figure 5.37. A) comparison of species' physiological tolerances (top line) versus native province Sea Surface Temperature range (bottom line); B) Comparison of Sea Surface Temperature for the eastern Pacific provinces (from Hewitt and Campbell unpublished data).

A posthoc assessment of species impact could lead to a greater refinement of the lists provided here, identifying those species which once inoculated and established could result in unacceptable impacts to economic, environmental, social or cultural values. Predicting impact (or consequence) of potential non-native marine species is problematic. In previous work, Hewitt et al. (2009e) evaluated the biofouling species risks to Australia and determined that of 657 species which were deemed to pose a threat to Australia, impact information could only be derived for 162 (24.7%). This information included both demonstrated impacts (or lack of impact) based on scientific assessment, as well as inferred impact based on expert opinion. For the remaining approximately 75% of species, no inferred or demonstrated impacts could be derived from the literature.

More recently, Dahlstrom (2012) evaluated the ability of biosecurity impact studies to detect an impact where the outcomes were non-significant. Dahlstrom focused on 31 algal and crustacean evaluations that have been cited to support an assessment of "no threat" by managers. Dahlstrom found consistently low power which led to an acceptance of Type II (false positive) errors at rates 5 to 19 times greater than acceptance of Type I (false negative) errors. These results suggest that for the suite of studied species for which no impact was discerned, 95% were unlikely to detect an impact due to poor design, and these species may have large impacts that have been missed due to high variation or small sample sizes.

These two examples suggest that researchers have no ability at the present time to assign consequence (impact) scores for between 75% and 90% of known invading species due to either a lack of scientific investigation, or poor implementation of impact studies leading to false conclusions. As a result, this study has focused on the quarantine endpoint to aid determination of species which require further study.

This study has identified 243 species which have a “High” likelihood of inoculation into at least one Micronesian jurisdiction or Hawai’i, with 85 species presenting a “High” likelihood of inoculation in at least one Micronesian jurisdiction, and an additional 168 species in Hawai’i. The 85 species representing an increased risk to Micronesia appear to be heavily influenced by traffic activities associated with Guam and with MSC vessels. These species include species that may impact aquaculture activities, coastal industries, wild fisheries and other living marine resources, protected and habitat-forming species, social/cultural values and human health.

PART III.

Marine Biosecurity Plan

Chapter 6: Marine Biosecurity Plan Recommendations for Micronesia

by Gregory M. Ruiz and Chela J. Zabin

6.1 Introduction

The purpose of this chapter is to outline key elements of a regional marine biosecurity plan for Micronesia. This begins with a brief review of the types of biosecurity plans that have been developed or proposed within the region. Next, a conceptual framework is outlined for vector management, serving as an operational structure to develop and advance biosecurity. Within this framework, specific recommendations are made for management practices, actions, and focused research and analyses needed to respond effectively to the threat of marine biological invasions. Finally, the structural (institutional) components necessary to meet these recommendations are considered. Throughout this approach, we draw upon information presented in the preceding chapters on (a) existing knowledge about marine invasion processes throughout the world, (b) the operation and management practices for vectors that transfer non-native marine species in Micronesia, (c) some critical gaps in baseline knowledge about regional vectors and invasions, and (d) the state of existing infrastructure (programs and capacity) for marine biosecurity.

While we identify critical components and actions for the regional biosecurity plan, a detailed implementation plan to achieve these goals is not presented here. The latter is clearly beyond the scope of the current project and represents a next step in the process. Pragmatically, it is important to recognize that any implementation plan is a political process, which requires (a) direct engagement and participation of the parties — countries, organizations, and people — involved in Micronesia, (b) consideration of possible legal instruments and approaches (i.e., regulations, agreements, partnerships, policies), and (c) assessment of available resources and institutional capacities to meet specific goals and timelines. In September 2011, the U.S. Navy entered into an agreement with the University of Guam to create a strategic implementation plan. The goal of this chapter, and indeed the entire report, is therefore to set the stage for this process, providing the necessary framework, activities, and actions.

The major impetus for this report is the current DoD Buildup in Guam, and associated activities, but the biosecurity plan recommendations are intended to be broader in spatial and temporal extent. For this reason, we have considered activities throughout Micronesia, as well as the linkage between Micronesia and Hawai'i. In addition, we have included consideration of some activities that may change through time. For example, it is clear that the magnitude and type of construction and vessel activities will change throughout the Buildup, and some transport mechanisms for marine species that are currently rare (or not in operation) in Micronesia may become important in the future. While we have attempted to capture this broad spatial and temporal scope, it is also important to acknowledge that our treatment cannot be comprehensive and anticipate all possibilities in this respect, especially given the time provided for this analysis. Nonetheless, we hope that the conceptual framework and rationale developed here can be applied broadly to any omissions or unanticipated future concerns.

In this chapter, as elsewhere in the report, the terms “non-native species” and “invasive species” are used unavoidably as synonyms. The term “invasive species” is variously and often vaguely defined throughout the literature (Ruiz and Carlton 2003). In general, it is meant to refer to species that have a negative or undesirable impact, but the effects of most non-native marine species have never been assessed in this regard (see Chapter 1, Section 1.4). The term “invasive” is used commonly in legislation, guidelines and management plans (see next section), and we refer to “invasive species” where it is used in this way. Elsewhere, we use the term “non- native species”.

6.2 Existing Plans and Recommendations for the Region

6.2.1 Ship-Mediated Invasions: Secretariat of the Pacific Regional Environment Program and The International Maritime Organization

A strategy for addressing shipping-related marine invasions in the region (SRIMP-PAC) was developed by the Secretariat of the Pacific Regional Environment Program (SPREP) in cooperation with the IMO (South Pacific Regional Environment Programme 2006). The SRIMP-PAC strategy takes a broad view, aiming to reduce the spread of marine invasive species to all Pacific Island countries and territories (PICTs). It emphasizes “pre-border” controls, or regulations, inspections and management actions in Pacific Rim countries to reduce biofouling on vessels and the uptake of organisms in ballast tanks before vessels leave port, as the most effective and cost-efficient approach. Such measures would also be taken in PICTs, along with at-border strategies to assess risk of incoming vessels and management strategies for reducing release of non-native species in ports and coastal waters. The plan also recommends the development of “post-border” strategies, such as early detection through monitoring, rapid- response plans, and eradication and control measures, while acknowledging that these are more costly and less-effective than prevention measures.

Other components of the SRIMP-PAC plan include structural and political components such as building an organization to carry out the plan (with SPREP/IMO as leads); mounting a major awareness campaign in all Pacific Rim countries; working to implement laws, regulations, and standards for ballast water and hull fouling; and building capacity for participating countries to carry out the plan elements. The strategy calls for a formal overall risk assessment for the region, with the intention of identifying high-, medium- and low-risk ports, as well as identifying risks posed by specific vessel types or voyages. The risk assessment would be used to guide the further development of management plans. In addition, the plan calls for a formal risk assessment for transiting vessels in the region, specifically for an analysis of regions where ballast water is discharged and a determination as to whether these pose a risk to PICTs.

Acknowledging the lack of baseline information about non-native species already present in the Pacific, the plan calls for initial surveys, along with three levels of ongoing monitoring for new invaders: comprehensive surveys at high-risk ports (based on the protocol developed by the Australian Centre for Research on Introduced Marine Pests); reduced scale surveys at medium risk ports (based on methods developed by Hawai’i’s Bishop Museum); passive settling plates at low-risk ports (based on methods developed by the Smithsonian Environmental Research Center). The document also notes the lack of taxonomic expertise in the region, and recommends coordination between countries in the region and scientific experts elsewhere, as well as the need for a coordinated database for information on species, ship movements and ballast water and hull fouling management issues. Taxonomic and DNA barcoding studies on invasive species may also be considered.

The SRIMP-PAC strategy includes a work plan which outlines what is to be done, when, by whom, as well as potential funding sources and existing models to follow. It does not specifically address military vessels.

6.2.2 Aquaculture Imports and Quarantine: Secretariat of the Pacific Community

SPC has developed quarantine guidelines for aquatic species introduced to the region for aquaculture (Humphries 1995). A draft version of these guidelines and recommendations was adopted by SPC in 1994. Essentially, the guidelines provide minimum standards for quarantine, including the following:

- Evaluating each proposed introduction on a case-by-case basis
- Risk assessment to assign risk categories for proposed introductions
- Health certification as well as pre- and post-entry examination for disease
- Secure quarantine facilities (including consideration of site of facility to minimize accidental releases due to natural disasters, e.g. floods and tsunamis) and training to improve ability to test for disease
- Preparation of a regional strategy on aquatic biosecurity
- Development of a regional disease database

6.2.3 General Invasive Species Plans: Secretariat of the Pacific Regional Environment Program

Guidelines for the development of national invasive species management plans (across all habitat types) for Pacific Island countries were drafted by the Secretariat of the Pacific Regional Environment Program, following a series of meetings and discussions with various agencies in the region (Tye 2009). The document advocates use of the precautionary principle in the management of invasive species, assuming, in the absence of information to the contrary, that any non-native species will become problematic and should be prevented from spreading and/or becoming established. As does the SRIMP-PAC document, it emphasizes a hierarchical approach to dealing with invasive species, i.e., prioritizing prevention, which is less costly and more effective than managing invasive species post-establishment, and advocating eradication where possible rather than long-term management. Biological control, using host-specific species, is recommended as a potential management strategy where eradication is not possible; with containment and long-term management by chemical or physical methods as last-resort actions.

The document addresses non-native species across all habitat types and presents an excellent overall framework for the development of invasive-species management plans. Unlike SRIMP-PAC, it focuses on species entering the country via imports; ballast water and hull fouling are not mentioned in the document. It contains guidelines broadly organized into three major thematic areas, which are further broken down into nine sub-themes as follows:

I. Foundations

A. Generating support for actions to manage and prevent invasions

B. Building capacity

C. Legislation, policy and protocols

II. Problem definition, prioritization and decision-making

A. Baseline and monitoring, specifically the development of baseline information on the abundance and distribution of invasive species

1) Prioritization of management activities

2) Research on priority species

III. Management Action

A. Biosecurity, defined as prevention of the spread of invasive species

B. Management of established invasive species

C. Restoration of native species

These thematic areas are further developed in the document, with steps and actions to be taken toward specific goals, but the SPREP plan does not provide specific strategies or methods. For example, the plan advocates the development of monitoring programs for invasive species but offers no details of best approaches for monitoring. Best management practices for different vectors or pathways are also not detailed.

6.2.4 Pacific Invasives Initiative

The Pacific Invasives Initiative reviewed national biosecurity/biodiversity plans and invasive species management activities (Pacific Invasives Initiative 2010) for 12 Pacific Island countries, to assess alignment with the SPREP document and to identify existing gaps in the plans. The countries reviewed in the Micronesian region were the RMI, FSM, and Palau. The review found that all countries except for RMI had addressed invasive species in their national biodiversity strategy and action plans (a biosecurity plan for RMI is currently in draft form; see next section). RMI, FSM (Pohnpei, Kosrae and Yap) and Palau had also completed invasive species action plans (Chuuk now has a draft plan; see Section 6.2.5 below). The review found that while all countries had taken some steps to address the issue of invasive species, major gaps existed in invasive species plans and activities.

In general, countries had done well in recognizing the need for public education and outreach and had engaged in such activities (Pacific Invasives Initiative 2010). Most countries recognized the need to build capacity of local agencies to address invasive species. Most also had management plans for some species and/or were already engaged in invasive-species management; most acknowledged the need for increasing capacity for invasive-species detection at ports of entry and for revising, coordinating, and streamlining legislation and policy related to invasive species.

Major gaps existed on several fronts: few of the countries recognized the need or had taken steps to gather baseline data on the abundance and distribution of non-native species already present; approximately half of the countries had not recognized the need for or taken action to prioritize which species should be targeted for management or to carry out research necessary for building a best approach to management of priority species. Countries in general had also done poorly in terms of garnering political support, developing pre-export protections (to reduce spread from a country), and including restoration of native species into invasive-eradication projects. Overall, the report concluded that most of the countries did not know how to plan an effective invasive species management program or how to identify and incorporate best-management practices into their programs (Pacific Invasives Initiative 2010).

6.2.5 Local Area Plans in Micronesia

Most of the countries in the region are addressing invasive species either in biosecurity legislation or invasive species plans or both. However, efforts to date have been limited and are mostly focused on terrestrial and to some extent freshwater species. Palau seems to have advanced the furthest in addressing invasive species in general and marine species in particular.

6.2.5.1 Palau.

Palau's National Invasive Species Strategy (2004) includes consideration of marine species and outlines a number of action items:

1) periodic review of the country's legal and regulatory framework with regards to invasive species, and the revision and adoption of updates to these as needed;
2) preparation of a National Invasive Species Strategy (below), which was drafted nearly simultaneously with the National Invasive Species Policy;
3) thorough initial surveys in terrestrial and marine environments to identify and quantify invasive species;
4) identification of priority species for management actions, and the identification of areas at greatest risk for entry and establishment of invasive species
5) prevention of new invasions, detection through regular monitoring, and management/eradication of established species;
6) restoration and re-establishment of native species to be included as part of management activities; and
7) cooperation between various local, regional and international agencies working on invasive species.

Many of these items have since moved forward.

Palau's National Invasive Species Strategy (2004), or NISS, acknowledges explicitly the potential importance of marine invasions in a country that depends heavily on a healthy marine environment. The NISS was written by the country's National Invasive Species Committee, after a review of relevant documents from Australia, SPREP, the Global Invasive Species Programme, the Convention on Biological Diversity, and the Bahamas National Invasive Species Strategy. The NISS lays out a series of objectives to meet four major goals:

1) the provision of a national framework for dealing with invasive species;
2) the prevention of new invasions;
3) management of invasive species already in Palau; and
4) coordination with other regional and international organizations dealing with invasive species.

Additionally, the document details the roles and responsibilities for dealing with invasive species for the national and state governments, traditional leaders and community members.

The NISS was formed after a SPREP-led workshop in 2003, and recommendations from this workshop appear as an appendix to the strategy document. Two specific recommendations for dealing with aquatic/marine species in Palau came out of this workshop: 1) immediate action to eradicate tilapia and 2) working with dive operators to involve recreational divers in hull inspections of yachts and commercial vessels. In addition, the appendices include voluntary codes of conduct for many sectors (vectors), including aquaculture. It was agreed that use of non-native species for aquaculture ought to be discouraged generally, and, wherever used, the species should be contained in secure facilities.

In 2006, the Palau National Invasive Species Committee reviewed the NISS. The committee modified language for clarity and to make several of the major goals and objectives more comprehensive (Palau Invasive Species Committee 2006a, 2006b). The NISS added a fifth major goal, that of increasing public awareness and support for invasive species prevention and management.

Following its review of the NISS, Palau's National Invasive Species Council developed an Action Plan (Palau National Invasive Species Committee 2007). The Action Plan follows the structure of the NISS closely, laying out specific actions to be taken to achieve the goals and objectives of the NISS as well as time frames for these.

Palau took some initial steps to gather baseline data on invasive marine species within its borders. With help from Australian scientists, the NISC and other agencies carried out a training workshop and a baseline survey of its major port in 2007. Several new non-native species were found as a result of this survey and a manual removal of some of these was attempted. In addition, a public awareness campaign was carried out by Koror state on an invasive anemone in Jellyfish Lake (Palau National Invasive Species Committee 2007). To the best of our knowledge, however, there have been no follow-up marine surveys, nor is it clear that any actions are being taken to prevent further introductions to Jellyfish Lake.

Palau also launched major campaigns to eradicate tilapia that involved the assistance and support of many agencies and community members (reviewed by Walsh et al. 2010). Tilapia was also added to the list of species prohibited for import into Palau, although the government is now reconsidering this (as noted in Chapter 4).

In 2010, during the present analysis, Palau was considering the adoption of a biosecurity bill. The bill would create a Division of Biosecurity, increasing the ability of biosecurity agents to inspect incoming vessels and goods and to act to control or eradicate pest or disease outbreaks. The bill would specifically prohibit the release of bilge or ballast water in Palauan ports (draft version February 2010), but otherwise would not address ship-mediated invasions. Many of its provisions, such as requiring an incoming vessel to submit voyage records prior to arrival, and granting biosecurity agents the power to sample vessels or parts of vessels, would create an initial framework to reduce ship-mediated invasions associated with ballast water and hull biofouling .

6.2.5.2 Republic of the Marshall Islands

At the time or our analysis, the Republic of the Marshall Islands (RMI) was also considering a biosecurity bill, which was nearly identical to Palau's (based on a draft version as of September2010). In this bill, discharge of ballast or bilge water is prohibited "at sea" in the Marshall Islands rather than specifically in port and the maximum fine for such discharge is $100,000 (no specific fine is listed in the Palauan bill). This is the only specific reference to marine species and their vectors.

6.2.5.3 Federated States of Micronesia .

Chuuk State's Invasive Species Taskforce has developed a draft strategic action plan (Chuuk Invasive Species Task Force Strategic Action Plan, draft version November 2010). The plan focuses on programmatic development, including finding funding and resources, building capacity, increasing coordination between agencies, and generating public awareness. However, it also (a) includes eradication/control measures for two terrestrial plants on the island of Weno, (b) identifies one marine species – the crown-of-thorns sea star (*Acanthaster planci*), a native species which can severely impact coral reefs -- for control measures in Chuuk Lagoon as well as some of the outer islands and (c) calls for 10 surveys in the Chuuk Lagoon and six on outer islands to identify other invasive marine species. No measures for preventing non-native species transfers are addressed.

Kosrae's Invasive Species Action Plan is modeled on the SPREP plan, based on that plan's three major theme areas and nine sub-themes (Section 6.1.3). The Kosrae plan lists specific objectives to achieve the more general objectives suggested by SPREP, however the proposed activities do not appear to meet objectives in many instances. For example, the general Objective 2 in Table B1.2 is "Monitoring invasive species movement on island, and between countries and territories." The matching proposed specific objective is to "review existing port and border surveillance and rapid response arrangements" and the proposed activity is "quarterly visits to Quarantine for bio-security updates." It is not evident how this would result in species-level monitoring information. Although marine species are mentioned in the Kosrae plan, no specific vectors are addressed nor are any actions proposed to deal with marine species.

6.2.5.3 Individual U.S. Military Bases.

A publication that reviews 12 case studies of invasive species on military bases and lays out some basic recommendations for the military was prepared for the DoD by the National Wildlife Federation (Westbrook et al. 2005). Among the recommendations is the inclusion of an invasive species management plan in a base's Integrated Natural Resource Management Plan. The document states such plans ought to emphasize prevention and rapid response and identify target species for which management actions should be detailed. The authors emphasized the importance of education and outreach and coordinating efforts with civilian groups and agencies already working on invasive species. Additionally, they called for specific funding for invasive- species management on bases and for bases to support research on prevention and control techniques. Marine species were not addressed specifically in the plan, either in the case studies or recommendations. As far as we can determine, the report's recommendations have not been officially adopted by the DoD.

6.3 Conceptual Framework for Vector Management

In marine ecosystems, invasions have often resulted from the broad scale transfers of entire species assemblages or communities, such as those associated with ships' ballast water or hull fouling communities. These are relatively non-selective mechanisms and literally thousands, if not tens of thousands, of species may be entrained by them. It is difficult to predict which organisms will be associated with any particular transfer (vessel), let alone estimate with any confidence which of these may cause severe ecological or economic impact. Neither is it easy to predict the next 'new' invasive species, particularly in the tropics. While targeted movement of individual marine species also occurs (as noted in Chapter 4), and some of these species have invaded new regions with negative effects, the fact remains that most invasions are attributed to the above "bulk" transfers.

As a result of this history, marine invasion management and policy has focused strongly on treating the vector, rather than taking a species-specific approach. This is particularly evident in the evolution of ballast water treatment (see Chapter 2 for review). This lead Ruiz & Carlton (2003) to outline a conceptual framework for vector management, highlighting the interplay of research, management, and policy. Although motivated by a particular vector, they also considered the general principles and approach to have broad application to other vectors and ecosystems, and even to management of single species.

Figure 6.1 illustrates the four core components of vector management. First, vector analysis (research) characterizes the propagule supply, or species composition and abundance, associated with a particular vector, including the operation of the vector and factors that affect the supply of organisms delivered. Second, vector strength assesses the number or proportion of invasions attributed to the vector. Third, vector interruption (or disruption) represents management action or treatment to reduce the likelihood of transfers and invasions. And fourth, efficacy of vector interruption measures the effectiveness of the action on (a) reducing or interrupting organism transfers and (b) decreasing the establishment of new invasions.

Vector management can be characterized as a stepwise and interactive process within this framework (Ruiz & Carlton 2003). Information about transfers and invasions of species associated with a vector (components 1 and 2, Figure 6.1) form the basis for management action (component 3) to interrupt the invasion process. Following management action(s), it is also important to evaluate the efficacy of this action (component 4), in terms of its intended effect on reducing transfers (4a) and also subsequent invasions (4b). The two types of efficacy measures are complementary and necessary. The former measures the short-term proximate effects of management on species during the transfer process, and the latter assesses whether the ultimate goal of reducing invasions is achieved.

While each of these components plays a clear and important role in vector management, it is important to recognize that it is the interaction among components that plays a vital role in creating an effective program and desired outcomes for biosecurity. This interaction or relationship among the components forms the basis for adaptive management, whereby initial management actions (component 3) are evaluated (component 4), providing feedback about whether these have been sufficiently effective or whether further actions are required.

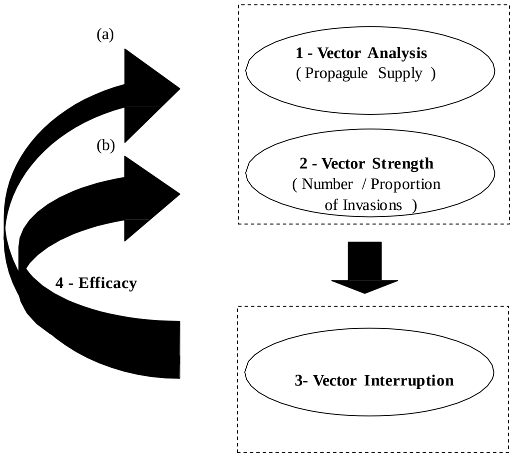

Figure 6.1. Framework for vector management. Vector management consists of four components and the interactions among them: (1) Vector analysis – characterization of vector operation, including organisms transferred by the vector; (2) Vector strength – assessment of the number or percent of invasions attributed to a particular vector; (3) Vector interruption (disruption) – actions taken to reduce the transfer of organisms and likelihood of invasions; (4) Efficacy – measurement of the effect of vector interruption on the transfer of organisms (4a) and number or rate of invasions (4b). [From Ruiz and Carlton 2003, Figure 18.3]

Such a feedback loop is a vital part of biosecurity, as in other areas of environmental management for multiple reasons. First, science often cannot predict the exact quantitative response of actions, due to uncertainties in the available data or sometimes complex mechanisms. Second, management is often based on historical patterns of invasion, which may not anticipate changes that will affect underlying processes and dynamics, such as global trade patterns or climate change (in the case of invasions).

