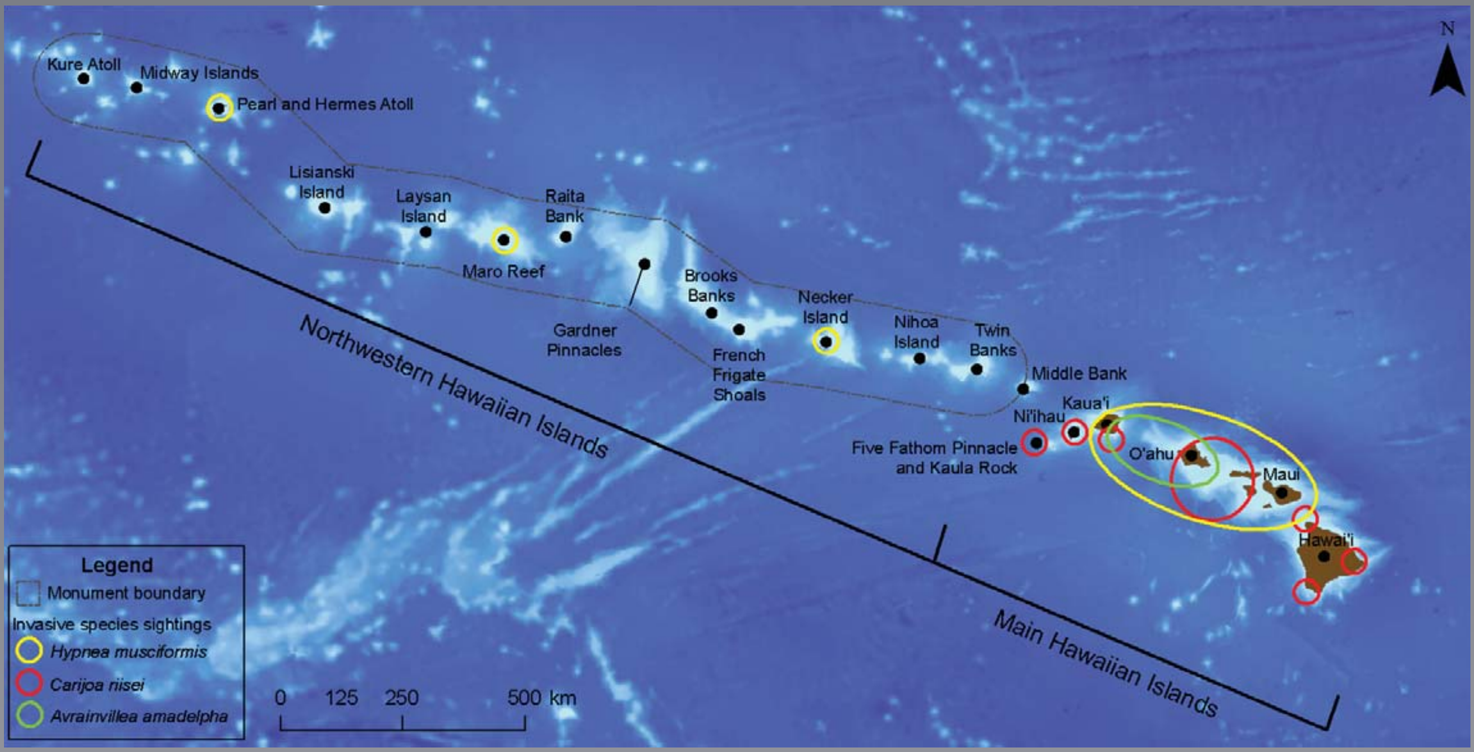
A Surveillance Strategy for Invasive Species of Concern in Deepwater Habitats of the Northwestern Hawaiian Islands



June 2010

A report by the Center for Coastal Monitoring and Assessment's Biogeography Branch for the Papahānaumokuākea Marine National Monument

NOAA Technical Memorandum NCCOS 108

Citation for this Report

Menza C., C. Caldow and M.E. Monaco 2010. A surveillance strategy for invasive species of concern in deepwater habitats of the Northwestern Hawaiian Islands. NOAA Technical Memorandum NOS NCCOS 108. Silver Spring, MD. 26 pp.

Acknowledgements

Many scientists and natural resource managers contributed to this report. Randy Kosaki, Scott Godwin and Kelly Gleason at the Papahānaumokuākea Marine National Monument provided guidance and support. Scientists at multiple institutions provided data and offered their expertise, including John Rooney, Jonathan Weiss, Peter Vroom, Oliver Vetter, Jamie Gove, Kevin Wong, and Vikrum Khurana at the Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division; Tony Montgomery at Hawaii's Department of Land and Natural Resources, Division of Aquatic Resources; and Cynthia Hunter, Margaret McManus, Heather Spaulding and Celia Smith at the University of Hawaii at Manoa. Funding for this report was provided by the Papahānaumokuākea Marine National Monument and Center for Coastal Monitoring and Assessment.