We consider this a useful framework to use in evaluating the operational structure and present gaps for vector management in Micronesia. A successful biosecurity program requires that each of these components, operating together to provide the necessary policy framework, management actions, and directed research for successful management. Moreover, vectors are the functional units that move species, and each vector often involves a specific set of operating requirements, organizations and people, regulations, and information resources. Thus, evaluating biosecurity from a vector management perspective, may more effectively target and transfer specific recommendations to the appropriate user groups.

In the section below, a vector management framework is used to evaluate the existing biosecurity program by vector in Micronesia. This summarizes some information presented previously in the report and uses this background to advance recommendations to address specific gaps for prevention of coastal marine invasions. Additional aspects of biosecurity, beyond those aimed at prevention, are considered in subsequent sections.

Although the current focus of this analysis is on Micronesia and Hawai'i, many of the same issues and recommendations are relevant to other global regions. This biosecurity plan therefore provides a model to consider for potential broader application, especially for DoD activities, where biosecurity practices are established globally by one entity; in contrast, practices for commercial and other non-DoD activities are highly variable around the world and governed by many different jurisdictions.

6.4 Prevention of Marine Invasions: Vector Management Recommendations

The primary objective of biosecurity is to minimize the likelihood of new invasions and associated undesirable impacts. While biosecurity can include post-border responses to new incursions, such as eradication, containment, and control, a premium is usually placed on pre- border efforts that aim to prevent invasions from occurring in the first place. Prevention, or minimizing the probability and number of new invasions, is usually viewed as the most cost- effective and desirable strategy to pursue, because it can be extremely difficult to eradicate or control species once they have colonized a region (Wittenberg and Cock 2005).

Prevention measures are directed usually at specific vectors and aim to reduce the magnitude (concentration or abundance) and frequency of species transfers to a target area. Such measures may be aimed at entire communities (e.g., ballast water of ships, as discussed in Chapter 2) or particular species of concern, and vectors are an explicit focal point for evaluation and management action(s) in most cases. Thus, vector management is a central aspect of most efforts to prevent invasions, whether on land or in water.

Here, the management of specific vectors is addressed to prevent or minimize marine invasions in Micronesia, considering current efforts and providing recommendations. This is organized by vector, treating separately DoD versus civilian activities, although we recognize that the level of DoD activities (and personnel) in the region also affects commercial and private activities. Our goal is to evaluate and consider three components of vector management (vector analysis, disruption, and efficacy; Section 6.3) in this treatment, focusing on the specific vector itself. This analysis does not yet consider broader issues, such as cross-vector management opportunities, institutional and political frameworks, or coordination and capacity within (and outside of) Micronesia, or post-border management of marine invasions. These other dimensions of biosecurity are discussed in subsequent sections.

In the treatment below, it is assumed that the transfer of non-native species to Guam presents some risk of invasion and impact, as outlined in previous chapters. Controlling for other factors, it is also assumed that the likelihood of establishment increases with (a) increased number of individuals, or propagule supply, of a single species and (b) the number of species. There is strong empirical and theoretical support for these assumptions. While not all species have the same probability of establishment or would result in the same impact(s), both of which would also vary geographically, the information needed to make such distinctions is extensive and simply not available; this limitation results from both a general lack of necessary data and also time. Thus, the evaluation that follows (a) takes a precautionary approach that assumes invasion risk is positively related to magnitude of organism delivery and (b) assumes the goal of vector management is to reduce the unintentional or unwanted transfer of species and associated probability of invasions; we recognize that the desired level of protection (or acceptable risk) depends upon values, requiring political and social decisions. This approach is consistent with that used to develop existing regulations and guidelines for ballast water management and which is also being used to advance recommendations for management of biofouling on vessels (see Chapter 2).

6.4.1 Military Vessels: (A) Ballast Water

6.4.1.1 Vector Analysis. There have been a few previous studies of organisms in ballast water of U.S. Navy vessels (Holm et al. 2005; Ruiz and Smith 2011), but we could find no such data for vessels arriving to Guam, other parts of Micronesia, or Hawai'i. It is clear from studies of ballast water, that geographic source(s), age, and environmental conditions affect biological contents in ballast water, such that extrapolation from other studies may not be representative of vessels arriving to Micronesia (Verling et al. 2005, National Research Council 2011).

More surprising, there is a conspicuous lack of available information on ballast water discharge and management for most U.S. Navy vessels, or any other military vessels, arriving to Micronesia or Hawai'i. While the Navy has a requirement to record ballast management information in ships' logs, these data are simply not available for analysis. It is not evident that any record keeping is required currently for other DoD vessels. For both U.S. Navy and other DoD vessels, no studies were found that characterize ballast delivery and management patterns in the region.

The lack of data on ballast water discharge and management represents a fundamental gap for effective vector management. Without access to simple reporting data it is not possible to assess the flux (quantity or quality) of ballast, the level of implementation with specific guidelines (see 6.4.1.3), and any gaps in current management practices, as is now undertaken for commercial ships (see Chapter 2).

As noted previously in Chapter 2, there is uncertainty about whether vessels operating under MSC are expected to follow ballast water practices required for U.S. Navy vessels under OPNAVINST 5090.1C, or whether these vessels are expected to follow USCG ballast water regulations for commercial ships when arriving to Guam, CNMI, and Hawai'i. At present, relatively few follow the latter, and most ballast water management and discharge practices are not known for these vessels.

To assess the potential transfers of organisms associated with ships' ballast water, in order to inform appropriate management responses, we recommend that the following minimum steps be adopted by DoD:

1. **Implement a system for U.S. Navy ships to report ballast water discharge per port arrival in Micronesia and Hawai'i, modeled after that used by USCG, such that the data are compiled electronically at a centralized database.** This should include key information on volumes, sources, and management (treatment). The data are not restricted to port activities but intended to include all ballast operations in Micronesia and Hawai'i. Although the U.S. Navy is required to log these data, none of this information is available, nor has it been examined or evaluated, to our knowledge.

2. **Extend a ballast water reporting requirement and reporting system to all military vessels operating in Micronesia and Hawai'i, including those operating under MSC and other branches of the military**. This could be the same reporting system outlined in Recommendation #1, to avoid redundancy. If multiple reporting systems, however, they should be designed to assure the same data are collected across vessels, using the same data fields and units of measure.

3. Conduct an initial comprehensive analysis of current ballast water discharge and management patterns by U.S. military vessels, including those operated under MSC and all branches of the DoD, for Micronesia and Hawai'i. This should be part of a report on the current operation of this vector, and it may be repeated at some regular interval, as part of assessing program efficacy (see Section 6.4.1.3).

We note that the number of vessels arriving to these regions is relatively small, compared to similar nationwide and continuous analyses of commercial vessels by USCG. Thus, implementation of these recommendations is not expected to require a large effort, especially as good models for these activities already exist, in the U.S. and other countries, and can serve as blueprints to minimize time and expense in system design.

A reporting and analysis program is a logical and necessary first step in evaluating current marine invasions risks associated with ballast water by military vessels in Micronesia and Hawai'i. Depending on the outcome, an analysis of associated biota may also be needed, as discussed further below.

It is also useful to recognize that such a program for ballast water analysis of DoD vessels in Micronesia could serve as a pilot project for possible broader application. First, this program could be applied to other geographic regions, and perhaps to all regions, because the same issues and information gaps outlined previously apply broadly. Second, an initial analysis would provide a useful baseline, against which ongoing or future data collection and analysis could examine effects or changes in ballast water management and risks (see Section 6.4.1.3).

6.4.1.2 Vector Disruption.

Although the U.S. Navy has requirements for ballast water exchange, these are not as stringent as those for commercial vessels, because the exchange is allowed to occur much closer to shore (see Chapter 2). In addition, the treatment requirements are changing for commercial ships, under pending U.S. regulations and IMO requirements, to the use of technologies to achieve particular concentration-based discharge standards. Although military vessels are not required to comply with the regulations for commercial vessels, it is evident that they frequently will exceed the commercial vessel standards in the future. No plans have been identified or stated by the U.S. Navy to address this disparity.

More broadly, specific guidelines or requirements do not appear to exist for ballast water treatment of vessels operated under other branches of the U.S. military. Under the U.S. Clean Water Act, discharges by military vessels must comply with UNDS. Since 1999, ballast water has been designated as one of the discharges for which standards are being developed, but specific UNDS requirements have not been provided to date (United Stated Environmental Protection Agency 1999).

Despite the U.S. Navy requirements for ballast water exchange, it is not clear whether vessels operating under MSC — especially those operated under contract that are not Navy-owned must follow Navy requirements for ballast water treatment (as noted above). Moreover, it does not appear that there are requirements for ballast water treatment by other vessels (e.g., barges and supply vessels) under contract to DoD, including those during the Buildup, other than those that may apply to commercial vessels. As with MSC vessels, however, we believe it is ambiguous to contractors and vessel operators as to which requirements may apply to them, and there are currently no requirements for private or commercial vessels arriving to Micronesia, outside of those in Guam and CNMI (see Chapter 2).

To reduce organisms transferred in ballast water and the associated invasion risks, we recommend the following steps by DoD:

4. Revise and upgrade current treatment requirements for U.S. Navy vessels to converge on those for commercial vessels. The goal should be to (a) increase the distance from shore for ballast water exchange in the immediate and short term and (b) plan for ballast treatment technologies to further reduce the concentrations of coastal organisms in ballast tanks.

5. Clarify explicitly whether current U.S. Navy regulations apply to all MSC vessels. We further recommend that the Navy inform all vessels (including contractors) operating under MSC whether they are subject to U.S. Navy or USCG requirements of ballast water treatment.

6. Establish ballast water treatment requirements for vessels operating under all branches of the U.S. military. We suggest a similar treatment approach to that recommended for U.S. Navy vessels (above), and this could perhaps be accomplished by UNDS. However, there is a premium on timeliness, especially with respect to the Guam Buildup.

7. Establish ballast water treatment requirements for vessels operating under contract to any branch of the U.S. military to include barges, supply vessels, or any other vessel type capable of carrying ballast water. This could include clarification that all U.S. federal regulations apply to these vessels, as well as separate requirements for other countries in Micronesia. We further suggest separate outreach and implementation tools should be considered for contract vessels and contractors, compared to those military- owned or operated vessels (see 6.4.1.3). As above, there is a premium on timeliness, to coincide with the context of expected increases of activity during the Guam Buildup construction phase.

6.4.1.3 Efficacy.

Previous work measures the efficacy of ballast water exchange aboard MSC vessels (Chapter 2), suggesting a greater distance from shore is desirable to minimize transfers of coastal organisms, as recommended above. While these experimental measures or assessments of efficacy are highly informative, there are two other dimensions of efficacy that require additional consideration and attention.

First, it is not clear the extent to which the current U.S. Navy policy is implemented. As discussed above, there has been no evaluation or analysis to verify the frequency of compliance with U.S. Navy requirements. This is perhaps most striking for MSC vessels (as above) and also likely most important here, because these vessels tend to carry and discharge more ballast than surface combatants (United States Environmental Protection Agency 1999). However, we have highlighted the lack of sufficient data and analyses to assess the performance (compliance) of all U.S. Navy vessels. This is largely an issue of short-term efficacy, evaluating whether the treatment is implemented properly to achieve the desired reduction in abundances of organisms in ballast water (component 4a of vector management; Figure 6.1).

Second, the extent to which new invasions by non-native marine species are accumulating in Guam or other areas is largely undefined. Past surveys indicate invasions are occurring, but the scope and timing of these is poorly resolved, because there are no consistent or long-term programs that exist in Micronesia with this purpose. This data gap presents a challenge for evaluating the long-term efficacy of management for ballast water, as well as all other vectors, to prevent invasions (component 4b of vector management; Figure 6.1). Although such data limitations are not unique to Micronesia (National Research Council 2011), they are more pronounced here than in some other global regions, where (a) more research has been conducted, (b) the biota is less diverse, and (c) the biogeography of organisms is better understood.

While field-based surveys of marine organisms are the only way to address this second measure of efficacy, it is important to also consider briefly the application and interpretation of field survey data. Although this section focuses on ballast water, surveys would in fact have application for other vectors as well. While surveys to test for invasions due to ballast water may focus on particular types of organisms (i.e., those transferred in ballast water), some organisms are specific to ballast water (holoplankton) and others are possibly transferred by ballast and hulls of ships (e.g., many benthic invertebrates with plankton larvae); the potential vectors associated with invasions can be ascribed based upon life-history information of the species (see Chapters 1 and 5). Importantly, for those species invasions attributed to ships, it is usually not possible to know which specific ship(s) caused an invasion, or in many cases whether it was military or commercial. Thus, field surveys provide critical information to know whether particular vectors are allowing invasions to occur, but they usually cannot pinpoint the exact, specific vessel or event responsible. In this sense, such field measures provide a broad indicator of status and trends of invasions, and the extent to which particular vectors continue to result in new invasions, in response to current management practices (vector disruption; Figure 6.1).

Another important application for field surveys is in creating the potential to respond to new incursions, when they occur. There is considerable literature and interest in “Early Detection and Rapid Response” (EDRR) to invasions, which obviously requires a system for detection of new non-native species as they arrive and establish new populations (Wittenberg and Cock 2001; McNeely et al. 2004). Thus, depending on the particular goals for field surveys, they have application for both assessing vector management (invasion prevention) and triggering invasion response (e.g., control, eradication, or containment).

To assess and improve efficacy of ballast water treatment, we recommend that DoD take the following steps:

8. Assess the extent of ballast water treatment (both in terms of percentage of vessel arrivals and discharge volumes) prior to discharge by U.S. Navy and other military vessels arriving to Micronesia. The data for this, as well as the analysis could be a component of Recommendation #3 (above), if implemented. This may need to be done at regular intervals, especially if and when (a) compliance with existing requirements is low or (b) requirements for ballast water treatment change.

9. Establish a program that implements targeted outreach and administrative tools to increase compliance with ballast water treatment requirements (see Recommendations #4-7) for military and non-military vessels associated with the DoD. This applies to commercial and contracted vessels (including barges and cargo vessels) that operate under contract to the Navy, or MSC, as well as all other vessels that arrive to U.S. Navy or other DoD facilities. For example, requirements could be explained in educational materials and also could be specified in contract agreements. No requirements are specified currently by DoD for many vessel types, and there is uncertainty about what requirements exist (as discussed above). Such a program would apply to U.S. Navy vessels only as needed, if compliance is low or requirements change (see Recommendation #8).

10. Implement a program of field-based surveys in Micronesia, including but not limited to Apra Harbor, to (a) assess efficacy of vector management practices to prevent invasions and (b) provide detection capability for response(s) to new incursions that occur. While this need exists throughout Micronesia, Apra Harbor is a high priority, given the high level of shipping and other vector activities that already exist and are expected to increase as a result of the Guam Buildup (See Chapter 3). This program should involve DoD working in partnership with other federal and local agencies throughout Micronesia. The use of these survey data are not restricted to management of the ballast water vector, but have broad applications. Further aspects of survey design and goals are discussed in Section 6.5.

6.4.2 Military Vessels: (B) Compensating Fuel Tanks

Although the discharge of seawater from compensating fuel tanks by DoD vessels has been suggested to be an activity with a “low risk” of transferring non-native marine species, we were unable to locate any analysis that characterized and evaluated the locations, volumes, and biological content of marine organisms being discharged from these tanks. The classification of “low risk” comes from the Phase I assessment review to develop UNDS, and it results because ships do not generally take on seawater in compensating fuel tanks within ports (United States Environmental Protection Agency 1999). However, vessels do discharge in coastal water or ports, and the sources of seawater in fuel tanks may be near to shore, depending on the particular mode of operations (i.e., where fuel is used and where seawater compensation occurs). Thus, despite the previous assessment, it does appear that transfers of organisms can occur with discharge of seawater from compensating fuel tanks, and that some of these organisms can be coastal species that are non-native at the discharge location.

The extent to which coastal organisms are transferred from one location to another will depend greatly upon the source locations of the seawater used in tanks. Although invasions can occur at many depths and distances offshore, most marine invasions are known from bays or ports, and some are known from adjacent coastal habitats (Chapter 1). Thus, minimizing transfers of coastal organisms, either directly between bays or in close proximity to bays (where adjacent coastal waters be a source or recipient of non-native organisms that can reach suitable habitat for colonization), has been the main focus of prevention for ballast water management, and a similar rationale would apply to compensating fuel tanks. To our knowledge, the extent (including frequency and volume) with which such transfers occur from discharge of compensating fuel tanks has not been characterized for DoD vessels operating in Micronesia or elsewhere.

Although we recognize many vessels are expected to carry seawater from open ocean sources in their compensating fuel tanks, low frequency discharges of water from coastal sources may pose an elevated risk of invasion. The key question that should be addressed is whether and the extent to which this occurs. To answer this question, and evaluate whether further management is desirable, we recommend that DoD take the following step:

11. Evaluate the locations and volumes of seawater operations (including both uptake and discharge) for compensating fuel tanks discharged in Micronesia. If uptake occurs close to shore, review and revise current practices to achieve one or more of the following outcomes: (a) prevent uptake close to shore, setting specific minimum distance requirements; (b) prevent discharge close to shore, setting a minimum distance requirement, for seawater from coastal sources (as outlined in “a”).

6.4.3 Military Vessels: (C) Biofouling

The U.S. Navy has focused considerable attention and resources in analysis and prevention of biofouling on vessels, as well as the development of methods for hull husbandry. Indeed, it is recognized as a world leader in advancing basic and applied research for this area. However, the primary focus of this effort has been on maintaining operational performance, efficiency, and readiness of the vessel, and not prevention of non-native species transfers and invasions.

As outlined in Chapter 2, a program for maintaining operational performance does not necessarily meet criteria for preventing invasions, as these are two very different objectives that strive for distinctly different outcomes. A vessel can operate within an acceptable range of performance, and still transfer significant numbers of organisms associated with the hull and underwater surfaces, especially in niche areas (e.g., rudders, intakes, thrusters). In the sections that follow immediately, existing practices are evaluated from a biosecurity and vector management perspective.

6.4.3.1 Vector Analysis.

Although the U.S. Navy has specific policies and protocols for assessing biofouling on its vessels (Naval Ships Technical Manual 2006), and collects a significant amount of data in the process, it appears that these have not been used to estimate the extent (including abundance and species composition) of living organisms that arrive on vessels to Guam, other parts of Micronesia, Hawai’i, or other global regions. We did not have access to these data to evaluate their scope and potential application for this purpose.

While the current U.S. Navy program for biofouling assessments applies to Navy-owned vessels, it appears that privately owned vessels under contract to the Navy generally do not participate in this program, including many vessels that operate under MSC. A limited survey of some of the latter vessels, upon arrival to Guam, indicated that the extent of biofouling can be relatively high (Chapter 2).

We are not aware of past analyses or existing programs that are designed to evaluate biofouling associated with amphibious vessels or other DoD vessels that arrive to Guam or other parts of Micronesia.

To assess the potential transfer of non-native species by ship biofouling, we recommend DoD take the following steps:

12. Evaluate the extent (including especially total abundance and species composition) of biofouling on all types of DoD and U.S. Navy vessels operating in Micronesia, including amphibious vessels and vessels operated under MSC. This requires in-water surveys of vessels at multiple time intervals, since biofouling changes through time. Particular attention should be given to “niche” areas (such as sea chests, rudder hinges, intakes, propeller, bilge keels, thrusters, and dry-dock block areas), as these are known to be areas of high-density and diversity. It is also important to include in this evaluation the different types of vessels, operating modes, routes and tempos; all of these characteristics affect biofouling. It may be possible to utilize existing U.S. Navy protocols, or augment these in some fashion, but this should be evaluated to confirm resulting data can address biosecurity dimensions. It should be noted that a small percent cover over much of the vessel can result in a large total number of organisms for the entire vessels, and especially if high-density niche areas are present.

13. Track and evaluate changes in vessel traffic patterns and operations (including vessel types, geographic regions visited, port residence times, and speed) for all types of DoD and U.S. Navy vessels operating in Micronesia, including amphibious vessels and vessels operated under MSC. Variation in vessel traffic patterns and operations affects the quantity and species composition of biofouling organisms and therefore invasion risks (Chapters 2 and 5). While the U.S. Navy collects some of this information on vessel movements and tempo, this is used for a different purpose than biosecurity assessment, and some of these data have not been accessible for this report. An analysis of biofouling on current vessels is proposed in Recommendation # 12 for current military vessel traffic, but this does not evaluate potential future changes in vessel types and behaviors. A system for anticipating and tracking shifts in traffic could serve as an “early-warning” mechanism and trigger an explicit evaluation (as outlined in Recommendation #12; see also next section) for novel types of vessels or vessel operations for the Micronesia region.

Although the DoD must know the voyage histories and other operational details of its vessels, we were not given this information (except for MSC records) and therefore cannot evaluate what exists. However, it appears that a mechanism for ready access and integration of these data across different commands may not exist. Even within a command, there may be missing data for voyage histories, as was found for vessels under MSC. Having an efficient system for access to vessel data, both within and across commands, is necessary to implement Recommendations #12 and #13.

Although we are considering the use of these data for marine biosecurity purposes, such an information resource would no doubt have many other applications within DoD.

It should be noted throughout this discussion on vessel traffic data that no assumptions are made about who would have access to this information. It is understood that security concerns exist for some types of vessels. However, this does not preclude developing an efficient system for vessel information key to biosecurity analysis, and implementation of such an analysis, by DoD or its designees that avoids disclosure of sensitive information.

6.4.3.2 Vector Disruption.

The U.S. Navy has guidelines for management of biofouling to sustain operational performance of vessels (Naval Ships Technical Manual 2006), but it does not have specific guidelines or standards that aim to address the separate biosecurity concerns with biofouling. As noted previously, existing guidelines for both inspections and hull husbandry apply clearly to vessels owned by the U.S. Navy, but there appears to be uncertainty or ambiguity about their application to private vessels operated under MSC, including some prepositioned ships (Chapter 2). In addition, it appears that specific husbandry guidelines or requirements may not exist for the movement of decommissioned DoD vessels or the operation of vessels by DoD contractors (e.g., movement of barges and dredges).

Biosecurity standards for biofouling on commercial vessels are now emerging at the state, country, and international levels (Chapter 2). There is still some uncertainty about acceptable levels of biofouling and also the application of tools (e.g., in-water cleaning and various coatings) to achieve particular standards. Despite some uncertainty about the specific standards, there is nonetheless broad consensus (both in the scientific literature and among advancing standards) that heavily fouled vessels represent a high and undesirable level of marine invasion risk. Thus, a clear priority for vector disruption is in preventing the movement of heavily fouled ships, which carry high abundances of organisms and possibly high diversity.

To reduce the transfer and invasion risk of organisms associated with ship biofouling, we recommend DoD take the following steps:

14. Establish specific biosecurity criteria (requirements) for acceptable levels of hull biofouling for all types of DoD and U.S. Navy vessels, including amphibious vessels and vessels operated under MSC. These criteria should consider and draw upon existing guidelines that have emerged recently in other regions (see Chapter 2). In addition, the biosecurity criteria for biofouling should be included in the Naval Ships Technical Manual (2006) or similar document for application within the U.S. Navy and other branches of the military.

15. Extend DoD biosecurity requirements for acceptable levels of hull biofouling (Recommendation #14) to include vessels under contract to any branch of the U.S. military, such as barges, dredges, and other vessels. Separate outreach and implementation tools should be considered for contract vessels and contractors, compared to those military-owned or operated vessels (see 6.4.3.3).

16. As the highest priority: Implement (a) inspection of vessels operated under DoD with high biofouling potential, due to extended periods of lay ups or port residence times, and (b) cleaning for those that are heavily fouled prior to their movement into, out of, or within Micronesia. This is singled out as the highest priority for immediate action for both military and non-military vessels, as components of Recommendations #14 and #15, because movements of these vessels pose a high risk of invasions. Of great concern are prepositioned ships, barges, dredges, decommissioned vessels, and any other vessels that have extended residence times. To implement this recommendation, residence time (weeks to months) in a port or location should serve as the trigger for such action. While we do not provide a specific model of implementation we note that several options could be considered. The U.S. Navy has an existing program for inspection of vessels, which may serve this purpose for Navy-owned and operated vessels. In addition, the state of California is proposing that commercial operators provide documentation of hull biofouling surveys and cleaning (if needed), at regular intervals and more frequently for vessels with extended residence times; some variation of this approach could also be used for DoD vessels.

17. Review and establish criteria for in-water cleaning methods that do not pose a risk of spreading or releasing non-native organisms (which do not presently occur) in surrounding waters. The results of this effort should be included in the Naval Ships Technical Manual (2006) or similar document for application within the U.S. Navy and other branches of the military.

6.4.3.3 Efficacy.

As outlined for ballast water in a previous section (6.4.1.3), assessing short-term efficacy of management (prevention) for biofouling transfers focuses on the extent to which biosecurity measures are met. To assess and improve efficacy, we recommend that DoD take the following steps:

18. Assess the extent to which vessels operating in Micronesia under DoD achieve acceptable levels of biofouling, as outlined in Recommendations #14-16. This assessment should include estimates (of percent vessels that meet desired biofouling criteria, as above) according to vessel type, allowing adaptive management to be targeted to address specific issues. The data for this analysis could be a component of Recommendation #12 and #16 (above), if implemented. Additional inspections may be desired, especially where data are insufficient and to ground-truth data for commercial operators. The assessment for this recommendation may need to be done at regular intervals, especially if and when (a) compliance with existing requirements is low, (b) biofouling levels change through time on each vessel, and (c) traffic patterns, vessel types, or vessel behaviors change.

19. Implement targeted outreach and administrative tools to increase compliance with biofouling requirements in Micronesia (see Recommendations #12-16) for military and non-military vessels associated with DoD. This applies primarily to commercial and contracted vessels (including barges, MSC, and other cargo vessels) that operate under contract to the Navy, or MSC, as well as all other vessels that arrive to U.S. Navy or other DoD facilities. For example, requirements could be explained in educational materials and also could be specified in contract agreements. Such a program would apply to U.S. Navy vessels only as needed, if compliance is low or requirements change (see Recommendation #8).

In addition to these short-term measures of efficacy, there is also a need to assess the extent to which new invasions continue to occur, for which biofouling is a possible vector. The recommended action for this was outlined previously, as Recommendation #10, which was intended to encompass and serve equally to the needs for ballast water, hull biofouling, and many other vectors.

Another potential longer-term approach to assess efficacy (and invasion risk) is in modeling the capacity of organisms associated with biofouling (or other vectors) to colonize environmental conditions present in Micronesia. Since it is likely that some organisms that arrive to Micronesia are not able to survive local conditions, such an approach could refine a risk analysis, removing from further consideration those species that are not able to colonize. Although this is theoretically possible, the necessary data to construct these models are very limited for many species (see Chapter 5), although such studies may be feasible for better-documented taxa, such as marine macroalgae. Perhaps more problematic, the potential number of species being moved on ships in particular is vast, and any modeling would require an extensive program of sampling and taxonomic identification, in addition to knowledge about the organisms' tolerances. This approach certainly has some merits, especially for targeted and limited groups of species, but it also has clear constraints in the scope and speed with which it could be applied from a vector management perspective.

Finally, any specific responses to low compliance or performance of vessels to meet specific criteria for husbandry have not been addressed here, as this is beyond the scope of our analysis and requires consideration of the various institutional tools and approaches available to DoD. However, two different types of responses may be considered here. The first is approaches and tools to increase compliance in the future. The second is a short-term response plan to a breach in biosecurity. For example, if a vessel arrives that is heavily fouled, and may even intend to stay in port for a prolonged period of time, what is the response by DoD? The same question is relevant for vessels expected to discharge untreated ballast water. We recommend that DoD develop a response plan for such breaches in biosecurity, and this may benefit from coordination with other federal and state agencies; this recommendation for such a coordinated response plan is included in a subsequent section.

6.4.4 Commercial Vessels: (A) Ballast Water

Outside of U.S. jurisdictions, there are no existing requirements for ballast water management or reporting by commercial vessels that apply broadly to Micronesia. While a few countries have considered or developed guidelines, it is not clear the extent to which industry (a) knows these exist or (b) follows them. In general, there is a paucity of regional data for vector analysis or to evaluate the extent of vector disruption (ballast water treatment).

While it appears likely that the international treaty (convention) passed by the IMO will come into force in the near future, requiring the global fleet of commercial ships to treat their ballast water before discharge, it is also the case that most countries in Micronesia do not have a program to assess compliance with such ballast water treatment requirements. Thus, outside of U.S.

jurisdictions (which fall under USCG and the Environmental Protection Agency oversight), there is presently no mechanism to enforce or measure efficacy of any international standards for countries throughout the entire region of Micronesia. This gap is largely a lack of capacity, in terms of personnel, training, and supporting data infrastructure. In addition, even if the capacity were to exist, there may also be the need in some countries to legally authorize a lead agency to implement oversight of ballast water management for arriving vessels.

We recommend the following steps for ballast water management of commercial vessels arriving to countries throughout Micronesia:

20. Establish ballast water management and reporting requirements for all commercial vessels (including cargo ships, cruise ships, passenger ships, barges, and any other vessel that can carry ballast water) that operate in Micronesia. While international requirements for ballast management may occur if the IMO requirements are imposed on global shipping, separate regional action may also have advantages, in timeliness or addressing gaps that may exist regionally with IMO requirements. Regardless of the specific requirements implemented, there are currently no reporting systems in place for ballast water management in Micronesia, outside of U.S. jurisdictions, limiting any ability to assess compliance or efficacy of management for this vector. While individual countries could implement this recommendation, a coordinated and consistent regional approach is most desirable, for consistency and efficiency. It may also make sense to establish one regional program for implementation (see Recommendation #21), with participation from member countries.

21. Develop the capacity (personnel, training, and data management infrastructure) to evaluate ballast water management reporting and compliance by commercial vessels that operate in Micronesia. Ideally, this would be an integrated regional program with participation from member countries, because this approach would provide consistency and also economy of scale, especially for data management and analysis. There are many models for structure of such a program, including central coordination and distributed agents in member countries, and participating countries should agree on most desirable and functional model.

22. Review and revise (as needed) legal authority to implement ballast water management program for commercial ships operating in Micronesia, as outlined in Recommendations #20-21. This review should address authority to require reporting, implement inspections of vessels, and any enforcement tools desired in Micronesia.

23. Implement targeted outreach to inform the shipping industry, ports, and resource management agencies of ballast water management requirements (see Recommendations #20) for commercial ships operating in Micronesia. As outlined in previous recommendations, a key component of outreach is regional coordination across the participating countries to provide a concerted and consistent message. A regional program for outreach should be considered, to achieve this outcome as well as economy of scale. If ballast water reporting is required (see Recommendation #20), this could use a web-based reporting system, which could also include a web-based information system on ballast water management requirements for the region.

6.4.5 Commercial Vessels (B) Biofouling

There are presently no requirements for management of biofouling on commercial vessels for biosecurity purposes in Micronesia. When considering a vector management framework, little information is presently available to assess hull husbandry practices or associated biota for vessels that operate in Micronesia. Yet, biofouling is responsible for a relatively large proportion of invasions on a global scale, and it appears to pose significant invasion risks to Micronesia (see Chapters 2 and 5).

Several jurisdictions around the world have voluntary guidelines for hull fouling management, and some of these are moving toward regulations to establish minimum frequency of hull inspection and treatment (e.g., dry-docking, coatings, cleaning). For example, California now requires commercial vessels operating in state waters to submit a Hull Husbandry Reporting Form once a year, as one step to assess potential biofouling based on hull husbandry and operations (especially extended residence periods in port), and has proposed regulations for permissible levels of biofouling.

For some regions, the types of approaches being considered or advanced to identify and treat vessels with potentially high biofouling levels include:

1. Ships agents/captains of vessels must maintain and submit records of anti-fouling measures and recent lay-ups to the harbor staff prior to arrival.
2. Vessels with extended lay-ups must provide evidence of inspection and (if necessary) hull cleaning, to meet acceptable levels of biofouling.
3. Any vessel which cannot present such records must remain in a quarantine area in water greater than 200 meters, in which remote video inspections could be done on the hull of vessels before entry into port is allowed.
4. Harbor staff or other designated enforcement agency staff have the authority to inspect vessels and require out of water cleaning (where possible) and/or refuse entry to heavily fouled vessels.
5. The harbor or other designated enforcement agency retains the right to clean the vessel at the owner’s expense (either in dry-dock or with methods that minimize release of organisms to local waters) if it is heavily fouled and/or fouled with species determined to be potentially detrimental to the region.

In general, we recommend that the region develop a similar approach and take the following steps:

24. Establish biosecurity criteria (requirements) for acceptable levels of hull biofouling for all commercial vessels (including cargo ships, cruise ships, passenger ships, barges, dredges, fishing vessels, and other vessel types) that operate in Micronesia. These criteria should consider and draw upon existing guidelines that have emerged recently in other regions (as above; see also Chapter 2).

25. Establish reporting requirements on hull husbandry practices and operational characteristics for commercial vessels (including cargo ships, cruise ships, passenger ships, barges, dredges, fishing vessels, and other vessel types) that operate in Micronesia. Vessels should submit husbandry and operational profile in advance of arrival, and at a minimum frequency (e.g., annually) if in routine operation. If a vessel has a long port residence time or lay up (weeks to months), a new submission should be required.

26. Establish requirements for routine inspection and certification of biofouling levels for any commercial vessel that operates in Micronesia with a long port residence time or lay-up. Of great concern are barges, dredges, decommissioned vessels, and any other vessels that have extended residence times, because these are prone to heavy biofouling levels. To implement this recommendation, residence time (weeks to months) in a port or location should serve as the trigger for such action. As one model to consider, the state of California is proposing that commercial operators provide documentation of hull biofouling surveys and cleaning (if needed to meet acceptable levels of biofouling).

27. Review and establish criteria for in-water cleaning methods for commercial vessels that do not pose a risk of spreading or releasing non-native organisms (which do not presently occur) in surrounding waters. In-water cleaning is currently used and is likely to continue as an important management strategy to reduce biofouling on vessels, and there is a need for specific guidelines and protocols aimed specifically at reducing the associated invasion risks. Such guidance is not available in Micronesia.

28. Develop the capacity to (a) assess the extent to which commercial vessels operating in Micronesia achieve acceptable levels of biofouling (see Recommendations #24), and (b) respond to high-risk commercial vessels (i.e., those with high biofouling) that arrive to a port in Micronesia. The first component requires establishing methods (i.e., protocols for hull biofouling assessment), training, personnel, and data management infrastructure to conduct an independent assessment of vector management efficacy at some interval and stratifies (distributes) measures according to vessel type. This may be repeated if and when traffic patterns, vessel types, or vessel behaviors change. The second component requires development of a response plan to unexpected events, in terms of who responds and the specific details or options for response; the need for response plans has broader application across many vectors, as well as response to new invasions, and is discussed in a subsequent section.

29. Review and revise (as needed) legal authority to implement biofouling management program for commercial ships operating in Micronesia (see Recommendation #24-26). This review should address authority to require reporting, implement inspections of vessels, and any enforcement tools desired in Micronesia.

30. Implement targeted outreach to inform the shipping industry, ports, and resource management agencies of biofouling management requirements (see Recommendations #24-26) for commercial ships operating in Micronesia. As outlined in previous recommendations, a key component of outreach is regional coordination across the participating countries to provide a concerted and consistent message.

In addition to measures focusing on incoming vessels, we agree with the recommendations of SRIMP-PAC (South Pacific Regional Environment Programme 2006) that countries should act to ensure that outgoing vessels, particularly those that have been in port for longer than a few days, are not departing with high levels of biofouling. Thus, the above recommendations focus on all operating vessels and are not restricted to just arriving vessels. In this context, relevant authorities may assess vessels prior to arrival or departure and determine that particular actions are required. An ideal long-term goal may be for increasingly broad-based programs, where countries in Micronesia work with SRIMP-PAC and SPREP to encourage Pacific Rim and other importing countries to develop uniform clean hull standards.

6.4.6 Fishing Vessels

As with other types of commercial and private vessels, there are no marine biosecurity requirements for fishing vessels that operate in Micronesia, except those that may apply to ballast water discharge (see above and Chapter 2). Fishing vessels vary in size, type, and operations, including the extent to which they visit ports. While this may present some challenges in implementation of vector management (including reporting, assessment, and outreach) for these vessels, they are considered here as a type of commercial vessel. **The same recommendations for biosecurity practices on commercial ships, above, apply to commercial fishing vessels that operate in Micronesia**. Those recommendations that focus on biofouling have the most relevance in this regard, as many fishing vessels do not carry ballast water.

In addition to movement of organisms on ships' hulls and ballast water, fishing vessels may transfer live marine organisms in storage tanks (live tanks, storage holds, and wells) and on fishing nets and gear. In many cases, these may not be the fisheries species but incidental associated organisms, which can be small in size and not immediately evident. The extent to which this occurs in Micronesia is not clear, as detailed information is currently not available for the region.

Finally, fishing vessels that are seized and held in port (due to fishing or other violations) may pose an added risk of species introductions, if they are heavily fouled (see Chapter 3). Although a biosecurity program should reduce the occurrence of heavily fouled vessels in the region, it is nonetheless imperative to treat impounded vessels with an added level of scrutiny.

For fishing vessels, we recommend application of the previously outlined recommendations for commercial ships as well as the following:

31. Establish biosecurity practices and requirements for fishing vessels that operate in Micronesia to prevent the release of viable organisms associated with flushing of tanks (live tanks, storage holds, and wells) or cleaning of fishing gear. This should consider (a) the potential use of on-shore facilities for disposal of biological waste and (b) distance from shore (or ports) as a strategy to reduce likelihood of invasions.

32. Implement inspections of any impounded vessel in Micronesia to (a) assess level of hull biofouling and (b) treat vessels (if needed) to reduce biofouling to acceptable level. This recommendation requires specific protocols and capacity, which are addressed in Recommendations #24-29.

33. Implement targeted outreach to inform the fishing industry, ports, and resource management agencies of biofouling management requirements for fishing vessels operating in Micronesia. While this may overlap somewhat with previous outreach recommendations for other types of commercial vessels, it is also important to recognize that this is a unique segment of the vessel traffic. Moreover, outreach for other vessels would not include guidelines for impounded vessels, fishing gear, or unique holding tanks on fishing vessels. Making outreach materials available in multiple languages may be especially important for this segment of the vessel traffic.

6.4.7 Recreational Boats and Yachts

There are no biosecurity guidelines or requirements for hull biofouling associated with recreational vessels that arrive to or operate in Micronesia. Even though some recreational vessels can be heavily fouled, including transient vessels that travel great distances, a lack of biosecurity measures is not unusual for most global regions. However, some programs do exist in some countries to address this gap.

New Zealand has voluntary guidelines for recreational boaters, which are expected to become mandatory shortly. Boaters arriving to New Zealand are asked to arrive with clean hulls, having applied antifouling paint within 1 year of arrival, and to keep logs and records of anti-fouling measures to present to biosecurity agents. These agents inspect a boat's records and carry out hull inspections at ports of first entry into the country. They can also direct boat owners of heavily fouled boats to cleaning facilities where boats are cleaned at the owner's expense.

In Australia's Northern Territory, concern for marine pests (invasions) has led to requirements for recreational vessels entering ports in the Darwin area. Boat owners are being asked to either 1) demonstrate that their boats have been cleaned or painted with antifouling paint in Australia, or 2) undergo a hull inspection and cleaning of internal seawater systems. The cost of inspection and seawater-system cleaning is borne by local government. Both overseas arrivals and boats that have visited other ports in Australia are subject to these inspections.

To reduce risks of species transfers associated with recreational vessels and yachts, we recommend the following steps:

34. Establish biosecurity practices and requirements for recreational vessels that operate in Micronesia to reduce the transfer of biofouling organisms. As the number of recreational vessel arrivals to ports in Micronesia is relatively low, it is feasible to require that all arriving boaters present evidence of anti-fouling measures to port authorities and customs. This paperwork should be reviewed by harbor staff or other management agency prior to a boat's arrival and assessment made of whether a hull inspection is appropriate.

35. Establish the capacity to inspect and treat (if necessary) recreational vessels that operate in Micronesia to reduce associated biofouling to an acceptable level. This recommendation requires identification of acceptable levels of biofouling, methods of assessment (inspection) and treatment, and personnel (with training and authority) to implement. Several risk matrices exist for recreational boats. The matrix developed for the state of Hawai'i (Leonard 2009) should be reviewed and considered for application in Micronesia.

Finally, the Port of Guam master plan suggests that the haul out facility at Perez Marina might not be needed and recommends instead building an inspection, maintenance and repair facility at the Harbor of Refuge. If this occurs, it may have relevance and potential application for biosecurity measures outlined above.

6.4.8 Kayaks, Outriggers and Personal Watercraft

The use of small, personal watercraft can potentially result in transfers of marine organisms. Although the potential magnitude (numbers) of organisms moved may be relatively small via this vector, such transfers can result in new invasions and spread of organisms. Although the current analysis focuses on marine organisms, the potential importance of this mechanism is demonstrated by overland transport of zebra mussels on small craft in North America.

We recommend that the following step be taken:

36. Implement a targeted outreach program for DoD and civilian populations with specific guidelines on methods to minimize species transfers associated with small boats, jet skis, and other water sports gear being moved into or within Micronesia. DoD, Customs, and other agencies could provide DoD personnel, visitors, marinas, and sports shops with a checklist of gear/equipment for use in water that outlines simple, appropriate biosecurity practices. This could be extended to include SCUBA diving, snorkeling, and recreational fishing (see Recommendation # 42).

6.4.9 Amphibious Vehicles

Although protocols exist for removing biota from amphibious vehicles, we were not able to obtain data or locate any reports that assess the efficacy of current protocols in Micronesia, including (a) the extent to which protocols are implemented, (b) the efficacy in removing marine biota, and (c) what residual organisms may exist.

We recommend that DoD take the following approach for biosecurity surrounding amphibious vessels:

37. Assess efficacy of biosecurity protocols and revise (as needed) for DoD amphibious vehicles operating in Micronesia. In general, amphibious vehicles and any in-water gear and equipment that is moved into or within Micronesia should be decontaminated before departure from a location or before redeployment in water elsewhere. If the latter, vehicles and gear should be cleaned onshore, such that all biological material, sediment and wastewater is retained and disposed of properly, to prevent release of biota (including small organisms and resting stages) to waterways in the country or state of entry.

6.4.10 Grounded Vessels

As with impounded vessels, invasion risks may increase for grounded vessels, due to increased residence time for any organisms associated with the vessels' hulls and underwater surfaces. Based on Harbor Rules and Regulations of the Port Authority of Guam (2000), it would appear that the Guam Port Authority has the authority to remove sunken or abandoned vessels on Guam at the owner's expense. However, jurisdiction, response plans, and mechanisms for implementation of desired actions surrounding grounded or abandoned vessels are not so clear in many parts of Micronesia.

From a biosecurity perspective, any response plan should include an assessment of possible biofouling organisms and whether this poses particular risks of invasion, in addition to any concerns about other impact to the local environment and navigation.

We recommend the following step be taken:

38. Clarify and establish for grounded and abandoned vessels in the various jurisdictions of Micronesia: (a) which agency has the legal authority for removal of grounded and/or abandoned vessels, (b) a response plan that includes assessment and removal of non-native species present, and (c) mechanisms (including funding and training) for implementation.

6.4.11 Other In-Water Structures, Equipment, or Gear

Any objects or surfaces exposed to marine waters can be colonized by marine (biofouling) organisms, and their movement from one location to another poses a risk of non-native species transfer and invasion. In addition to vessels, examples of other in-water structures, equipment, and gear that are moved commonly among locations include:

- Fish aggregating devices (FADs), which are objects deployed for long periods of time to attract fish, including vessels, buoys, and other floating objects.
- Dry-docks.
- Floating docks or pontoons, such as those in marinas.
- Fixed maritime structures, which are sometimes constructed elsewhere from new material or refurbished materials, are held in-water at other locations (including overseas) before transport and deployment.
- Mobile platforms, drilling rigs, and related equipment, such as used for oil and natural gas drilling/exploration.
- Buoys and channel markers.
- Scientific equipment.

All of these particular structures often have extended in-water residence times in one location before movement (if it occurs) to another location. In fact, many of these structures are known to accumulate dense aggregations of biofouling organisms, and examples exist in the published literature that document the movement of these structures (and sometimes very dense biofouling) among locations without any treatment. Importantly, this movement can occur across large geographic distances, introducing novel non-native biota.

At the present time, there are no biosecurity requirements for the movement of these and other similar structures into or within Micronesia. This represents an important gap in preventing non-native species transfers. Even though the frequency of moving these structures may be low, such rare events have the potential to represent high-density inoculations of marine organisms in the absence of any assessment and management action (where needed to reduce such transfers).

We recommend the following steps be taken:

39. Establish biosecurity practices and requirements for the movement of any in-water structure (including FADs, dry-docks, floating docks, fixed structures, mobile platforms and drilling rigs, buoys and channel markers) to reduce the transfer of biofouling organisms into or within Micronesia. This recommendation includes establishment of acceptable levels of biofouling and also the legal authority to implement these practices in the various jurisdictions.

40. Establish the capacity to inspect and treat (if necessary) in-water structures that are being moved into or within Micronesia to reduce associated biofouling to an acceptable level. This recommendation requires specifying methods of assessment (inspection) and treatment, a lead agency with authority, and personnel (with appropriate training) to implement.

Because the movement of some types of in-water structures by DoD has occurred historically, and may occur in the future, this recommendation applies to both DoD and the various countries of Micronesia, understanding that the particular assets or structures may differ among jurisdictions.

6.4.12 Construction Materials

Movement of construction materials can transfer associated marine organisms, especially when materials are moved directly from one in-water or shore location to another. Examples of construction materials that are commonly moved from one geographic source location for application or disposal at another, which can transfer organisms, include: sand, gravel, rock, coral rubble, and dredge spoils. Even a brief holding period (days to weeks) out of water may not prevent biotic transfers associated with construction materials, because some organisms (and their resting stages) can persist out of water for long periods, especially under damp conditions. We recommend the following biosecurity measure:

41. Establish biosecurity practices and requirements for the movement of any construction materials that are sourced from marine waters and shores (including sand, gravel, rock, coral rubble, and dredge spoils) to reduce the transfer of marine organisms into or within Micronesia. This should include consideration of sources, treatment (including extended holding periods on land), and certification or inspection to confirm implementation.

This recommendation applies to both DoD and the various countries of Micronesia, as construction and construction materials are used by all entities.

6.4.13 Diving and Recreational Fishing Gear

Movement of diving gear and recreational fishing gear has the potential to transfer non-native marine organisms among locations, even though in-water exposure is episodic relative to structures and vessels (above). Invasions appear to have resulted from this mechanism, including invasions by zebra mussels in isolated quarries used for diving in the eastern U.S. (http://www.dgif.virginia.gov/wildlife/zebramussels.asp).

To minimize the transfer of organisms, we recommend the following step:

42. Implement a targeted outreach program for DoD and civilian populations with specific guidelines on methods to minimize species transfers associated with diving gear (whether work or recreational) and fishing gear being moved into or within Micronesia. DoD, Customs, and other agencies could provide DoD personnel, visitors, sports shops, and marinas with a checklist of gear/equipment for use in water that outlines simple, appropriate biosecurity practices. This could be extended to and coordinated with a similar effort for recreational small water craft (see Recommendation # 36).

6.4.14 Live Trade of Marine Organisms

It is evident that live trade, or the moving of live marine organisms, is common practice around the world, especially associated with aquaculture, food, bait, and pets (aquaria). Micronesia is no different in this regard. While there are some current biosecurity measures focused on live imports and aquaculture throughout the region, there are also inconsistencies and some gaps, and no overarching framework has emerged to date.

The International Council for the Exploration of the Sea (ICES), established in 1973, has developed a code of practice for reducing the negative impacts of non-native species associated with aquaculture and fisheries enhancement. This code, which is being promoted by the Food and Agriculture Organization (FAO), the IUCN, the Convention on Biological Diversity (CBD), and other international organizations, has since been revised several times. The current version (International Council for the Exploration of the Sea 2005) also covers organisms imported live for other purposes, such as food and bait, and includes practices to reduce the spread of disease and exotic genetic material.

ICES asks member countries considering new introductions to submit a detailed prospectus, including a risk assessment, to ICES for comment. Following an approval, countries are asked to adhere to a set of management guidelines for that species and to submit follow up reports to ICES. This process is largely advisory in nature, with implementation up to the countries involved, as ICES does not have regulatory oversight for participating countries.

Detailed guidelines for implementing the code are provided in three ICES documents (International Council for the Exploration of the Sea 1984, 1988, 2005). Appendices in these documents detail the preparation of the prospectus, risk assessment, quarantine procedures and monitoring.

Guidelines for species introductions for aquaculture were also developed and adopted by the FAO. These are outlined in two technical reports (Food and Agriculture Organization 1995,1996). The FAO advocates for the use of local species when production strategies are known and feasible; and it recommends the introduction of exotic species when the positive benefits are higher than possible negative impacts, always applying the precautionary approach when there are big information gaps. Taking the stance that all imported species will eventually escape the confines of their facility, the FAO recommends that risk assessments should be based on the assumption that these constitute introductions into the wild. Thus, the guidelines recommend that if a species is approved for importation, a contingency plan for dealing with escape and mitigation of impacts ought to also be in place, and that the importing country should establish the legal framework for funding for such plans (Food and Agriculture Organization 1995).

The Secretariat for the Convention on Biological Diversity (CBD, 2004) has also published a series of recommendations for the development of sustainable mariculture. Like the FAO, the CBD recommends the use of endemic or native species in mariculture, and whenever possible, of culturing in contained facilities, rather than in open pens.

Finally, as noted previously, guidelines for evaluation of diseases and quarantine measures of aquaculture species have been recommended by SPC (Humphries 1995; see Section 6.2.2 above).

In general, we recommend that Micronesian countries and territories adopt the protocols and approaches outlined by ICES, FAO, CBD, and SPC. While some of these protocols are for a particular segment of live trade (e.g., aquaculture), their application should be considered more broadly to include all movement of all live marine organisms intended for the aquarium or pet trade, bait, scientific research or any other purpose that could result in the organism being released into the environment.

We recommend that the following steps to taken:

43. Establish explicit aquaculture biosecurity practices for Micronesia. This includes identification and adoption of specific protocols for risk assessment (see Recommendation #44, below), screening of pathogens, quarantine, inspection, and regional program oversight or assessment. A key dimension requires coordination and active involvement of relevant agencies and groups such as resources development, community colleges and invasive species management organizations. National, state, local/traditional governing bodies need to specify (and perhaps authorize) lead agencies and also oversight authority.

44. Establish a formal risk assessment process for all marine organisms used or proposed for live trade in Micronesia. The risk assessment should be science-based and applied consistently; the precautionary principle should be applied in cases where data are absent. Many references and toolkits for the development of risk assessment are available (i.e., International Council for the Exploration of the Sea 2005; Secretariat of the Convention on Biological Diversity 2010). Forums for sharing data relevant to risk assessment across the region should be developed. Risk assessments should be carried out for species already in trade or on already-developed “white lists.”

45. Create quarantine facilities for marine organisms for use in Micronesia. This may be a single regional facility or multiple facilities; if the latter, consideration should be given to having at least one facility with high-level technical capability and infrastructure. The facilities should follow specific, accepted protocols (see Recommendation # 43). The facility must have trained staff to carry out protocols, and must be sited in a secure location to minimize risks of accidental releases due to natural disasters such as typhoons, tsunamis, and floods.

46. Improve reporting and screening systems for import of live marine organisms in Micronesia. Ideally, prior to import, organisms would be identified to species and certified as free of disease or associated by-catch organisms (such as additional species of invertebrates). Reporting or labeling for shipments would facilitate and improve biosecurity screening and reduce unwanted imports.

47. Provide quarantine agents in Micronesia with the necessary legal authority, training, and support to enforce requirements at border entry and post-border locations (e.g., aquaculture facilities and sales outlets). Capacity building and institutional strengthening of quarantine officers and agencies on aquatic biosecurity measures and aquatic animal health will be crucial for biosecurity management. There is currently a large knowledge gap on aquatic biosecurity within the agencies that will be tasked with implementing biosecurity measures.

Although Micronesia is a large and diverse region, with many cultures and jurisdictions, the recommendations for biosecurity practices of live trade apply throughout the region. Advancing a uniform and consistent approach to biosecurity throughout the region is most desirable, because it would likely reduce the effort and cost and would serve to increase clarity and possibly compliance, compared to an uneven patchwork of requirements and guidelines. Thus, communication, coordination, and participation among all member countries and jurisdictions in Micronesia is a critical approach toward this outcome.

6.5 Detection of Marine Invasions: Recommendations

Detection plays a vital role in implementing an effective biosecurity program. First, detection is used in vector management to assess (a) the extent to which new invasions are occurring and (b) the vector(s) responsible for these invasions. Repeated measures over time assess the efficacy of vector management to prevent new invasions, providing a core component of the vector management framework discussed above (Section 6.3; see also Figure 6.1). Second, the detection or occurrence of non-native species, and their geographic distribution, forms the basis for responses to new incursions, including eradication, control, or containment. Put simply, without knowledge of existing invasions no such post-border responses are possible.

Field-based surveys are required for both applications of detection. Moreover, it is critical that surveys are conducted using standardized and quantitative measurements that are repeated over time, if a goal is to understand temporal changes in non-native species diversity (number) at a site associated with particular vectors. It is clearly possible to detect species occurrences with many methods, but we suggest that assessing differences in time or space requires a formal, statistical approach (Ruiz and Hewitt 2002; Ruiz and Carlton 2003).

The design of field-based surveys should be driven by the particular objectives. Some of the key variables to consider include taxonomic focus, habitat focus, frequency, geographic scope, and specific methods. Methods include not only those surrounding the collection and analysis of biotic samples, but also issues of data and sample management or continuity (see Ruiz and Hewitt 2002 for discussion), especially if an objective is to provide comparisons with long-term measures, which engage different people (with staff turnover) through time. In addition, the use of genetic tools is a valuable component of surveys, providing (a) independent verification of taxonomic identification and (b) new methods to efficiently screen large numbers of species, using next generation sequencing /NGS (Hayes et al. 2005; Darling and Blum 2007; see National Research Council 2011 for brief discussion). However, prior to embarking on massive environmental sequencing using NGS technologies, it will be necessary to build a DNA barcode library for the fauna and flora of the region. This will allow identification of environmental sequences obtained through NGS. One way to achieve this may be to undertake molecular-assisted alpha taxonomic studies (i.e., DNA barcoding-assisted taxonomic studies), which would provide rapid, standardized, quantitative, and reproducible results, particularly for insufficiently studied biota characterized by cryptic species (which is the case for almost all marine benthic taxa). The costs of DNA sequencing are rapidly going down, so in the near future this may be the most cost-efficient, as well as time-efficient, manner to undertake field-based surveys.

We recommended previously that a program of field based surveys be implemented in Micronesia, in part to assess vector management by DoD associated with vessels' ballast water and hull biofouling. Recommendation #10 states: "**Implement a program of field-based surveys in Micronesia, including but not limited to Apra Harbor, to (a) assess efficacy of vector management practices to prevent invasions and (b) provide detection capability for response(s) to new incursions that occur."**

Here, further detail is provided to design and implement such a program, with a particular focus on these shipping vectors. While this is relevant to DoD activities and associated biosecurity, such a program also has relevance to commercial shipping in Guam and other regions of Micronesia.

We recommend the following steps be taken to advance a program of field-based surveys in Recommendation #10:

48. Develop a specific design for standardized, quantitative, and repeated field-based surveys for detection of non-native marine species in Apra Harbor, Guam, especially to examine species invasions through time associated with DoD and commercial vessels. We recommend that DoD assume a lead role in developing the design of these surveys, as well as their implementation (Recommendation #10), working in close partnership with (a) other federal and local agencies in Guam and (b) other countries and jurisdictions in Micronesia (see below). Surveys should focus on invasions due to shipping, because it is a dominant vector for marine invasions. In addition, an initial focus should be on Guam, because it is a regional hub for shipping in Micronesia (see Chapter 3). The design should explicitly define the taxonomic focus, habitat focus, methods for collection and analysis, frequency of sampling, and study duration to detect changes in non-native species diversity (i.e., new invasions) attributed to ships ballast water and biofouling through time. As noted above, these data examine the efficacy of vector management to prevent new invasions.

49. Develop a specific design for standardized and quantitative field-based surveys to compare non-native marine species present in Apra Harbor to other bays and ports in Micronesia, focusing particular attention to species invasions associated with vessels. We recommend that DoD also assume a lead role in developing and implementing these surveys. This is intended to examine geographic distribution of non- native species present in Guam (that resulted from transport by ships) and the extent of spread to other locations in the region. These data examine the efficacy of vector management to prevent the spread of invasions from Guam to other regions. Ideally, these surveys would be repeated over time, although perhaps at less frequent intervals than above (Recommendation #48). In addition to the broad-based surveys, a more focused and intensive approach could also be advanced for a few species, serving as important model systems or indicators to understand spread dynamics (risk) in the region.

The above recommendations address the need to rigorously assess the pattern and rate of invasions to support vector management, including especially efficacy of current prevention measures, but do not provide a mechanism for early detection. New invasions may certainly be detected at an early stage in such surveys, but these are not designed explicitly for the purpose of early detection. To implement early detection capability, there are two general types of approaches that are used:

- First, field-based measures are explicitly designed and used to detect selected species of concern, focusing on sites where incursions are likely. These are usually focused efforts for known species, allowing tailored protocols (such as those implemented for brown tree snakes) at key points of entry; the goal here is intensive and efficient measures, instead of broadly trying to achieve early detection for many species at once.

- Second, a public outreach effort and reporting system is established to encourage any new or suspected non-native species to be detected. These can be either focused efforts (and complementary to the first method) for particular species of concern, or very broad- based efforts to include many species, taxonomic groups, and habitats. This approach obviously benefits from many potential observers who may encounter non-native species, either due to search or accident, and it is clear than many new marine invasions are first detected by the public (e.g., Chinese mitten crabs along the eastern U.S., Ruiz et al. 2006).

To be useful and effective at early detection, both approaches require personnel time and resources. This is most obvious in the first approach. For the second approach, the actual detection effort is distributed broadly, which has clear advantages and perhaps little direct cost, but it is also important to recognize that personnel are required for coordination (including communication and outreach) as well as verification and tracking of reported sightings.

To develop early-detection capacity for marine invasions, we recommend the following step:

50. Design and implement a public reporting system for new or suspected non-native marine species in Micronesia, as a component of education and outreach efforts in the region. This system could be designed for focus on particular species of concern (see next section) or provide broad-based early detection capability. This system should include a permanent hotline number and website, allowing the general public to report suspected non-native species and also provide a portal for additional information on non- native marine species, current policies, and actions throughout Micronesia. This contact information should be included in public outreach/education materials. A specific lead agency should be designated and provided sufficient trained personnel to respond to inquiries from the public, as part of the overall biosecurity program infrastructure for Micronesia (see Section 6.7.3). This reporting system, and overall program, must obviously be designed and implemented as a partnership between DoD and other agencies and jurisdictions throughout Micronesia. Some information is already shared within and among countries on an informal basis, and this reporting system would serve to (a) build upon current efforts, (b)establish a stronger framework, and (c) contribute to a regional database on non-native species records.

Focused early detection efforts, using the first approach above with field surveys to detect target species of concern, are considered further as possible responses in the next section.

6.6 Response to Marine Invasions: Recommendations

Throughout this chapter, a premium is placed on steps to prevent new invasions, as the highest priority for marine biosecurity, but we also recognize that there will be breaches of this security, occurring either as (a) the delivery of non-native organisms associated with a particular vector or (b) the establishment, colonization, or occurrence of non-native organisms in the natural environment. In each case, it is appropriate and desirable to consider a response plan to limit undesired impacts or outcomes associated with a breach or incursion. Part of this plan is a clear decision process about when and how to respond, as well as who should respond.

In Section 6.4 on vector management, specific recommendations were outlined for assessing and detecting breaches in biosecurity, during the transfer (vector) stage. For a breach at the vector stage, such as the arrival of a vessel that exceeds an acceptable level of biofouling, these previous recommendations included the development of a response plan; this is intended to define specific response actions, how and when to implement them, who would implement them, and the necessary resources to implement them.

A similar response plan is needed for a new incursion and breach at the invasion (colonization) stage, serving to define first if a response is triggered and then the nature of the response. The decision of whether to respond to a new invasion is a complex one, as it depends upon many factors, including: (1) the potential consequences or impacts of the invasion; (2) the chances of success or feasibility of achieving a desired outcome; and (3) the capacity and available resources needed for action.

In recent years, several non-native marine species have been the focus of successful eradications, demonstrating the feasibility of such efforts to achieve the desired outcome (Culver and Kuris 2000; Bax et al. 2002; Miller et al. 2004; Anderson 2005; Hopkins et al. 2011). However, not all invasions are conducive to eradication (or control and containment), as the effort and likelihood of success depends greatly upon the organism, its areal extent and abundance, and particular treatment options (Myers et al. 2000; Crombie et al. 2008; Edwards and Leung 2009). Furthermore, the consequences of invasions will differ among species and locations, reflecting the type and magnitude of effects as well as the social values in a region (see Appendix A).

Ideally, a response plan for new incursions would begin with an analysis of costs, benefits, and feasibility of achieving a particular outcome or objective, before proceeding to implement specific actions. The initial part of this two-step process is important for setting priorities, because (a) it is simply not possible to implement actions for all invasions with limited resources nd (b) only a subset of non-native species will have high impacts. Unfortunately, the initial analysis step often requires data on the impacts of a species and the value assigned to those consequences (in addition to feasibility), which may not yet exist. Furthermore, where data on potential impacts are available, it is important to consider the level of uncertainty about how robust or relevant the data are for the region (Micronesia). Evaluating this information is thus central to establish an efficient response capability, and may guide the design of detection efforts (see Recommendation #50).

To develop a response plan for marine invasions, we recommend the following steps be taken:

51. Evaluate social, cultural, economic, and ecological values in Micronesian countries that may be impacted by invasions by non-native marine species. This follows and expands directly upon the pilot project (Appendix A) to adequately characterize core values at risk to invasions in the region, for inclusion broadly in decisions about management and response. The new survey must be statistically adequate, in order to begin to answer some of the questions raised in Appendix A.

52. Establish a watchlist of high-risk non-native marine species that are known or thought to pose significant ecological, economic, social, or cultural impacts to Micronesia, focusing on species that are not established or widely distributed in the region. This list should be developed by experts based upon evaluation of those species that (a) have known invasion histories (or unusual potential for invasion), (b) are thought to pose a high risk to core values, (c) are likely to survive regional environmental conditions, and (d) are likely to be transported by known vectors in operation in Micronesia. We recognize various methods could be used to evaluate these four criteria, from quantitative to qualitative, and given existing data limitations for all criteria and species, this is not a precise process. The resulting list is not intended to be comprehensive but serves to identify a list of potential high-impact species for possible management action, including detection (see previous section) and response. Although there is no specific target number of species for this list, limiting this to a small and manageable number has clear advantages for some applications, such as detection.

53. Develop a detection program and response plan for new incursions by a few focal non-native marine species on the watchlist of high-risk non-native marine species for Micronesia (see Recommendation #52). Species should be selected from the watchlist, based upon detection ability (due to size, morphological uniqueness, habitat distribution) and perceived severity of invasion consequences. The goal of this recommendation is to establish a demonstration project, using a few high-impact species to develop this response capacity and experience, instead of a program with comprehensive coverage. Ideally, the detection program would include focused surveys and a public reporting system (Recommendations #49-50), using these focal species as model system to develop these capabilities.

6.7 Implementation and Capacity: Priorities and Recommendations

This chapter is intended to provide recommendations for marine biosecurity and best management practices in Micronesia, addressing current gaps that exist across all sectors of activity (military, commercial, and private). This is a large scope for even one country, let alone for many countries that span such a broad range of cultures, activities, and geography. While we have addressed key areas of marine biosecurity in the region, there are no doubt some omissions, due to the scope of the endeavor and available time.

The effort to implement all of the proposed recommendations for Micronesia is extensive and may appear daunting, requiring considerable capacity that does not now exist. Although development of these recommendations is linked to the Guam Buildup, it is important to recognize that (a) these are core elements and objectives for a regional biosecurity plan and (b) the timeline for implementation of each recommendation is not yet specified. As indicated elsewhere in this report, the specific timeline and extent of implementation is obviously contingent upon available resources for this purpose. Defining the specific timeline, resources, and responsibilities for implementation is beyond the scope of this report, requiring a detailed implementation plan produced by DoD in partnership with other parties (i.e., agencies, jurisdictions, organizations, and groups) in Micronesia to address these elements.

From the onset of our analyses, an implementation plan was specified as the next stage in the process, for which this report would provide necessary background and recommendations. In an effort to help advance an implementation plan, however, we provide some priorities and also discuss possible approaches and structural aspects for implementation in the sections below.

6.7.1 Initial Priorities for Implementation

A clear priority is the prevention (reduction) of marine species transfers associated with the movement of vessels and in-water structures. This applies to any movements to Guam, other parts of Micronesia, and Hawai'i. This applies to DoD activities, including: (a) the movement of any vessels, whether owned by the DoD, operated by MSC, or operated by a contractor (either under MSC or for another purpose); and (b) the movement of any in-water structures such as dry-docks, piers, dredges, and platforms. This applies equally to movement of any vessels or in-water structures for commercial or private use.

This area is emphasized as a priority for multiple reasons. First, the movement of vessels and in-water structures is a dominant source of non-native species transfers and invasions on a global scale. Second, it is clear that there are critical gaps, and a lack of clarity, in biosecurity in Micronesia for management of these vectors, leaving the door open for species transfers to occur by such movements (Section 6.4; see also Chapter 2). Third, there is a high level of regional connectivity of vessel movements in Micronesia, creating the opportunity for spread of associated non-native organisms (Chapter 3). Fourth, some vessels are known to arrive to Guam with high levels of biofouling (Chapter 2). Fifth, increased movement of vessels into Guam is expected during the Buildup, including those types of vessels (e.g., barges) prone to high biofouling, creating an additional sense of urgency.

While many specific recommendations have been made in this chapter to establish a broad-based biosecurity approach surrounding movement of vessels and in-water structures (and materials), we also have underscored throughout the **critical need to address vessels and structures that have high levels of biofouling**. The movements of such in-water assets (with high biofouling) pose relatively high risks of invasion and spread of non-native marine species in Micronesia, but specific biosecurity requirements on acceptable levels (or management) of biofouling do not exist for movement of these assets, either within or outside DoD.

Thus, **one of the highest priorities for rapid implementation are the specific steps to identify, assess, and treat (if necessary) vessels or structures that have propensity for the highest biofouling accumulations**. Specifically relevant to DoD activities in this regard are steps outlined in Recommendations #14-19, 39, and 40; a parallel set of recommendations are provided for commercial and private activities. In addition, we recommend that any vessel or structure with a long residence time (weeks to months) in a location or uncertain hull husbandry should receive an explicit, high level of scrutiny before movement among locations. While long residence time can occur for any vessel, certain vessel types are particularly prone to experience long residence times, including:

- Preposition ships operated under DoD;
- Mothballed or decommissioned vessels (either military or commercial);
- Barges and dredges (used in support of military or commercial activities);
- Any laid-up vessel.

The planned, predicted, or observed arrival of any vessel or structure with history of long residence times in a location should trigger an assessment and response, to achieve effective vector management. While establishment of a reporting (detection) system was recommended to identify vessels with potential high biofouling levels (see Section 6.4), a critical aspect is training for assessment and response. Thus, we emphasize the need to implement an education and training program in order to identify and respond to vessels (and structures) with high biofouling levels. Ideally, such training would be done as a single program, together for DoD and commercial activities, including the various countries and responsible agencies throughout Micronesia (see also next Section). This approach would serve to provide a consistent approach and avoid redundant efforts, and also address the full spectrum of commercial and military assets that may operate under the DoD, especially when considering activities by contractors.

The movement of vessels and in-water structures are identified as a high priority for rapid implementation, providing the rationale for this selection, but we do not imply that other recommendations are low priority. Movement of organisms with live trade (such as aquaculture) or other vectors also poses significant risks, which should be mitigated and reduced. Indeed, invasions that result from any vector have the potential to cause severe impacts, even if they occur at low frequency. Vessels and in-water structures were selected merely as a dominant vector and starting point to advance regional biosecurity in marine ecosystems.

6.7.2 Approaches to Implementation

We have attempted to provide a strong conceptual framework as the basis or set of organizing principles for our recommendations, which are presented and organized by vector in this chapter. As a result, many of these recommendations are closely related, with strong parallels (by design) across vectors. The intention in creating these separate recommendations (#1-53) was to identify explicit needs and steps for a marine biosecurity plan. However, implementation should be advanced as a coordinated and integrated approach, organizing according to the parallel themes and objectives.

An integrated approach would serve to streamline the overall effort and resources required for implementation. This is perhaps best exemplified by considering vector management for ballast water and biofouling of vessels, including both DoD and commercial vessels across Micronesia:

- First, approaching recommendations for the entire Micronesia region, with full participation of member countries, offers clear economy of scale. There are relatively few vessel visits in Micronesia overall, compared to some global regions. Most vessels visit

Guam, and many of these vessels visit multiple countries (instead of completely novel vessels to each country). This suggests that some data collection and assessment needs can be combined efficiently on a regional scale, rather than conducting completely separate programs.

- Second, there is strong overlap between activities recommended for DoD and commercial vessels, such that there is excellent opportunity to jointly develop and implement some activities, especially in establishing uniform methods, criteria, response plans, and outreach components.

- Third, although recommendations were developed for ballast water and hull fouling as separate vectors, some of the reporting, training, infrastructure, and legal framework components can be combined effectively.

- Fourth, a regional approach to implementation (with similar standards and approaches) also serves to simplify and create a consistent, uniform message for outreach and implementation by the diverse sectors involved in operating and managing vessels.

An integrated approach does not require any specific assumptions about authority or oversight for implementation of specific components, as no recommendations were made in this regard. Instead, an implementation planning process is suggested that seeks simply to integrate activities in order to enhance coordination, efficiency, and consistency.

One approach and a logical next step to advance an implementation plan would be to create a matrix (table) of recommendations that is used to characterize the scope and possible integration of specific actions. For each recommendation, the initial goal would be to develop a matrix that lists of the following information:

1) Specific vector (e.g., all cargo ships, barges, fishing vessels, live food, pet import).
2) Specific type of actions required by category (e.g., recording, inspection, treatment, outreach, training, protocol development, criteria for acceptable level of vector operation).
3) Current agency responsible for each type of action (if one exists) by each jurisdiction in Micronesia. [Note: this does not imply responsibility for funding or capacity to implement.]
4) Likely responsible agency in each type of action by jurisdiction in Micronesia. [Note: this does not imply responsibility for funding or capacity to implement.]
5) Estimated cost associated for each type of action, including that for each jurisdiction and for Micronesia overall.
6) Estimated time required to implement each type of action (assuming available resources exist), including that for each jurisdiction and for Micronesia overall.
7) Estimated recurring cost (if one exists) for each type of action, including that for each jurisdiction and for Micronesia overall.
8) Possible sources and amounts of funding to implement each action, including that for each jurisdiction and for Micronesia overall.
9) Priority for each action according to jurisdiction and overall.

This information serves to outline the operational details for implementation and could be used to evaluate feasibility, timeline, cost, responsibilities, coordination and integration for the specific actions. It would be useful to consider various levels of effort for each of the cost estimates (e-g, above). This overall approach would provide a solid basis developing an implementation plan. By necessity, collecting this information would require involvement, participation, and partnership among the various jurisdictions in Micronesia.

Although this treatment is focused on biosecurity for marine habitats, coordination and integration of activities with those in terrestrial and freshwater environments should also be evaluated. This may be especially relevant and useful for overall program structure, communication, and outreach activities. In addition, we recognize that border control, customs, and other agencies within Micronesia likely operate across these boundaries already.

6.7.3 Structural Aspects of Implementation

Many of the specific recommendations made in this document cannot be put into place without some institutional and structural changes, which require the cooperation and coordination of agencies throughout Micronesia. There is also a need for increased communication and integration in activities, if the goal of implementing a truly regional plan is to be realized.

To provide some of the structural capacity of the Micronesian region to deal with marine invasive species, we recommend the following:

54. Create a single program, the Micronesian Marine Biosecurity Facility (MMBF), to serve as a focal point, coordinating body, communication and information center, and training resource for marine biosecurity activities throughout Micronesia. The MMBF would not replace the need for biosecurity activities within the individual countries but instead would serve as a resource center for the Micronesian countries, agencies, industry, and the public to (a) provide training and advice, (b) develop protocols and methods, (c) help establish detection and response capability, (d) implement education and outreach campaigns on a regional scale, (e) characterize current regulations and guidelines that exist, and (e) seek and coordinate regional funding. The MMBF could also serve as a central data center for reporting, analysis, screening, and maintaining records for vector activities or non-native species information (see Section 6.4). The MMBF should be formed as a formal partnership among the countries of Micronesia.

55. Establish a Memorandum of Understanding (MOU) among government agencies and the DoD departments establishing a response plan and command structure in cases where urgent action by multiple agencies is needed to respond to marine biosecurity. Responses to non-native species are often delayed when such a response plan and structure are not in place, especially when multiple agencies or jurisdictions are involved (Anderson 2005). Moreover, this MOU would allow joint action across countries within Micronesia, rather than requiring independent capacity be developed in each country. If it is not possible to have such a MOU across government and military jurisdictions, then we recommend the development of parallel command structures with an agreement to coordinate efforts through joint activities of the commanding officers.

56. Identify and establish a source of dedicated, long-term funding to implement marine biosecurity recommendations outlined in this chapter. While the type of analysis discussed in section 6.7.2 provides one approach to identify funding needs and possible sources, the most likely outcome will be a combination of funding sources to achieve the desired objectives. Funding sources, amounts, and durations certainly will vary for the different activities recommended in this report. However, in addition to advancing individual objectives, there is a critical need to sustain marine biosecurity as a long-term and vital activity, just as customs and border security (for goods and people) is an ongoing activity. To sustain marine biosecurity and provide long-term continuity requires some core level of activities, personnel, and coordination, which will require dedicated funding.

57. Define management and oversight for implementation of regional marine biosecurity activities in Micronesia. Defining management and oversight is a critical part of implementation planning and the overall function of biosecurity efforts in Micronesia. The MMBF could serve or assist in a management and oversight role. However, if this is not done, another administrative structure should be arrived upon to provide necessary oversight, evaluation, and management. In particular, the current capacity that exists in Micronesia is dispersed across countries, and it is possible that a broad range of people and organizations around the globe may participate in various aspects of implementation. Thus, management and oversight is required to assure that work and directed research addresses specific objectives, and also to provide continuity among countries and over time.

Finally, education and outreach are considered an integral tool for marine biosecurity and for implementation of a programmatic approach to fall under the umbrella of the MMBF. Moreover, we note that many of our recommendations include specific and targeted outreach or training components, in order to advance specific objectives in vector management.

6.8 Summary

The overall goals of this report were to (a) evaluate current activities that pose a risk of marine invasions to Micronesia and (b) provide recommendations for management practices to minimize the likelihood of invasions and associated negative impacts. We have identified specific gaps in marine biosecurity, resulting from current practices, critical information gaps, and lack of capacity (which includes infrastructure, people, and resources). To address these gaps, we have presented 58 separate recommendations, which outline particular steps that could be taken. This analysis and information is intended as input for development of a detailed implementation plan, as the next step to be undertaken. Importantly, some recommendations and approaches were identified as high priorities for implementation. It is also evident that implementation planning also requires evaluation of available resources (which determine the scale or rate of implementation) and involvement of agencies and jurisdictions in Micronesia (i.e., those engaged and affected by implementation activities), which are beyond the scope of this report.

Although the Guam Buildup was the primary for advancing this analysis and a biosecurity plan, the approach undertaken is visionary in its scope. Guam is clearly a hub for military and commercial activities and therefore the potential transfer of non-native species into Micronesia. The analysis and recommendations for biosecurity were funded due to proposed DoD activities in the Mariana Islands but extend throughout Micronesia and include linkages (indirect effects) for Hawai’i. The spatial scale examined is very broad. Moreover, similar analyses have been undertaken for marine, freshwater, and terrestrial components at this scale. The overall approach is unusual for its broad geographic and taxonomic scope, as well as including many countries and cultures.

In many respects, advancing the regional biosecurity plan for Micronesia provides an important model for many reasons:

- First, the approach explicitly considers multiple vectors and environments (marine, freshwater, and terrestrial systems) together, using an appropriate spatial scale at which invasions operate.

- Second, implementing a large-scale, integrative, and cross-cutting plan should result in improved biosecurity protection, efficiency, and consistency, compared to advancing many individual activities in isolation.

- Third, this plan seeks to establish a coordinated and consistent strategy that operates internationally, across many different countries and cultures.

- Fourth, most understanding and management of marine invasions come from temperate latitudes and continents, and this plan aims to address invasions on tropical islands ecosystems, having high relevance on a global scale.

Even though Micronesia is a large area and spans many countries, current levels of trade and the number of points of entry are small relative to many other global regions. This suggests that understanding transfers of vessels and goods is more feasible here than many areas, even for Guam, and should make biosecurity more feasible than in many regions. In short, this underscores the value of Micronesia as a model. It is important to recognize that current capacity and resources limit current biosecurity activities in Guam, and Micronesia more broadly, and this must be considered a major focus of any implementation plan for the region.

By implementing a cohesive regional plan and key protocols to address marine invasions, DoD and its partners across Micronesia would become world leaders in advancing marine biosecurity, especially in tropical ecosystems. Such a program could effectively become a global model and training center, providing benefits to Micronesia and many other regions.

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Appendix A: Perceptions of Impact of Non-Native Marine Species

By Marnie Campbell & Chad Hewitt

A.1 Background

This research forms a component of a risk assessment undertaken for the U.S. Defense forces transfer of U.S. troops (and associated infrastructure) from Okinawa, Japan, to Guam. It is expected that this relocation to Guam will inadvertently result in a transfer of non-native species to Guam that may subsequently spread throughout Micronesia. A component of this work was to determine the risk (the combination of likelihood that a species will be transferred to Guam and other Micronesian countries and the consequence [impacts of these transferred species]) to the marine environment of Guam and Micronesia.

This research targets Guam, Palau and Saipan, using questionnaires and interviews to collect information about environment, economic, social and cultural core values that people in these locations hold and how they perceive that non-native species will affect these values. It was planned initially that this information would be used as a component of the consequence analysis for the overall risk assessment (see Chapter 5). However, the risk assessment used a quarantine end point and hence all consequences were considered significant. As such, this Appendix now represents a measure of the values that would be affected and provides a values mapping for a risk assessment that would have an impact end point. Typically, environmental risk assessments ignore social and cultural impacts and thus we are ensuring that this aspect is not lost, to provide a voice to the local and indigenous people in this region.

The importance of recognizing valid risk perceptions has been identified and studied for a number of years with the main insight for this study being the ability to understand and anticipate people's responses to a hazard [non-native marine species] (Slovic 1987, 2000; Sheeran and Orbell 1999) and hence managing this response within a holistic risk management framework.
By ascertaining people's motivations, actions and beliefs the driving factors associated with intentional and unintentional introductions and further spread (secondary transfers) can be effectively managed. This is pertinent for this risk assessment, as the public are potentially hostile to changes that they are seeing as being foisted upon them (such as the increase in military presence in Guam and subsequent exposure to shipping).

A.2 Aims

This research had two specific aims:

1. Identify known and perceived values that may be impacted by non-native marine species and

2. Assess the perception of changed values if non-native species occur in the region.

This research is preliminary (a pilot study), focusing on Guam as the primary site of impact, with a further assessment of two trading partners within Micronesia (Palau and Saipan). The results and trends seen are country relevant and cannot be extrapolated to other countries within or across Micronesia.

A.3 Determining Consequence – Values

Within this appendix, the use of the terminology “value” refers to things and/or notions/beliefs that people feel are important to them. Although the inclusion of economic, social and cultural values is beyond the initial scope of the project, the research team was approached by the NISC project coordinator to include this aspect within this report. This has occurred, but the report is limited due to the methods that could be utilized. Thus, what is presented in this appendix is a very preliminary assessment of all values (the assessment is limited in its scope) that provides some insights, and there are a number of important caveats (see next section). It is recommended that further investigation of these preliminary findings is necessary to truly elucidate the social, economic and cultural aspects.

A.4 Caveats

A number of caveats are important to note for this aspect of the consequence data:

1. This work was not a component of the original tender and thus it was not budgeted for.

Instead, it was fit into the study as possible while undertaking the major component of work (as presented in Chapters 1-6). But this meant that data was collected in a manner that is acceptable in western style questionnaire surveys (i.e., responses were elicited via an electronic survey by emailing the survey to people that were able to send the email onto others [referred to as snowballing]) but is of less use for studies wishing to collect data from cultural or social groups. Thus the data presented for the values has limited scope. An improved collection method (such as a temporal ethnographic study that incorporates participant observation and immersion in local culture) would see a better outcome for this data.

2. When working with cultural and social groups a better technique to collect data is via a series of meetings, informal chats, focus group interviews, and observations via immersion within difficult cultural contexts. This type of work is more field intensive and unfortunately could not be undertaken in this situation. The research presented in this chapter has identified a number of values through our initial face-to-face interviews and meetings and further reading, but often these values may have represented a miniscule aspect of cultural identity, which is difficult to ascertain and to value as a whole.

3. Values are based on a person’s heuristics, which are influenced by aspects such as their cultural background and identity, age, gender, and income level. Because of the manner in which the questionnaires were administered (see caveat 1), it was unlikely that indigenous cultural or social groups would respond. Thus, the data received is more likely to be influenced by ‘outsider’ opinions and under-represents Chamorro and Carolinian culture. This is particularly true for the analysis of change in value.

4. It is recognized that respondents may potentially overvalue aspects of their culture as a sense of cultural pride, when in reality that particular aspect is neither practiced or has been forgotten by most of the population. The same can be said for activities that respondents may be involved with or an area that they may wish not to have affected. The researchers do not judge these aspects and

believe that all aspects are worth consideration and assessment. Thus, the research as used all data as presented on face-value.

The response rates for our electronic questionnaires were relatively low and typically limited to expatriate American citizens, with few indigenous respondents.

What was achieved was a number of meetings (interviews) that elucidated values based on face-to-face interviews (see Table B.1) and the identification and support of values via reading the published literature, informal discussions, and visiting museums. This information was used to develop a questionnaire to ascertain the validity of these values, to collect further values that may have been missed and to see if people felt that a value would change if a non-native marine species entered a region. This means that the results under-represent the indigenous population and the general public.

A.5 Methods

A.5.1 Data Collection

A three-staged approach was used to collect values and then to investigate whether respondents perceived if values would change once a non-native marine species arrived in their region (Guam, Palau and Saipan). Ethics approval was provided for this research (H11233) by the Tasmanian Social Science Human Research Ethics Committee. In all instances researchers followed the ethics approved sampling methods and met the Australian National Statement standards. Data was collected using interviews and three questionnaires that were distinct for Guam, Palau and Saipan. Non-random purposive sampling (e.g., Babbie 2007; Walter 2010), with additional snowballing, was used given that this was a preliminary assessment. The sampling frame was restricted to scientists, environmental managers, industry (shipping and tourism related), government officials, and the public that had declared an interest in non-native marine species risk associated with the potential alterations in Guam vessel traffic associated with the U.S. Defense Force redeployment of troops to Guam. The sampling frame[6] was restricted in that other participants were identified as sampling progressed and hence the frame could not be fully identified. As such, snowballing (the description of this method is provided below) was also used.

Stage 1: Identification of values. A triangulation process (e.g., Esterberg 2002) was used to identify and clarify values. The initial step in the triangulation was to hold face-to-face meetings

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[6] "Sampling frame: the listing of all units in the population from which the sample will be selected" (Bryman 2012).

and focus group interviews. These occurred from 31st March 2010 until 24th April 2010. These meetings and interviews elucidated people's values and served to direct us to further individuals to meet/interview. The second step of the triangulation involved researching the literature and/or materials that could help substantiate the values that were identified. A bibliography of the literature that was reviewed is provided (see References) to give insight into the literature that was assessed with regards to this study. The outcomes of this were the creation of a draft list of values that were relevant to Guam, Palau and Saipan.

Interviews occurred in Guam (31 March – 9th April 2010), Palau (10 April – 18th April 2010) and Saipan (19th April – 24 April 2010) and occurred on an individual basis or via group discussions. Discussions (in the form of semi-informal interviews) were held by introducing the topic and providing a background on the research that was occurring. Participants were encouraged to express their opinions and ideas related to the research topic. As such, the participants were involved in the construction of meaningful results related to the topic (i.e., they could drive the interview direction within the bounds of the research topic). Although the agenda for discussions/interviews was restricted to the research topic, the direction of the discussions was guided by the participants and hence participants were able to articulate what was important to them, to have more 'power' in the discussions and subsequently influence the results by choosing what they would and would not discuss.

Stage 2: Alteration of values. Based on the values identified at stage 1, a questionnaire was developed that asked respondents to: (a) rate each provided value on a scale of worth (1 = low, 5 = high); (b) add additional values that may have been missed; and (c) rate these new values on the same scale of worth.

Stage 3: Change in value. Based on the values identified at stages 1 and 2, respondents were asked if a non-native species arrived in their region could they state whether this would change their view on the value. If they answered "yes" then they were asked to rate how the value had changed (i.e., a decrease in value is now worth less or an increase results in the value being worth more). Please note that "worth" does not have a dollar value, but instead its used to infer an importance to someone – this importance can be intrinsic (i.e. hold importance merely for being) or utilitarian (i.e. holds an importance because it can used by humans [provides a service]), or a combination.

A.5.2 Bias in Data Collection

A non-random purposive sampling method was used with a restricted sampling frame (scientists, environmental managers, industry, government officials and the public that had stated an interest in non-native marine species risk associated with the potential alterations in Guam vessel traffic), which under-represents the actual population. Thus, the results do not reflect the population in each country but rather reflects people that might be affected by the changing vessels movements into and out of Guam or have to manage these altered vessel movements or potential increases in non-native marine species. In this situation, under-representation of the sample is not a major concern because this is a preliminary study that is highlighting trends (Walters 2010). In essence, the sampling was guided by a theoretical sampling plan that would enable the problem of non- native marine species to be explored.

A snowballing technique was implemented (e.g., Bryman 2012). This method targeted people that work in areas relevant to non-native marine species and marine species and then used these people to establish contacts with others. This technique was used as the ability to establish a sampling frame given the short time frame for the research, was not possible.

To overcome recall bias (Szklo and Nieto 2007), each participant in meetings, interviews and questionnaires were briefed on the issues being investigated prior to beginning the questionnaire. Briefing all participants ensured that everyone involved was exposed to the same data pertaining to non-native marine species and the redeployment of U.S. Defense Forces.

To ensure that leading questions were not used and to identify any wording issues within the questionnaire, a pilot group of individuals was used as a trial. Two interviewers were used, with each having been trained to standard protocols (to ensure replicability; Stewart and Cash 2008), and one interviewer being in charge of quality control and quality assurance of interview techniques.

A.5.3 Data Analysis

Due to the preliminary nature of this research quantitative analyses are not possible. Instead descriptive statistics were used to describe the trends, with value network maps being used to explore the strength of linkages across and between values.

A.6 Results

A.6.1 Identified Values

A total of 337 values, from 61 participants, were identified across environment, economic, social, cultural values and combinations of these values (Figure A.1). We identified 140 values for Palau, 105 for Guam, and 92 for Saipan.

Guam identified the most environmental values, followed by Palau and then Saipan (Figure A.1). Palau, closely followed by Guam identified the highest amount of economic values, with a similar trend for the social values. Palau, followed by Saipan identified the most cultural values, with a large reduction in the identification of cultural values occurring in Guam.

In Saipan, the following additional values were identified:

- Coastal protection from reef
- Coastal protection provided by seagrasses
- Water quality improvement (filtering) provided by seagrasses

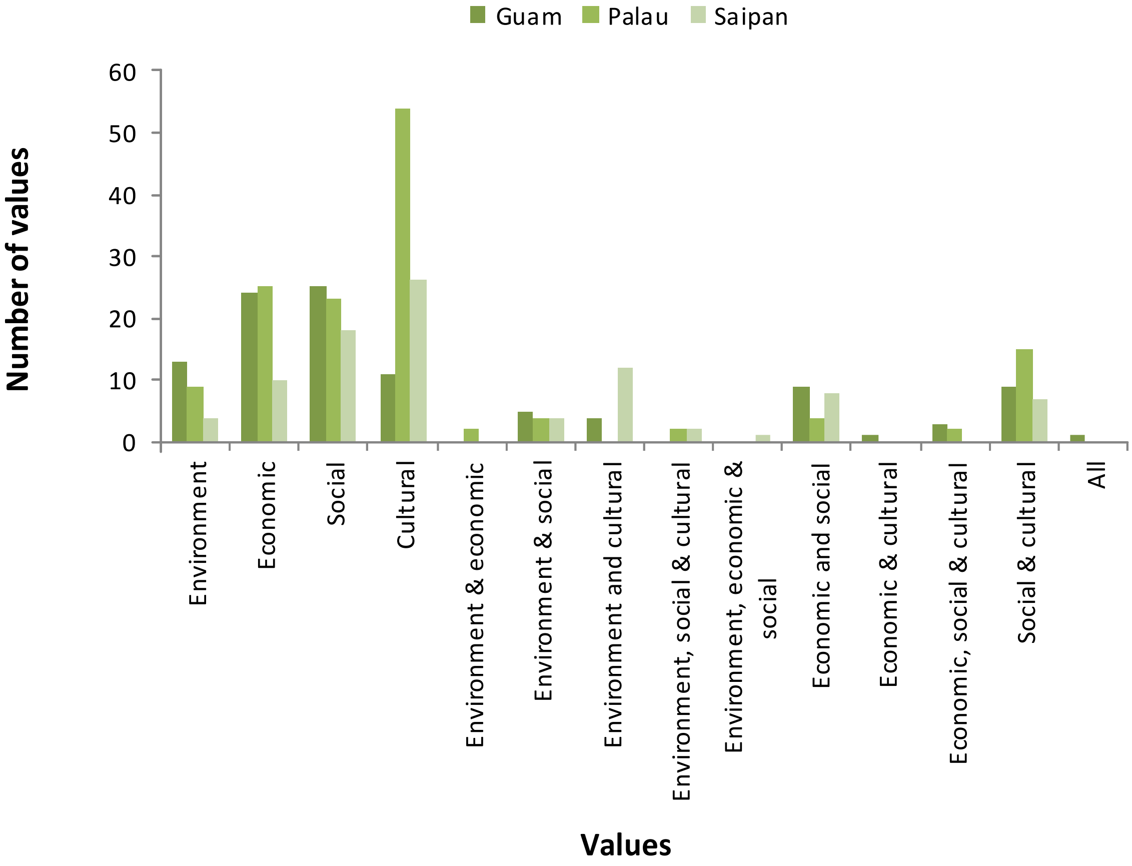

Figure A.1. Total numbers of values within each presented category for Guam, Palau and Saipan. The category "All" represents the identified value(s) that spanned across the environment, economic, social and cultural aspects.

A.6.2 Value Networks

Value networks (Figure A.2) were then used to illustrate the strength of connection across and between the core values (environment, economics, social and cultural). Each value had a number of identified 'subcomponents' (an element of a core value that with other subcomponents forms the entire core value) that represented a single core value (circles in Figure A.2), or could represent multiple values (lines connecting two, three, or four core values). Within Guam, there was minimal overlap or sharing of values, with most subcomponent values representing just one value and relatively little cross-over of values or participant perceptions that values crossed over (Figures A.1 and A.2). The values identified in Guam had a stronger social and economic focus compared to the other two regions. In Palau, there was a stronger network of subcomponents shared across core values, with social and cultural values sharing the strongest linkages (Figures A.1 and A.2). A similar trend was evident for Saipan (Figures A.1 and A.2).

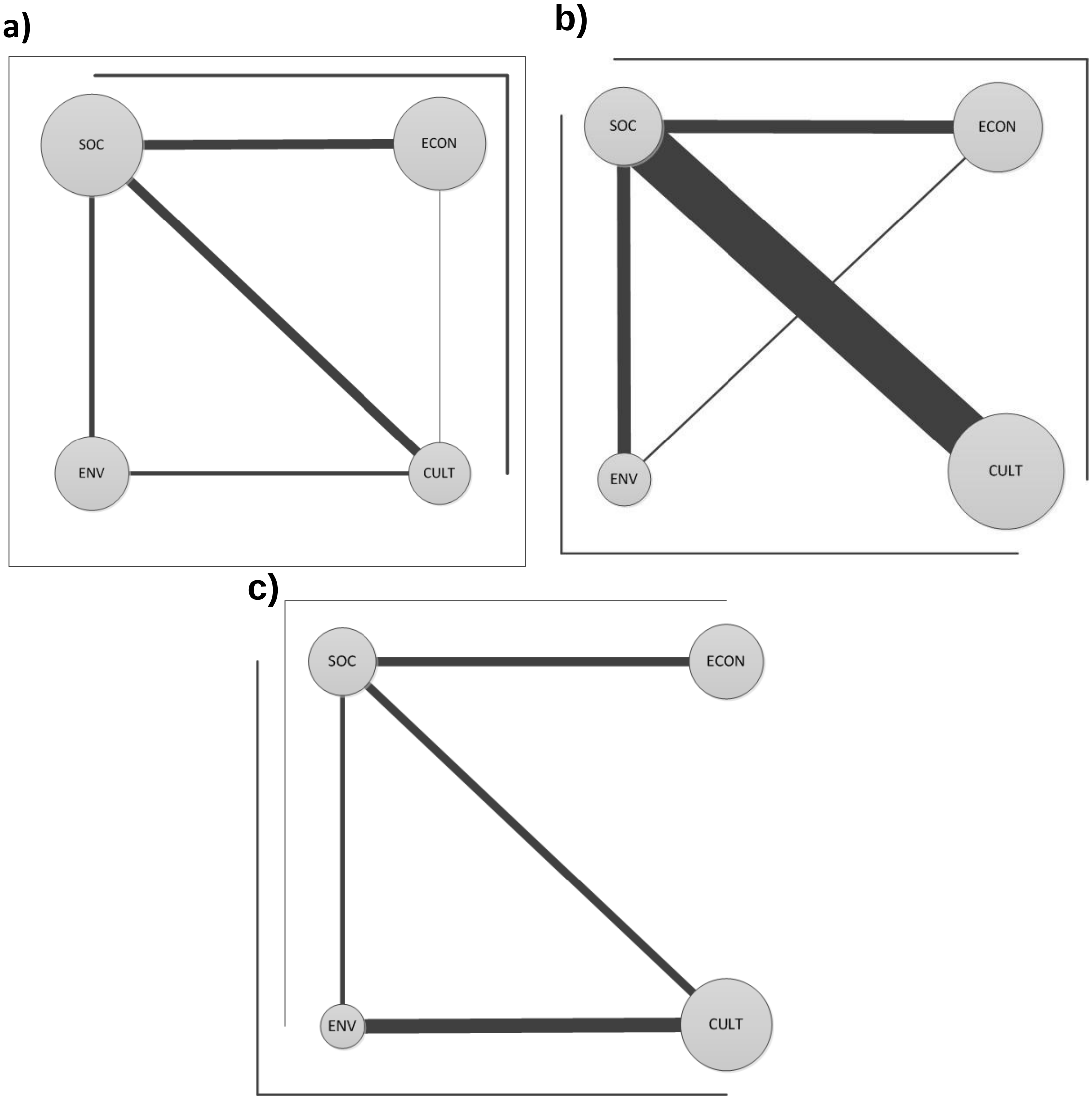

Figure A.2. Value networks illustrating the proportion of core values for each region and the strength of linkages between core values for: a) Guam; b) Palau; and c) Saipan. Core values are denoted by SOC = social; ECON = economic; ENV = environment; and CULT = cultural. The number of identified subcomponents in each category (one, two, three, four core values) is represented graphically by the size of the circle or thickness of the lines (networks).

A.6.3 Worth of Values

No responses were received from Palau and hence they are excluded from this portion of the analysis. It is recommended that further investigations are undertaken to elucidate the patterns and to better engage with the Palauan population to provide reliable outcomes concerning their perceptions about the identified values, the identified values worth and change in identified values worth.

The survey (questionnaire) results are preliminary, with low response rates; hence questionnaire findings discussed below need to be taken in the context that reliability is low. The data indicate some preliminary trends that need further investigation. In Guam, survey participants rated 63% of identified values as high value, with 21% having a neutral value (neither high nor low), and the remaining 16% having a low value. This differentiation between value worth can be further categorised based on each of the core values: 74% of the identified environmental values were rated as a high value, followed by 64% of social values, 57% of economic and 54% of cultural values (Figure A.3a).

In Saipan, 52% of the identified values were rated as having high value, with 44% having a neutral value and 4% having a low value. On a core value basis, 64% of environmental values were rated as high, with 59% of economic, 72% of social and 21% of cultural values being rated as high. Saipan participants rated the majority (73%) of cultural values as having a neutral value (Figure A.3b). This may reflect an inability to properly assess the value and hence a choice to select the middle option (i.e., to fence sit or to remain undecided).

A.6.4 Change in Value Worth

The participant’s perceived change in worth of the core values due to a non-native species varied across the countries. Within Guam, 57% of the values remained unchanged, 39% of values would decrease in worth and 4% would increase in worth (Figure A.4a). A small number of social (Education – University of Guam, and education Schools) and cultural values (Seasonal fisheries: impediment to equipment; and food gathering) were perceived as potentially increasing in worth if an introduction occurred. The largest impact (decrease in core value worth) occurred for the cultural values (72% of values would decrease in worth), followed by social (44%), environment (43%) and economic (21%).

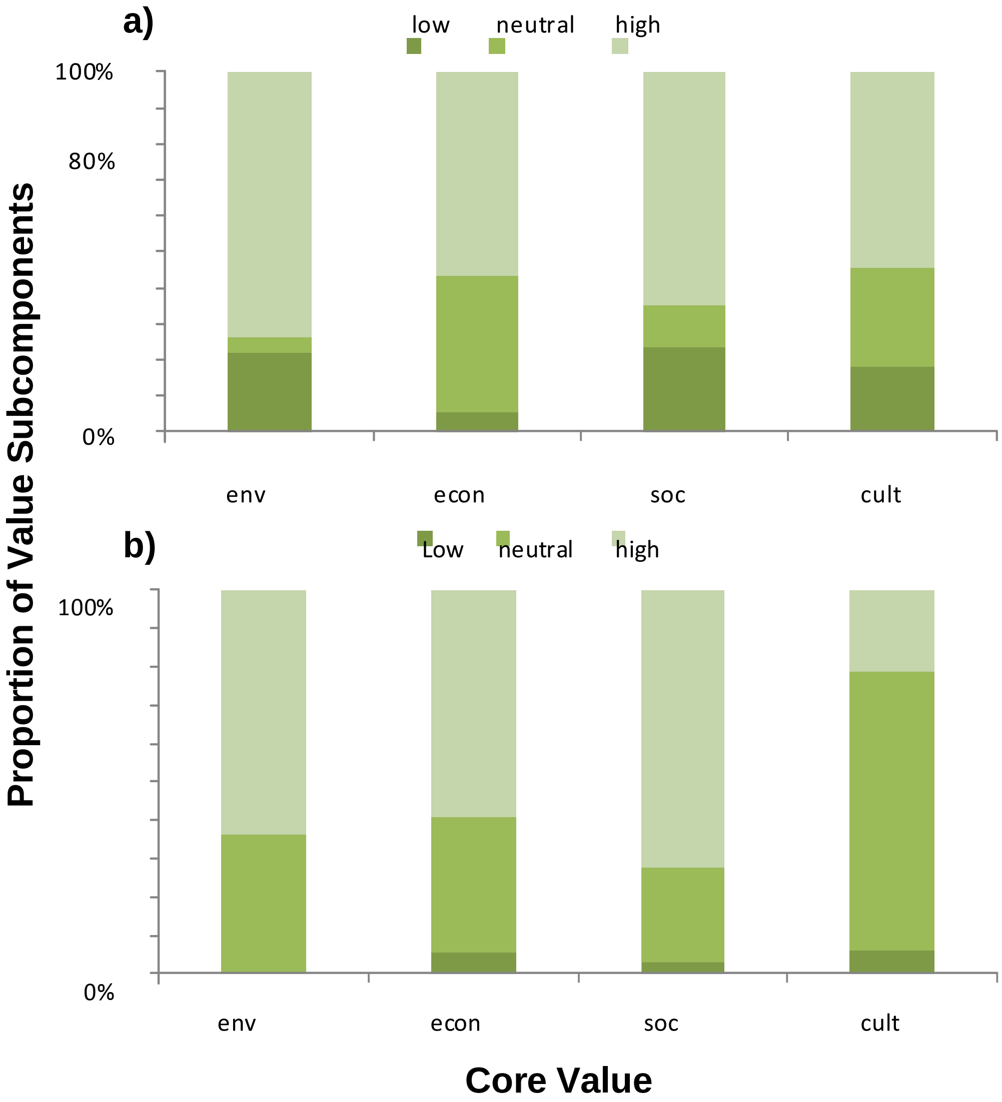

Figure A.3. Proportion of each core value subcomponent that was rated as having a high, neutral or low value by survey respondents for a) Guam; and b) Saipan. Where values are denoted as env = environment; econ = economic; soc = social; and cult = cultural.

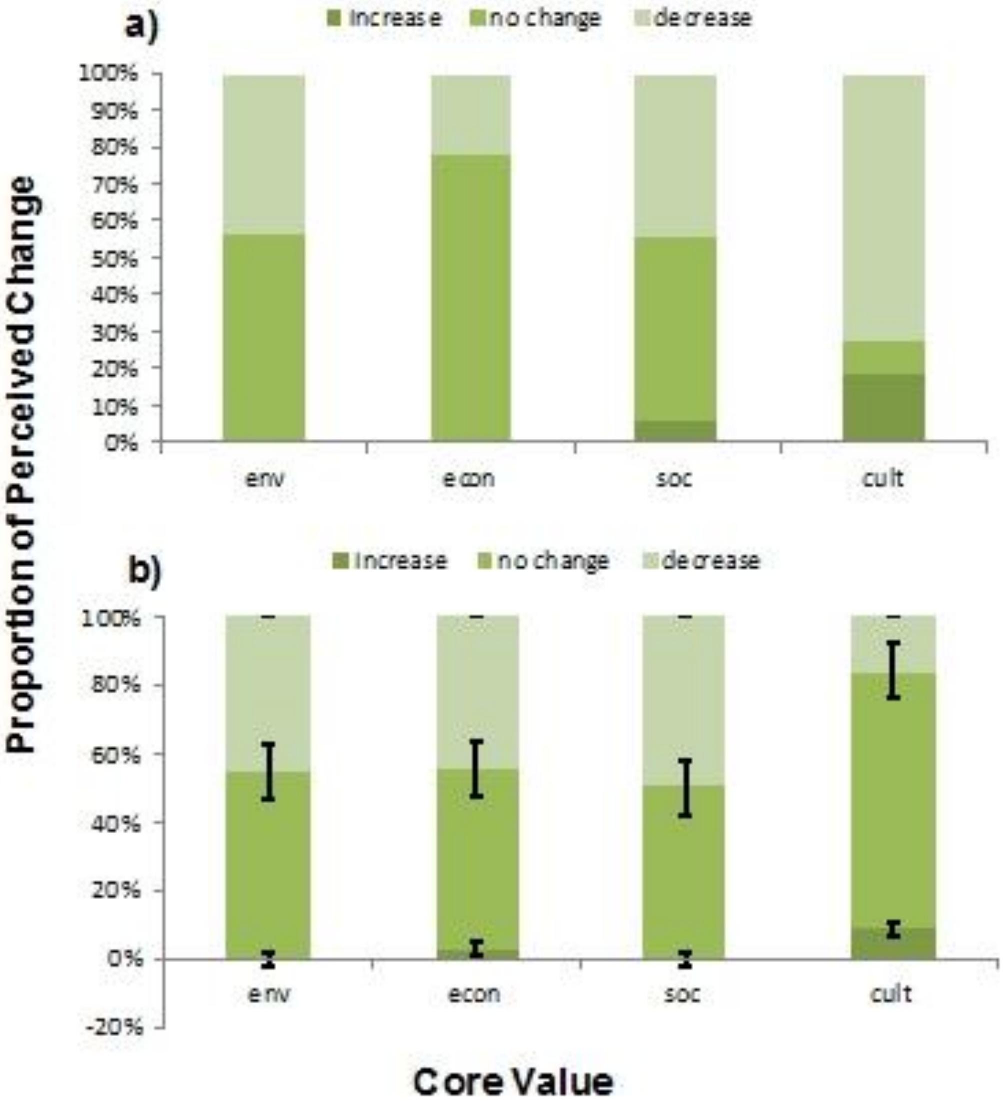

Figure A.4. Participant's perceived change in core value worth after an non-native species enters a countries water for: a) Guam; and b) Saipan (with standard error bars). Where values are denoted as env = environment; econ = economic; soc = social; and cult = cultural.

Within Saipan, the change in value was variable. Fifty-nine percent of the values did not change worth. Yet, there was a decrease in perceived value for 37.5% of the values with a small (3%) increase in value worth. At the scale of the core value, 54.5% of environmental values remained unchanged, and a further 45.5% of environmental values decreased in perceived worth (Figure A.4b). Economic values had a similar trend, with 53% remaining unchanged, 44% decreasing in perceived worth, and 3% increasing in worth. Social values were divided equally (50:50) between worth remaining unchanged or worth decreasing. Cultural values had the largest dichotomy, with 75% of values remaining unchanged, 16% decreasing in worth and 9% increasing in perceived worth.

A.6.5 Participant Feedback and Comments Received to Date

An opportunity for participants to provide feedback and make comments about the discussions and interviews and the questionnaires was provided. Further feedback will be collected after the report is released. Feedback and comments collected to date is summarized in Table A.1. A number of participants wished to remain anonymous and provided verbal information but requested that this information not be repeated within the report. The authors have respected these wishes and have used these data to inform the report in a manner that maintains anonymity (and these are not listed in Table A.1).

Table A.1. Participant's initial feedback

	Country relevance		
Feedback and comments	**Guam**	**Palau**	**Saipan**
The marine environment is intrinsic to our life and lifestyle.	✓	✓	✓
We rely heavily on marine resources (food and tourism)		✓	
Loss or impacts on marine resources will increase poverty		✓	
Attempting to place a value on single aspects of cultural identity is difficult (if not impossible) because the real value, in many cases, is with the whole and not the individual parts. This could also be said for ecological systems	✓	✓	✓

Table A.1. Continued

Feedback and comments	Country relevance		
	Guam	**Palau**	**Saipan**
The assessed values may be dependent (auto-correlated) upon the cultural background of the recipient and their time spent in Micronesia (level of exposure to the culture and environment)	✓	✓	✓
Most of your respondents in the CNMI will most likely be outsiders. Consequently, their answers may reflect their impression of what others may have on certain issues or be biased by their own cultural identity.			✓
Indigenous respondents may overvalue aspects of their culture as a sense of cultural pride - when in reality, that particular cultural aspect is neither practiced or has been forgotten by most of the population.	✓	✓	✓
Some cultural values may be rooted in the marine environment but unaffected by change in this area.	✓	✓	✓
Biggest risk (from non-native species) is that we are not prepared.		✓	
Developing countries have a goal to support their economies and therefore sometimes things are lost	✓	✓	✓
An important part of our culture is the community projects that are organized by Chiefs.		✓	
Traditionally always people saved for tomorrow. This sustainability has been lost. A breakdown of traditions is occurring.	✓	✓	✓

Table A.1. Continued

Feedback and comments	Country relevance		
	Guam	Palau	Saipan
Buul (traditional management of resources in Palau) is managed by the Chiefs, with the community providing enforcement. Buul is now also used to manage behaviors. Fishing seasons and techniques were originally managed by Buul's, but now these are managed by legislation.		✓	
There needs to be an improved flow of information so the community knows what's happening with non-native marine species.		✓	
There is no important social/cultural importance of the sea, except when people want to use this resource			✓

A.7 Discussion and Conclusions

This research set out to identify known and perceived values that could be impacted by non- native marine species and to determine if perceptions of these values may be altered if a non- native marine species incursion occurred. The research successfully identified a large number of values (n = 337: Guam 105; Palau 140; and Saipan 92; Supplemental Tables 1-3) for the three different countries assessed. These values ranged across environment, economic, social, and cultural, with combinations thereof. Values vary from place to place, with place-culture being the greatest influence for the spatial and temporal patterns that can be detected (e.g., Williams 1981).

Although cultural and environmental values were kept as separate core values, it is noted that these values are often categorized together because philosophically environmental values themselves are considered to be embedded within culture (i.e., culture is a whole way of life), making it difficult to separate the two effectively. Thus, in some instances within this research, there was a downgrading of environment values (i.e., fewer environmental values may have been identified) that does not truly reflect the realized value or its worth. It is also noted that U.S. imperialism (i.e., Zimmerman 1998) has potentially influenced the values identified and reported for Guam and Saipan. Yet, the U.S. influence in Palau is less intense (Palau remains a Republic that was once a U.S. Protectorate but has now attained its own freedom), which is reflected in Palau by the higher number of identified cultural values and the strength of network connections between cultural and other values. This topic is discussed further below, noting however that the authors of this work are not sociologists and therefore the interpretation is limited and potentially naïve from a social science perspective.

A.7.1 Value Networks

A.7.1.1Guam

Environmental and cultural values exist in Guam but were not valued as highly as economic and social values. Also, from a network perspective, Guam had little connection between core values (Figure A.2a). This lack of connection may be related to the history of this region. Guam has had a long history of being occupied by foreign nations, including occupation by the Spanish, Japanese and the U.S., which has resulted in the loss of the Chamorro culture (Jennison-Nolan et al. 1979a, 1979b; Diaz 1994; Rogers 1995; Zimmerman 1998).

The stronger social and economic focus of the identified values in this study may be related to the utilitarian societal norms witnessed in this region. Guam is heavily influenced by the U.S. (it is a U.S. Territory) and the resource conservation ethic (i.e., natural resources abound in nature and should be used, with conservation standing for development: "…the greatest good of the greatest number for the longest time…" (Pinchot 1947, 1968; Callicott 1990)). The resource conservation ethic is strongly ensconced in the U.S. legislation and government management of resources (Callicott 1990; Groom et al. 2006). As a U.S. Territory in the Pacific Rim, a perception exists that local norms and beliefs are often diluted as the country is forced to adopt U.S. laws and practices (i.e., 'peripheralization'[7]; Wilson 2000a; Perez 2002).

Within this research, there was a strong indication that participants felt that Guam was disenfranchised, resulting in a loss of culture through 'Americanization' (e.g., Barusch and Spaulding 1989; Diaz 1994; Perez 2002). This was reinforced by participants indicating that they did not want more U.S. Defense Forces in Guam. This opinion was further reinforced by street protests that occurred during the survey work and subsequent protests that have occurred (e.g., http://ww4report.com/node/8160; http://links.org.au/node/1547; http://reefrescue.wordpress.com/2010/02/26/guam-protests-navys-plan-to-dredge-coral-reef/; http://www.horseopera.org/Insular_Empire_2010/?page_id=564).

There was also a general perception amongst some survey (Guam and Saipan) participants that cultural values are no longer authentic because they are not practiced by the majority of the population or that modernization of society has no room for these outdated concepts. However, typically these sentiments were provided by Caucasians expatriate Americans, not Chamorro or Carolinian participants.

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[7] Peripheralization refers to the "differential distribution of power, interest, labor, and capital across space, and the domination of local spaces and cultures by the mandates of military-industrial time" (Wilson 2000a).

A.7.1.2 Palau

Cultural values, followed by economic, social and then environmental values were identified in Palau (Figure A.2b). The strongest of connections occurred between social and cultural values, probably related to the strong community and cultural identity that still remains in this country. Palau also has a strong cultural law that governs usage of species (Buul 8-tiered system and fishing grounds; e.g., Johannes 1978, 2002) and influences lifestyles, including environmental goals aligned with conservation (D Olkeriil pers. comm.). The parliament is currently working on translating traditional stewardship into legislation that will simplify the three tiered system that currently exists (N Idechong and D Alexander pers. comm.). Marine protection has a strong focus within Palau (e.g., Gilman 1997a), especially within tourist focal areas such as the Rock Islands and Koror or on specific species that have a cultural value (e.g., Campbell 2003; I Olkeriil pers. comm.). This protection stance is often linked with customary management of marine resources (Gilman 1997a; Johannes 2002; D Olkeriil and I Olkeriil pers. comm.), which has been degraded in the past but is being rebuilt at present (N Idechong and D Alexander pers. comm.).

A.7.1.3 Saipan

The number of values identified for Saipan was similar to Palau, with a large number of cultural values, followed by an equal weighting of social and economic values, with fewer environmental values (Figure A.2c). Although, within Saipan, the importance of the sea turtle has been used to express and maintain Carolinian culture (Kolinski et al 2001). This value was identified, and its subsequent worth was identified as high, by survey participants. Much like Guam, the connections between values were relatively weak, with the strongest connection existing between the environment and culture. Again, the history of Saipan may have an influence on the identified values and assessed worth/changes in worth. Saipan has had five centuries of colonial rule, seen four empires and accommodates two indigenous cultures (Rios-Martinez 2000). Chamorros were forcibly removed from Saipan for a significant portion of the islands history, with the Carolinian culture becoming dominant during this period. When the Chamorro people returned to Saipan a disjunction in their Saipan culture had been created (R Hunter pers. comm.).

Saipan is within the U.S. CNMI (became a Commonwealth of the U.S. in 1986; Gilman 1997b; Rios-Martinez 2000) and is subsequently heavily influenced by the U.S. (Rios-Martinez 2000; Warheit 2010). Saipan constitutes part of the U.S. colonialism where a number of ‘insular areas’ are occupied by the U.S., where they are provided with some political willpower, but have fewer rights (King 1991; Rios-Martinez 2000; Warheit 2010). For example, a number of elements of sovereignty were surrendered when Saipan and the U.S. formed the Commonwealth (King 1991; Rios-Martinez 2000; Warheit 2010), with a major issue being the loss of the Islands rights to self-governance. This loss of power has caused some issues through time.

A.7.2 Worth and Changing Values

Although this information was collected, the low response rate to the survey tools leaves little that can be accurately stated about these data. In general, there are a multitude of ways to identify values (e.g., Corraliza and Berenguer 2000; Kalof and Satterfield 2005; Fraj and Martinez 2006) and to determine a value's worth (e.g., Knetsch 1994; Satterfield 2001; Emerton and Bos 2004; IUCN/The Nature Conservancy/The World Bank 2004; Pagiola et al. 2004; The World Bank 2004; Kalof and Satterfield 2005). Recently there has been a move away from Willingness to Pay (WTP) and Willingness to Accept (WTA) style assessment of a value's worth, because of fundamental flaws in these processes (Kalof and Satterfield 2005). The result has seen the development (or further development) of axiomatic traditions that capture 'non-cost' and 'non-utilitarian' values. These methods are 'divorced' from the market and recognize that the environment (or at least many components of the environment) is a limited resource (Satterfield 2001; Kalof and Satterfield 2005).

The methods that were employed for this research, although in hindsight were not effective at collecting values from indigenous groups, did not use WTP/WTA style methods and did not rely on a dollar based system. Instead, the elicitation techniques attempted to use a narrative style (via interviews, group discussions, and surveys) to collect or identify values for each country and gauge worth and change in worth. The central question that was investigated was what were the values that would be impacted from an introduction of a marine species? This method was separated from the Guam Buildup research so that values, worth, and change in worth could be identified and driven by participants that are local to the countries being examined (i.e., not influenced by outside observer preferences). This method has been suggested as ideal for identifying and capturing the worth of values when non-market based values are explored (Satterfield 2001). Thus, the elicitation method was sound, but it required more time in country to fully explore the values in a face-to-face method that was more suitable to the countries sampled.

What this research has managed to achieve is some insight into the potential value worth and changes to worth that may be perceived of as occurring if a non-native marine species was to arrive in Guam or Saipan (Palau is excluded here due to a no response rate to the questionnaire). In general, participants from Guam and Saipan indicated that few values would benefit from a non-native marine species arriving in the country. A non-native marine species incursion would decrease the worth of a number of values, with more than 50% of values (summed across all core values) being negatively impacted (Figure A.4). Although the study needs further validation, in a management context the 'no change in worth' values would be excluded from further assessment as the perception is that these values are not deleteriously impacted by an incursion. It is the values that have decreasing worth that have a high management potential. Again, the authors reiterate that our findings are preliminary and hence no action should be taken until further exploration of these values is conducted.

One obvious missing link in the data that was collected is the 0% (i.e., no response) questionnaire response rate from Palau. This poor buy-in of participants to the questionnaire was not reflected within the interviews and discussions that had elicited keen interest, with people expressing a desire for inclusion. The poor survey response rate in Palau might be due to the cultural implication where freedom of enquiry is restricted in some instances. For example, Kesolei (1977) discusses the concept that Palauans believe that there is a hierarchy to data availability. Full information disclosure to the public is rare. In a social context, the more you know in Palauan society the more credibility that person is afforded, with information flow (or the right to know) being based on an individual's social status, age, or lineage (Gilman 1997b).

A.7.3 Future Research Needs and Recommendations

The preliminary research indicates that there is some concern over the impacts that non-native marine species will have in Guam, Palau and Saipan. Hence, it is strongly recommended that a full-scale perceptions study be undertaken in the Micronesian region to determine the perceptions of impact (involving the identification of values, identifying each value's worth and identifying potential changes in value). The collection of information needs to be done in a format that would feed into a non-native marine species risk assessment framework to enable to social and cultural values to be assessed equally with economic and biological values.

The authors note however, that because of the preliminary (pilot) nature of this research it is necessary to re-iterate that the outcomes are descriptive, they under represent the population (small and non-random sample size), and hence have a low reliability. Further exploration of the perceived worth and impacts (change in worth), especially to the core values assessed here, is required. The authors urge that this further research follow an ethnographic design that enables the researchers to spend more time with the populations within Micronesia, to truly gauge the level of worth and potential change to values with the perceived potential introduction of marine species. To this effect, it will be valuable to include an expert with non-native marine species expertise and risk assessment to be involved in these studies to help guide the work to ensure that useful data for a risk assessment can be obtained.

Data collection methods need to be refined to meet each countries needs and cultural requirements and to allow face-to-face interviews with a greater sample size of people. Questionnaires were not an effective tool in this instance and the reliability of the data could easily be improved via the running of a number of stakeholder workshops, group interviews, and single interviews. In general, interviews (individual or group) provided the most valuable data, but workshops facilitated by local or a regional agency with expert input, may provide more effective to gauge, especially with regards to the social and cultural elements of impact form non-native species. In societies where information flow is select or restricted (e.g., Palau) the need to more fully engage with government agencies is required. This could be achieved via the use of more intensive one-on-one interviews that collected the questionnaire information directly.

Supplemental Data Tables for Appendix A

Table S.1 Guam values defined where grey shading denotes an identified value. Where -1 denotes a perceived decrease (loss) of worth for the identified value; 0 denotes a perception of no change in worth for the identified value; and 1 = a perceived increase in the worth of an identified value.

Value	Environment	Economic	Social	Cultural	Change in Value*
Catchment effects	▨	▨	▨	▨	0
Harmful algae blooms and nuisance species: health	▨		▨		0
Habitat forming areas: mangroves	▨		▨		-1
Habitat forming areas: coral	▨		▨		-1
Disease	▨		▨		0
Natural authenticity	▨		▨		-1
Water: quality	▨			▨	-1
Water: potability	▨			▨	-1
Water: disease & parasites	▨			▨	-1
Endangered species (sea turtles)	▨			▨	0
Water: flocculants	▨				0
Integrity of Preserves (protected areas)	▨				-1
Biodiversity	▨				-1
Protected species (mammals, sea birds)	▨				0
Ecological functions	▨				0
Blooms and nuisance species: oxygen deprivation	▨				0
Blooms and nuisance species: pH impacts	▨				0
Trophic interactions	▨				0
Maintaining resiliency	▨				-1
Habitat loss: mangroves in Apra harbor	▨				-1
Offshore dredge disposal	▨				0

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Table S.1: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Pollutants disposal (PCB's, WWII equipment, etc.)	▨				0
Joint defense force exercises: impacts	▨				0
Loss of natural space		▨	▨	▨	0
Reduction in access to natural space		▨	▨	▨	0
Use restrictions: port		▨	▨	▨	0
Access restrictions		▨	▨		0
Public health: mortality		▨	▨		0
Public health: morbidity		▨	▨		0
Tourism: tropical experience (beaches)		▨	▨		0
Tourism: relaxation		▨	▨		0
Tourism: WWII experience (not common anymore)		▨	▨		-1
Iconic International significance: blue holes		▨	▨		0
Iconic International significance: crevice		▨	▨		0
Iconic international significance: water visibility (diving)		▨	▨		0
Seasonal fisheries: artisanal		▨		▨	0
Cost of maintenance: boats		▨			0
Cost of maintenance: infrastructure		▨			0
Cost of access		▨			0
Maintenance of ecotourism		▨			0
Industry seawater intakes: power plants (Piti and eastern)		▨			0
Industry seawater intakes: marine lab (UOG)		▨			0
Industry seawater intakes: Underwater world (tourism)		▨			0
Industry seawater intakes: aquaculture hatchery		▨			0
Industry: effluent discharge		▨			0

Table S.1: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Ocean Thermal Energy Conversion (OTEC)		▨			0
Aquaculture: Disease free image		▨			-1
Aquaculture: market access		▨			-1
Aquaculture: health of product		▨			-1
Live rock culture		▨			-1
Hotel trade		▨			0
Tourism: divers		▨			0
Tourism: fishing		▨			0
Tourism: submarine – sightseeing		▨			0
Loss of tourism business		▨			0
Loss of business		▨			0
Tourism infrastructure		▨			0
Port traffic flow (added time and hold-ups)		▨			-1
Effluent discharge: sewerage		▨			-1
Tuna fleet		▨			-1
Seasonal fisheries: subsistence			▨	▨	-1
Food gathering: subsistence			▨	▨	-1
Pacific Island Culture			▨	▨	-1
Family beaches: harvest			▨	▨	-1
Family beaches: tradition			▨	▨	-1
Restricted access: public access to beaches (total)			▨	▨	-1
Restricted access: public access to beaches (time limited)			▨	▨	-1
Food gathering: Mangrove crabs			▨	▨	-1
Food gathering: other fishing			▨	▨	-1
Sailing			▨		0
Access restrictions: boat launching			▨		0

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Table S.1: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Deployment (DOD)			▨		-1
Spearfishing: subsistence			▨		0
Spearfishing: competition/tournament			▨		0
Boat racing: derbies (Micronesia wide)			▨		-1
Boat racing: local events			▨		-1
Social events: Beach going (outings)			▨		0
Social events: picnics			▨		0
Social events: parties, weddings, funerals/wakes			▨		0
Aesthetics: beauty of the ocean			▨		-1
Private owned beaches: locals			▨		0
Private owned beaches: hotels			▨		0
Private owned beaches: other			▨		0
Family beaches: picnics and BBQ's			▨		0
Family beaches: swimming			▨		0
Yacht moorings			▨		-1
Vessel moorings			▨		-1
Loss of access: 6 mile danger zones			▨		0
Loss of access: 12 mile possession/domain			▨		0
Education: University of Guam			▨		1
Education: Schools (rare)			▨		1
Fishing derbies: international			▨		0
Use restrictions: firing range			▨		0
Use restrictions: Navy in port			▨		0
Seasonal fisheries: impediment to equipment (difficulty in throwing nets)				▨	1
Food gathering: Eels and shrimp				▨	1

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Table S.1: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Exposed water-land sites (freshwater seeps and caves)				▨	0
Wetlands: dry season grazing (Caribou)				▨	-1
Caribou raising				▨	-1
Prestige: Food gathering				▨	-1
Prestige: Food preparation				▨	-1
Rites of passage (fishing)				▨	-1
Prestige: food (green turtle)				▨	-1
Loss of habitat: turtle grass (food for turtles)				▨	-1
Loss of habitat: sponge gardens (food for turtles)				▨	-1

Table S.2 Palau values defined where grey shading denotes an identified value. Where “NA” denotes that no data on change in an identified value was collected.

Values	Environment	Economic	Social	Cultural	Change in Value
Water quality: issue of increased waste water outfall (sewerage)	▨	▨			NA
Coral quality (environmental appreciation): diver interactions quality	▨	▨			NA
Protected species: Dugong (local name Mesekiu)	▨		▨	▨	NA
Important species: green turtle (local name Melob)	▨		▨	▨	NA
Marine Protected Areas: tourism and recreational activities	▨		▨		NA
Protected species: shark	▨		▨		NA
Important species: mangroves	▨		▨		NA
Water quality: issue of increased marine debris	▨		▨		NA
Marine Protected Areas: conserve fish and other seafood	▨				NA
Marine Protected Areas: conserve fish and seafood habitats	▨				NA
Marine Protected Areas: conserve turtle populations	▨				NA
Marine Protected Areas: protected endangered dugong	▨				NA
Marine Protected Areas quality: boating impacts	▨				NA
Marine Protected Areas quality: invasive species	▨				NA
Water quality: pollution from oily water	▨				NA

Table S.2: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Ecosystem quality: pollution from anchorage damage	▨				NA
Rock Islands: Potential World Heritage site	▨				NA
Commercial fishery: tuna		▨	▨	▨	NA
Traditional knowledge: control fishing seasons		▨	▨	▨	NA
Food items: commercial		▨	▨		NA
Access: increased attraction for yacht cruisers		▨	▨		NA
Social species: mandarin fish (aquarium species)		▨	▨		NA
Social species: game fish (blue marlin, black marlin, sailfish)		▨	▨		NA
Marine Protected Areas: infrastructure		▨			NA
Beach development (creation)		▨			NA
Industry: water intakes (PICR)		▨			NA
Industry: waste water discharge		▨			NA
Industry: Bureau Marine Resources - mariculture		▨			NA
Industry: Bureau Marine Resources - hatchery		▨			NA
Industry: aquaculture (milk fish, rabbit fish and groupers)		▨			NA
Commercial fisheries: subsistence		▨			NA
Aquarium trade (export)		▨			NA
Tourism: diving		▨			NA
Tourism: kayaking		▨			NA
Tourism: snorkeling		▨			NA
Tourism: surfing (new)		▨			NA

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Table S.2: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Myth: sunken villages (magic breadfruit tree)		▨			NA
Tourism species: shark (main) (tiger shark - Mochelas; ocean white-tip - Melkakl; great hammerhead - Ulach; white-tep reef shark - Ulebsuchel; silver tip reef - Besachel; grey reef shark - Mederart; black tip reef shark - Matukeoll)		▨			NA
Tourism species: manta rays (local name Ouklemedao)		▨			NA
Tourism species: turtles		▨			NA
Tourism species: Whale sharks (Pelilou)		▨			NA
Tourism species: reef fish (barracouta, unicorn fish etc.)		▨			NA
Tourism habitats: coral reef		▨			NA
Tourism habitats: pelagic environment		▨			NA
Tourism habitats: wrecks (few)		▨			NA
Tourism/local interactions: unwelcome behaviors ('shark city')		▨			NA
Tourism/local interactions: unwelcome behaviors (military)		▨			NA
Tourism: dive reputation		▨			NA
Cultural species: giant clam			▨	▨	NA
Cultural species: coral reef			▨	▨	NA
Cultural species: seaweed (lesser extent)			▨	▨	NA
Food items: customary			▨	▨	NA
Fish weirs: ancient Palau			▨	▨	NA
Important species: trochus (Japanese)			▨	▨	NA

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Table S.2: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Community action: keeping environment clean and safe (chief led)			▨	▨	NA
Community actions: mangroves			▨	▨	NA
Community actions: rock islands			▨	▨	NA
Traditions: maintenance of traditions			▨	▨	NA
Cultural management: females - clam, trochus and sea cucumbers			▨	▨	NA
Cultural management: males - triton and fish			▨	▨	NA
Village sacred sites			▨	▨	NA
Village protector species			▨	▨	NA
Social species: napoleon wrasse (local name Maml)			▨	▨	NA
Access: natural space			▨		NA
Access: open access			▨		NA
Access to fishing locations			▨		NA
Access to certain fish stocks			▨		NA
Rock islands: birthdays			▨		NA
Rock islands: family get-togethers			▨		NA
Rock islands: camping			▨		NA
Rock islands: visits			▨		NA
Rock Islands: fishing			▨		NA
Aesthetics			▨		NA
Family group dynamics altered by immigrants			▨		NA
Information flow: maintenance			▨		NA

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Table S.2: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Social species: fluted clam (tourist item)			▨		NA
Social species: cuttlefish (local name Milngoll)			▨		NA
Social species: octopus (local name Bikutang)			▨		NA
Social species: nautilus (local name Kedarm)			▨		NA
Social species: sea cucumbers (local names teatfish, Bakelungal, Oas) - food, toxin, booties			▨		NA
Social species: shrimp (local name Cherchur)			▨		NA
Social species: hermit crabs (local name Chum)			▨		NA
Social species: coconut crab (local name Ketat) - food			▨		NA
Social species: moray eel (local name Kesebeku)			▨		NA
Social species: damsel fish (local name Mud/Cheremelamerand)			▨		NA
Social species: triggerfish (local name Dukl)			▨		NA
Myths: giant clam				▨	NA
Myths: shrimp				▨	NA
Myths: rock islands				▨	NA
Myths: crocodile (local name Ius)				▨	NA
Traditional fishing rights				▨	NA
Ceremonies: funeral food (eg Napoleon fish)				▨	NA
Ceremonies: engagement food (eg Pohnpei parrotfish)				▨	NA
Ceremonies: tiger shark for funerals/festivities (in the north)				▨	NA
Cultural tools: clam shells for carving				▨	NA
Important species: sea cucumbers				▨	NA

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Table S.2: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Important species: mangrove crabs				▨	NA
Myths: rabbit fish and Imelik God				▨	NA
Myths/Customs: banded sea crate (protector, God) (local name Mengerenger)				▨	NA
Myths/Customs: manta ray (protector)				▨	NA
Sacred species				▨	NA
Buul: turtle				▨	NA
Buul: turtle shell				▨	NA
Cultural sites: underwater heritage sites unknown				▨	NA
Myths: village specific					NA
Ocean: life				▨	NA
Ocean: stories				▨	NA
Ocean: legends (myths)				▨	NA
Cultural items: dugong bracelets (Olecholl)				▨	NA
Myths: origin/creation (giant clam and shrimp)					NA
Cultural food items: dugong for installation ceremonies substituted by nuts)				▨	NA
Cultural items: turtle (Hawksbill; local name Ngasech) shell				▨	NA
Cultural items: clam shell (food and tools)				▨	NA
Cultural items: trochus shell (bracelets, buttons)				▨	NA
Cultural items: triton shell (horn)				▨	NA
Traditional harvest: turtle				▨	NA
Myths: Uleb and island creation				▨	NA
Myths: turtle breeding season				▨	NA

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Table S.2.: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Cultural management: males - fish weirs/traps (rare, ancient)				▨	NA
Cultural species Black lip pearl oyster (tools, jewelry, inlays in woodcarvings)				▨	NA
Cultural species: Golden cowrie (decoration on war and sailing canoes)				▨	NA
Cultural species: Cone shells (bracelets)				▨	NA
Cultural myths: rays (related to Gods)				▨	NA
Fishing regulated species: Groupers				▨	NA
Fishing regulated species: Rabbitfish				▨	NA
Fishing regulated species: Humphead parrotfish				▨	NA
Fishing regulated species: Napoleon wrasse				▨	NA
Fishing regulated species: Aquarium species				▨	NA
Fishing regulated species: Rock lobster				▨	NA
Fishing regulated species: Mangrove crab				▨	NA
Fishing regulated species: Coconut crab				▨	NA
Fishing regulated species: Turtles				▨	NA
Fishing regulated species: Giant clams				▨	NA
Fishing regulated species: Blacklip pearl oyster				▨	NA
Fishing regulated species: Trochus				▨	NA
Fishing regulated species: Sea cucumbers				▨	NA
Fishing regulated species: Rock lobster				▨	NA
Fishing regulated species: Dugongs				▨	NA
Fishing regulated species: Sponges, hard corals and marine rock				▨	NA
Cultural items: giant clam (pestles, tools and weapons)				▨	NA

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Table S.3 Saipan values defined where grey shading denotes an identified value. A range of values for worth reflects differing perceptions (uncertainty). Where -1 denotes a perceived decrease (loss) of worth for the identified value; 0 denotes a perception of no change in worth for the identified value; and 1 = a perceived increase in the worth of an identified value.

Value	Environment	Economic	Social	Cultural	Change in Value
Corals: attracts divers	▨	▨	▨		-1, 0
Cultural species: Tellimis (food)	▨		▨	▨	0
Cultural species: Strombids (food, tools)	▨		▨	▨	0
Social species: seaweed (Japanese - food)	▨		▨		-1, 0
Protected habitats: seagrass	▨		▨		-1, 0
Protected habitats: mangroves	▨		▨		-1, 0
Protected habitats: wetlands	▨		▨		-1, 0
Cultural species: coconut crab	▨			▨	-1, 0
Cultural species: turtle	▨			▨	-1, 0
Cultural species: sea urchins (food)	▨			▨	-1, 0
Cultural species: clams	▨			▨	-1, 0
Cultural species: napoleon wrasse	▨			▨	-1, 0
Historic artifacts: tridacnids (clams)	▨			▨	-1, 0
Historic artifacts: spongylus (tools)	▨			▨	-1, 0
Cultural species: lobster	▨			▨	-1, 0
Cultural species: sea cucumber (food)	▨			▨	-1, 0
Cultural species (Carolinians): Sea birds (frigate bird) associated with navigation	▨			▨	-1, 0
Cultural species (Coralinians): black trochus	▨			▨	-1, 0
Cultural species (Coralinians): cowrie (presents)	▨			▨	-1, 0

Table S.3: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Habitat forming areas: mangroves	▨				-1, 0
Habitat forming areas: coral	▨				-1, 0
Habitat forming areas: seagrass	▨				-1, 0
Marine Parks: protecting natural resources	▨				-1, 0
Maintenance of historical sites (removal of pest species)		▨	▨		0, 1
Industry seawater intakes (firefighting)		▨	▨		0
Tourism: WWII artifacts/shipwrecks		▨	▨		-1, 0
Tourism: yacht race		▨	▨		-1, 0
Tourism: Saipan international fishing tournament		▨	▨		-1, 0
Tourism: Rota international fishing derby		▨	▨		-1, 0
Tourism: getting to paradise		▨	▨		-1, 0
Tourism: relaxation		▨	▨		-1, 0
Vessel maintenance		▨			-1, 0
Wharf/marina structure maintenance		▨			-1, 0
Tourism: diving		▨			-1, 0
Tourism: Japanese memorials		▨			-1, 0
Commercial fish species: rabbit fish		▨			-1, 0
Commercial fish species: parrot fish		▨			-1, 0
Commercial fish species: unicorn fish		▨			-1, 0
Commercial fish species: nozzle flatfish		▨			-1, 0
Aquaculture		▨			-1, 0
Maintenance of ecotourism		▨			-1, 0

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Table S.3: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Fish traps: wooden			▨	▨	-1, 0
Eminent domain			▨	▨	-1, 0
School mascots (sacred species): octopus			▨	▨	-1, 0
School mascots (sacred species): turtle			▨	▨	-1, 0
School mascots (sacred species): unicorn fish			▨	▨	-1, 0
School mascots (sacred species): dolphin			▨	▨	-1, 0
Fishing - offshore (Chamorro)			▨		-1, 0
Fishing - inshore (Carolinian)			▨		-1, 0
Recreational activities: spearfishing			▨		-1, 0
Recreational fishing			▨		-1, 0
Subsistence fishing			▨		-1, 0
Pace of life (island style)			▨		-1, 0
Aesthetics: natural beauty			▨		-1, 0
Recreation: beaches			▨		-1, 0
Tourism: beach access (includes dive site access)			▨		-1, 0
Aesthetics: isolation			▨		-1, 0
Social: Island life			▨		-1, 0
Social: Tranquility			▨		-1, 0
Beach activities			▨		-1, 0
Barbeques (beaches)			▨		-1, 0
Swimming			▨		-1, 0
Rod fishing			▨		-1, 0
Outrigger - paddling			▨		-1, 0
Commercial sport - competitions			▨		-1, 0
Cultural artifacts: WWII shipwrecks				▨	-1, 0
Cultural Carolinian: funeral traditions				▨	0

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Table S.3: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Cultural Carolinian: fishing traditions				▨	-1, 0
Cultural Carolinian: ocean navigation				▨	0
Cultural Chamorro's: fish weirs (ancient)				▨	0
Kite fishing (ancient)				▨	-1, 0
Achumaern fishery (bait fishes and bringing them up from deep)				▨	-1, 0
Connectivity with the sea (Carolinians)				▨	0
Historic artifacts: smaller clams (food and tools)				▨	0
Historic artifacts: trochus (food)				▨	0
Restrictions on Carolinian activities: cultural				▨	0
Restrictions on Carolinian activities: fishing				▨	0
Cultural species (Carolinian): green turtle (Wongemangusch Mool) - healing, cultural harvest and food				▨	0
Cultural species (Carolinian): marine plants/algae (medicinal)				▨	-1, 0
Sacred sites (Carolinians): beaches, cliffs (everything near the sea)				▨	-1, 0
Sacred waters (Carolinians): provision of food				▨	0
Sacred waters (Carolinians): provision of healing				▨	0
Cultural species (Carolinians): trochus (food)				▨	0
Cultural species (Carolinians): shore crabs (food)				▨	0
Cultural species (Carolinians): clams (food)				▨	0

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Table S.3: Continued

Value	Environment	Economic	Social	Cultural	Change in Value*
Cultural species (Carolinians): reef and deep water fishes (fish names not specified)				▨	0
Cultural species (Carolinians): seagrass for weaving				▨	0
Carolinian Culture: ocean is the mother of the footstool of heaven				▨	0
Carolinian culture: connectivity between people and ocean				▨	0
Cultural species: blue spotted grouper				▨	0
Cultural species (Carolinian): hawksbill turtle (Wongemaaw) - jewelry, funeral ceremonies				▨	0
Marine Parks: protecting history, culture and recreational values			▨	▨	-1, 0

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Supplement to the Regional Biosecurity Plan for Micronesia and Hawaii Marine Risk Assessment

Based on comments received from various reviewers of the Micronesia Biosecurity Plan Marine Risk Assessment

Edited by members of the University of Guam Micronesia Biosecurity Plan Development Team

August 2013

Critique of Chapter 5 of the Marine MBP

Many of the sections of the marine MBP report provided a solid and reliable overview of biosecurity issues in Micronesia, as well as offered useful implementing suggestions. Part I provides a good background on the history, mechanisms, and the impacts of marine invasions. In addition, the political, economic, and legal framework important to the development of risk assessment and biosecurity plans were outlined, and the vectors and human activities conducive to the introduction of non-native species in Micronesia were reviewed. Part III presented an exhaustive and thoughtful list of recommendations to develop a successful marine biosecurity plan tailor-made to the region. However, several of the marine experts contacted to review the draft marine MBP had serious concerns with the quality of Part II/Chapter 5 of the report (the Risk Assessment). A detailed critique of these sections follows, based on the reviewers' comments.

Chapter 5 suffers from erroneous assumptions, gross simplifications, wrong metrics, and a failure to include environmental and ecological data. This assessment should serve as a guideline to develop management strategies and assessment protocols specific to Micronesia. As presented, however, the risk assessment is not credible and does not provide any guidance for the implementation of a marine biosecurity plan because of:

- the non-transparent methodology employed (analyses based on a proprietary and incomplete database)
- the grouping of donor regions into unacceptably large geographical units
- the disregard of environmental and ecological data
- the lack of a thoughtful and informed review of taxonomic query results
- the masking of raw data which prevents an evaluation of the presented results, and
- the flawed likelihood-metric used to evaluate arrival/inoculation risks.

Many of these issues can be traced back to the proprietary database on which the risk analysis is based. This database consists of a limited number of potentially invasive species. Most of the analyzed species are considered to pose an invasion threat to Micronesia, as ship traffic to the region originates from many of the 18 large bioregions (apparently the basic units to document distribution ranges in the database). For this reason the taxon lists in tables 5.3 - 5.8 are almost exact copies of each other. Therefore, the risk assessment is not tailor-made to Micronesia but is in fact a generic one. If – for example – this risk assessment approach was applied to a location in the Artic that received vessels from some of the 18 large IUCN bioregions, most of medium to high risk invasive species listed for Micronesia would also appear in the "risk assessment analysis" of this Arctic locality because these species (i) are absent from the Arctic and (ii) have a broad distribution range (overlapping with many of the vast bioregions ships originate from). This underscores the necessity to include environmental and ecological variables in the analysis. Furthermore, the taxonomic identity of many of the listed invasive species is questionable. As a result, many of the medium to high risk invasive species listed for Micronesia can be rejected because:

(i) they already occur in the region (many being natives)
(ii) many are temperate (to subtropical) species that are highly unlikely to survive in tropical waters, and
(iii) many are bulk container taxa that from a practical perspective represent a large proportion of the species diversity in their respective genera.

It is difficult to imagine the utility of the Chapter 5 Risk Assessment given that the so-called "invasive species watch lists" (a) fail to list many of the important potentially invasive species, (b) are riddled by species that pose no threat (native species and non-natives restricted to other climate regions), and (c) list a number of species for which correct identifications are next to impossible.

To expand on point (c), although difficult to include in the risk assessment, one must keep in mind that cryptic diversity abounds in many groups of marine organisms (as is alluded to in part 3 of the report). Therefore simple "species watch lists" fail to capture the true extent of the potential marine invasive species in the region.

The most vocal critic among the marine experts ends with the following statement: "Lastly, please realize that you are writing a very important document that will steer future development, management, and conservation efforts in a highly biodiverse region, which is often considered to be one of the last strongholds of relatively pristine tropical reef systems. To do justice to the people and the natural heritage of the region, I sincerely hope that the authors consider improving the risk assessment analysis specifically focusing on non-native species (not just "databased" invasive species) that can realistically invade the tropical waters of Micronesia.".

More specific criticisms of Chapter 5 have been grouped into 5 categories:

1. On the accessibility of the species dataset:
The Risk Assessment depends on a listing of non-native marine and estuarine species that have "demonstrated or inferred potential to cause impact". Species listed in this database were compiled from many literature sources (over 1,000 data sources, according to the report) from both peer reviewed publications and grey literature. The authors of Chapter 5 did not see fit to release the full database they used, nor did they list their literature sources. This is very unfortunate as it precludes independent analysis of the adequacy of the available data. For instance, were there species of potentially high concern that were missed in the risk analysis? How were the species lists compiled? Are newest reports of invasive species included in the listings? Are there taxonomic issues with any of the listed species? Aside from allowing independent review of the Chapter 5 risk analysis, access to this database would be particularly useful to develop and optimize management strategies concerning invasive species in the region (that is, be able to rank which taxa are of highest priority for invasive species managers).

It is assumed that the database is based on research supported by public funds, and that the development of the species database itself was likewise supported by public funds. Therefore it seems reasonable to suppose that the species database should be available to the public. It seems, however, that this database is proprietary. A clarification seems necessary – is the database indeed proprietary? If so, what are the reasons for protecting it?

2. On the species included in the likelihood/watch lists:
As mentioned above, there are five main problems with the list of non-native marine species used in the risk analysis:

a. Assumption that only species known to be invasive pose any risk:
The literature is loaded with new records of hitherto unknown invasive species, which certainly does not support the hypothesis that a complete compilation of all invasive species is possible at this stage nor that all currently known invasive species have been archived. Moreover, little work on invasive species in the tropics has been done in comparison to the less species-rich temperate regions. Therefore the species lists are biased towards temperate species (many of which might not be able to establish populations in the tropics), and fail to take into account emergent invasive species from the tropics. It is important to acknowledge the possibility that a species which is not catalogued in the database and which does not occur in Guam can be introduced (for example, any species that belongs to a genus of which invasive representatives are known).

b. Problems with geographic range designations:
There seem to be numerous errors in the listed geographic ranges of species. Many species presumed native to Guam are nonetheless listed as having medium or high likelihood of arrival. Among the marine macroalgae, *Bryopsis pennata, Caulerpa mexicana, C. racemosa* var. *lamourouxii, Dictyosphaeria cavernosa, Neomeris annulata, Ulva clathrata, Valonia fastigiata, Chnoospora minima, Padina boryana, Acanthophora spicifera, Asparagopsis taxiformis, Centroceras clavulatum,* and *Hypnea spinella* already occur in (are native to?) Guam.

The red alga *Acanthophora spificera,* a very aggressive tropical invasive, is listed as a "Medium" likelihood of arrival for Guam, the CNMI, and FSM (see table 5.11) – yet it is actually believed to be native in these areas. However, it has been reported that this species successfully invaded the RMI and UMI (Line Islands) (Tsuda et al. 2008, Knapp et al. 2011). Table 5.11 fails to list *A. spicifera* invasion likelihood risk for either RMI or UMI. *Acanthophora spicifera* might be the best-documented and fiercest "red algal invader" in the region and is recorded as such in the following publications:

Tsuda R.T., Coles S.L., Guinther E.B., Finlay A.O. & Harriss F.L. 2008. Acanthophora spicifera (Rhodophyta: Rhodomelaceae) in the Marshall Islands. Micronesica 40: 245-252.
Knapp I.S., Godwin L.S., Smith J.E., Williams C.J. & Bell J.J. 2011. Records of non-indigenous marine species at Palmyra Atoll in the US Line Islands. Marine Biodiversity Records 4: e30.

c. Known invasive species omitted from database:
Several known invasive species that should be included in the watch lists are inexplicably not listed in the database. These include the macroalga *Spyridia*, and 3 species of marine fish reported from Apra Harbor (Smith et al. 2009). Given the methodology used in the risk analysis, one would expect to see the infamous invasive strain of *Caulerpa taxifolia* to be listed in the tables, but it is not listed. It is unclear why this species did not make the watch list. Perhaps it is considered by the authors to be the same taxon as the native *C. taxifolia*? However, from a biological perspective, the reviewer who raised this concern is fine with it not being listed on the watch list. This brings up the next point (d).

Based on the fact that many of the listed species (natively) occur in the recipient region, it seems that this analysis does not focus on non-native species but all species that are likely to be transported (which differs from the methodology description). Are the authors concerned with genetic exchange between donor and recipient regions even if the (morpho-)species already occurs in the recipient region? If so, this should be clearly stated in the report.

Smith, B.D., T.J. Donaldson, T. Schils, A. Reyes, K. Chop, and K. Dugger. 2009. Marine Biological Survey of Inner Apra Harbor, Guam. University of Guam Technical Report No. 126.

d. Inclusion of species from temperate and colder waters (non-consideration of environmental parameters and ecology):
Plenty of temperate species are considered to have a medium or high risk to be introduced, despite biologically low likelihood for establishment. Case in point: the giant kelp *Macrocystis pyrifera* almost certainly would not survive in the tropics. In fact, a recent post on the algae-l list inquired about intentional introductions of this species in France and China, where it apparently wasn't able to survive. Here it is listed as a medium risk invader in the tropics. On p. 312, the chapter authors cite Graham et al. (2007) in support of their inclusion of Macrocystis in their species list. However, Graham et al. (2007) mention that the alga occurs over a wide temperature gradient from boreal to warm temperate waters. Why would you then consider this species to be an invasive outside of this wide temperature range (i.e., in tropical Micronesian waters)?

Other temperate algal species that are deemed unlikely to be established in Micronesia and Hawaii include *Sargassum muticum*, *Pylaiella*, *Bangia*, *Caulacanthus*, and *Corallina officinalis*.

Graham, M. H., J. A. Vásquez, and A. H. Buschmann. 2007. Global ecology of the giant kelp *Macrocystis*: From ecotypes to ecosystems. Oceanography and Marine Biology 45: 39-88.

e. Problems with cryptic species:
A large proportion of some of the groups included in this report are in fact cryptic species (currently lumped in species complexes). The marine MBP categorizes them as cryptogenetic species (=species of uncertain geographic origin), but this is not exactly correct. Many of these species can reasonably be assumed to be native to Micronesia, but their identification to species-level is dependent on a molecular–assisted alpha taxonomy approach and has not been conducted on most of the considered taxa. Some of these groups in which cryptic diversity abound include textbook examples of invasive species in the region.

For example, the *Ulva* species listed in the tables are bulk container taxa that include a diversity of species throughout their distribution range. The listed names have often been used out of convenience because morphological characteristics to identify *Ulva* species are limited. Indicating that "just" these *Ulva* "species" have a high likelihood to spread shows the shortcomings of the methodology based on a preconceived list of invasive species. The same is basically true for all the other listed green algae in this and subsequent tables. Among the red algae, *Laurencia brongniartii* (an often misapplied name) and *Hildenbrandia rubra* also stand out. Inclusion of *Hildenbrandia rubra* shows that the data was analyzed without much knowledge about phycology. Records for *Hildenbrandia* are scarce in the region & this particular species identification has often been one of convenience – it is unlikely that this is the same species throughout its huge distribution range. The type locality of this species is in Norway. It’s unrealistic to assume that this species can grow in Micronesian waters.

3. On the bioregions used in the risk assessments:

Geographic distributions of the species used in the Chapter 5 risk assessments were delineated based on 18 large scale IUCN marine bioregions (see figure 5.3). These bioregions are too broad to be useful for risk assessments. The entire area covered by the Micronesian Biosecurity Plan falls within one vast bioregion (bioregion #14) that stretches from the Marianas in the west to Hawai'i and the Tuamotus in the east (N.B., the placement of Palau is not clear from figure 5.3 – it could be in bioregion #14 or #13). Bioregion #14 straddles a large portion of the well known "mega-transect" of declining marine biodiversity from the western to the central Pacific (driven largely by processes such as isolation and dispersal limitation). For example, there are marine species native to the Solomon Islands that are not present in Guam, and there are native species in Guam that are not found in Fiji, much less Hawai'i (which is very depauperate and has proportionally higher marine endemicity than other areas of the Western Pacific). Therefore, placing a species of interest as belonging to bioregion 14 is not at all useful, as it will tend to erroneously designate introduced species as native. Consider the impact of the assumed size of bioregion 14 on Hawai'i: the assumption used in this analysis disregards risks of exchanging invasive species between Micronesia and Hawai'i. This doesn't seem logical and it invalidates the risk assessment. The prime objective of the MBP is to prevent arrival and establishment of invasive species in Micronesia and Hawai'i, and Micronesia is undoubtedly a major source of invasive species for Hawai'i (and vice versa).

The authors of Chapter 5 imply that they do not only rely on the 18 regions designated by IUCN. They state that the IUCN bioregions have overlapping boundaries, resulting in a sequence of 'core' and 'transitional' areas that are roughly equivalent to a newer, finer-scale, and more widely-accepted biogeographic analysis by Spalding et al. (2007). However, it is difficult to comprehend how the bioregion overlaps can be equivalent to Spalding et al.'s approach, given that Spalding et al. (2007) identified a total of 62 marine provinces and 232 ecoregions. Logically, some of this geographic detail must be lost in an analysis based on only 18 bioregions.

The 'conservative approach' to estimating species distributions favored by the chapter authors simply does not result in a useful risk assessment, when the geographic scale employed is so large that there is virtually no difference between a region-specific risk assessment (what the authors set out to do) and a global analysis (what actually resulted from their work). While it is true that fine-scale geographic distribution data are not available for many taxonomic groups, there are some better studied groups for which such data are readily available (e.g., marine macroalgae, fish, etc.). Why not work on a finer geographical scale when possible? A finer geographic grain could have been applied for those taxa for which data are available, and a coarser-grained analysis could still have been done for taxa that lack such resolution.

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4. On environmental & ecological parameters, and niche modeling:

This has already been referred to in point 2, but it is important to stress that the inclusion of ecological data and environmental parameters (especially temperature data) is essential to produce a tailor-made invasive risk assessment plan for a specific region, i.e. the goal of this report. Given that that very little biological information was included in the risk analysis, this chapter is essentially an extension of chapter 3, and should be included there as a subsection.

On page 311 of the original document, the chapter authors reject the use of “environmental matching” studies (more popularly known as environmental niche modeling), which is employed to model species distributions (including predicting potential species invasions). They cite Hewitt and Hayes (2002) in support of their arguments; however their 2002 paper does not represent the current state-of-the-art of remote sensing products. It is suggested that they have a look at Verbruggen et al. (2009) and Tyberghein et al. (2012) on niche modeling of marine species using environmental data. The reviewer in this case disagrees with the rejection of environmental matching/niche modeling, arguing that this is currently the only realistic method to conduct a risk analysis of a large suite of invasive taxa incorporating environmental conditions. If the distribution ranges of the taxa of interest are of high resolution, most of the environmental data will be too. Also, with the availability of increasingly better satellite imagery products, this is the only option if one wants to include the temporal variability in environmental variables (seasonality) to model invasive risks on a global scale (consistent use of a single product of the same resolution and similar error margins). This approach is the norm and - although not perfect - a great improvement on analyses that ignore environmental parameters completely (like the here-presented analysis).

Also (still on p. 311), the environmental match between the Port of Sydney and the Port of Hobart based on an IUCN bioregion approach indicates the weakness of the methodology used in this report. If the authors opt for a very coarse-scale biogeographic concept (as commented on before), indeed little environmental variability is to be expected. If, however, they used the widely accepted and most current biogeographic concept of Spalding et al. (2007), the authors would have noticed that both ports are two ecoregions apart (Sydney: marine ecoregion 203; Hobart: marine ecoregion 205). Furthermore since the authors are from Australia they should be aware that the IMCRA bioregion model is at an even finer scale than Spalding's marine ecoregion model and is completely compatible with the latter. So, if one conducts an invasive species risk analysis confined to a specific region, why not use the best biogeographic concept available for that region? Both harbors are 4 meso-scale IMCRA bioregions apart, which clearly indicates that these regions differ environmentally. The reason for the failure of niche modeling to accurately predict the species distribution of *Asterias amurensis* is not because of a fundamental flaw with niche modeling studies, but rather because the biogeographic region used in the analysis was too large. Inaccurate prediction of the range of the seastar does not justify the exclusion of environmental data in the marine MBP risk assessment.

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Tyberghein L., Verbruggen H., Pauly K., Troupin C., Mineur F. & De Clerck O. 2012. Bio-ORACLE: a global environmental dataset for marine species distribution modeling. Global Ecology & Biogeography 21: 272-281.

Verbruggen H., Tyberghein L., Pauly K., Vlaeminck C., van Nieuwenhuyze K., Kooistra, W.H.C.F., Leliaert F. De Clerck O. 2009. Macroecology meets macroevolution: evolutionary niche dynamics in the seaweed Halimeda. Global Ecology & Biogeography 18: 393-405.

5. On assumptions in the analyses:

To determine the risk of introduction of a potentially invasive species, Chapter 5 authors equated likelihood of introduction with the proportion of vessel arrivals originating from different global bioregions. Given the acknowledged incompleteness and inaccuracy in the available vessel traffic data, it would have been better to concentrate on environmental/ecological factors that determine the establishment, survival, and spread of potentially invasive species in tropical waters. An inoculation only needs to occur once to be successful, probabilities of how many times such introductions can occur are rather irrelevant for a good biosecurity plan. If species X has the physiological capability to invade Micronesia (for instance, if it is a habitat generalist and only occurs in a geographically confined tropical location), then the inoculation only has to happen once for a successful establishment. On the other hand if species X only occurs in temperate waters then the likelihood of inoculation in Micronesia is practically zero (contradicting the unrealistic likelihoods calculated in the risk assessment). Chapter 5 does not assess the risk of species invasions; rather it estimates the probability of an invasion from a generic representative of a bioregional fauna/flora.

Table 5.2 presents a likelihood matrix that defines probability of inoculations based on proportion of vessel traffic from different bioregions. There are two major problems with this likelihood matrix:

a) the levels are arbitrarily defined (e.g., what is the real-life difference between 1-10% probability – “extremely low” – and 10-25% probability – very low? And as mentioned above, wouldn’t a single successful inoculation be sufficient to establish a species in a new locality?

b) flawed use of the *proportion* of vessel traffic, rather than the actual number of vessels. The problem with this method is illustrated in the following example:

Say, you have two regions for which you do a risk assessment (R1 and R2).

For R1 you have 500 ship arrivals from Bioregion A, 100 from Bioregion B, and 50 from Bioregion C.

For R2 you have 5 ship arrivals from Bioregion A, 10 from Bioregion B, and 50 from Bioregion C.

This translates into the following percentages of total arrivals:

R1: 77% from A, 15% from B, and 8% from C

R2: 8% from A, 15% from B, and 77% from C

So, you conclude that the risk of an invasion in R1 is highest from A (once again incorrectly ignoring environmental/ecological variables), then B, and then C.

For R2 you find the reverse.

However, when you look at the real risk, you see that both regions are similarly connected to bioregion C (equal risk, both have 50 ship arrivals from this region). Yet, in your risk analysis you conclude that the likelihood of a non-native species arrival from Bioregion C at R1 (based on 50 ship arrivals) is "extremely low" whereas this likelihood is regarded to be high at R2 (based on the same number of ship arrivals: 50). Similarly, you find an equal risk (77%) of a species from Bioregion A arriving at R1 as one from Bioregion C arriving at R2, whereas R1 receives 500 ship arrivals from Bioregion A and R2 "only" 50 from Bioregion C.

It could be argued that you could conduct this likelihood for the two regions combined (which is not done in this report), but the essence remains the same: where do these proportional cut-off margins come from and how were they arbitrarily defined? The arrival of a single heavily fouled barge from an unlikely tropical donor region is a much greater risk than hundreds of clean Navy vessels from San Diego.

The errors of this approach are well illustrated in the results of the risk analyses for the FSM and RMI. For the FSM, the total number of vessel arrivals was 811 while for the Marshall Islands, there were 1170 arrivals. So, if a non-native species X could be "imported" on 615 vessel entries in the FSM, this would be regarded as a high risk likelihood (76%). The same number of potential arrivals of this species (bioregion in fact) in the Marshall Islands (615), would suddenly become a medium (almost a low risk: 53%) for the Marshall Islands. This "proportional" risk assessment approach is wrong, in the above scenario species X poses an equal invasion threat to the FSM and the Marshall Islands.

Because the total number of arrivals is higher and because of the limited number of "predetermined" potentially invasive species in the data set, it is mathematically obvious that the Marshall Islands have a lower number of species that meet the proportional thresholds that determines the "high risk category" when compared to the FSM.

Recommendations:

The inclusion of an analysis that pinpoints/ranks the last ports of call that pose the greatest threat to import viable non-native species to Micronesia would be of great benefit to the development of a biosecurity plan.

Also, on p. 318 there is mention of ranking ports of inoculation into high-risk, medium-risk, and low-risk – such a ranking would be extremely useful for invasive species managers.

Likewise, a ranking of species from those of negligible concern to species of serious concern (=high likelihood of introduction coupled with large potential ecological impacts) would be a very important contribution to the risk assessment and biosecurity plan. This would require consideration of environmental parameters (of the receiving environment) and ecological data (of the potential invasive species) to derive better predictions of which species are physiologically capable of establishing themselves in Micronesia and Hawai'i (i.e., environmental niche modeling).

A comprehensive marine risk assessment would not focus solely on biofoulers on commercial and MSC vessels, but also consider:

(a) biofouling communities brought in by recreational vessels and barges (both are less maintained than commercial vessels, therefore have higher risks of transporting invasive species), and

(b) other vectors, most importantly introductions from the live trade and from ballast water.

Consider expanding risk analyses beyond the known invasive species, by including species that are likely to exhibit invasive characteristics – for instance, including all species in genera that include invasive representatives.

Consider gathering new (primary) data on tropical marine invasive species in Micronesia. Chapter 6 of the marine MBP already recommends baseline surveys and periodic monitoring of port areas, and the development of a coordinated database on information on species, vessel traffic, and ballast water (section 6.2.1, p. 318). To these very timely recommendations, one could add alpha-taxonomic studies on species complexes that include invasive members. Such studies should include a molecular/ DNA barcoding component, which would provide rapid and inexpensive determinations of taxa.

Lastly, to improve the quality of the existing analyses as they stand, the following are recommended:

- release of the full species database, including references used, mention of availability of ecological, environmental, and distributional data (or lack thereof), and an assessment of the reliability / accuracy of the data provided
- assembly of more data (and better data) on the distribution of species
- improvement of species lists (acknowledgement of cryptic species/ species complexes, known invasive species not currently in database)
- geographically finer-scale analyses for those groups where available data permits more detailed analyses (e.g., marine macroalgae, which have a good database on species' biology and geographic distributions).