For more information

For more information about this report, please contact Charles Menza at CCMA's Biogeography Branch. (301) 713-3028, charles.menza@noaa.gov or visit http://ccma.nos.noaa.gov/about/biogeography/. A project website was developed to provide free access to many of the spatial datasets, visit http://ccma.nos.noaa.gov/stressors/invasivespecies/monitoring.html.

Cover photos by Sam Kahng of *Carijoa riisei* (left) and by Kelly Gleason of Randy Kosaki searching for deepwater invasive species at Nihoa (Moku Manu) (right).

A Surveillance Strategy for Invasive Species of Concern in Deepwater Habitats of the Northwestern Hawaiian Islands

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NOAA Technical Memorandum NOS NCCOS 108
June 2010

Executive Summary

This report describes a surveillance strategy to detect deepwater invasive species in the Northwestern Hawaiian Islands. A need for this strategy was identified in the Papahānaumokuākea Marine National Monument Management Plan and the Monument's Draft Natural Resources Science Plan. This strategy focuses on detecting two species of concern, the octocoral *Carijoa riisei* and the red alga *Hypnea musciformis*.

Most research on invasive species in the Hawaiian archipelago has focused on shallow water habitats within the limits of conventional SCUBA (0-30 m). Deeper habitats such as mesophotic reefs are much more difficult to access and consequently little is known about the distribution of deepwater invasive species or their impacts. Recent deepwater (>30 m) sightings of *H. musciformis* and *C. riisei*, in and near NWHI, respectively, have prompted a call for further research and surveillance of invasive species in deepwater habitats.

This report compiles the most up to date information about these two species of concern in deepwater habitats. A literature search and conversations with subject matter experts was used to identify their current distribution, preferred habitat types, optimal detection methods and ways to efficiently sample the vast extent of NWHI.

The proposed sampling strategy prioritizes survey effort where *C. riisei* and *H. musciformis* are most likely to be found. At coarse spatial scales (tens to hundreds of kilometers), opportunistic observations and distance from the Main Hawaiian Islands, a principal propagule source, are used to identify high-risk islands and banks. At fine spatial scales (meters to tens of kilometers) a habitat suitability model was developed to identify high-risk habitats.

The habitat suitability model focused on habitat preferences of *C. riisei*, since the species is well studied and adequate data exists to map habitats. There was insufficient information to identify suitable habitat for *H. muscifomis*. Habitat preferences for the algae are poorly understood and there is a lack of data at relevant spatial scales to map those preferences which are known. The principal habitats identified by the habitat suitability model were ledges and the edges of rugose coral reefs, where the shade loving octocoral would likely be found. Habitat suitability maps were developed for seven atolls and banks to aid in survey site selection.

The protocol relied on technical divers to conduct visual surveys of benthic habitats. It was developed to increase the efficiency of surveys, maximize the probability of detection, identify important information relevant to future surveys and standardize results.

The strategy, model and protocol were tested during a field mission in 2009 at several atolls and islands in NWHI. The field mission did not detect any invasive species among deepwater habitats and much was learned to improve future surveys. Data gaps and improvements are discussed.

Goal

This document provides strategies to detect deepwater invasive species in the Northwestern Hawaiian Islands (NWHI) in support of the Papahānaumokuākea Marine National Monument (PMNM). The strategies use technical diving to conduct visual surveys and focus on two invasive species of growing concern, the octocoral *Carijoa riisei* and the red alga *Hypnea musciformis*. Both of these species are well established in the Main Hawaiian Islands (MHI), and managers and scientists are concerned they will negatively impact the relatively pristine marine ecosystems of the NWHI.

About this Document

This work is part of a collaborative investigation by the Center for Coastal Monitoring and Assessment's Biogeography Branch and PMNM. Since 2007 the Biogeography Branch has collaborated with PMNM to improve invasive species surveillance and satisfy objectives outlined in the Monument Management Plan (PMNM 2008) and the Draft Natural Resources Science Plan (PMNM 2009a). This document supported a field mission to NWHI in 2009 with requirements for a sampling design and survey protocol. It builds upon a previous investigation of survey technologies and modeling techniques for improving deepwater surveys of invasive species (Menza and Monaco, 2009).

Background

NWHI consists of a remote chain of islands, atolls and submerged banks which stretch for over 2000 km (1,250 mi) northwest of the Main Hawaiian Islands (Figure 1). The chain includes vast expanses of relatively pristine marine ecosystems and is characterized by high biodiversity and endemism.

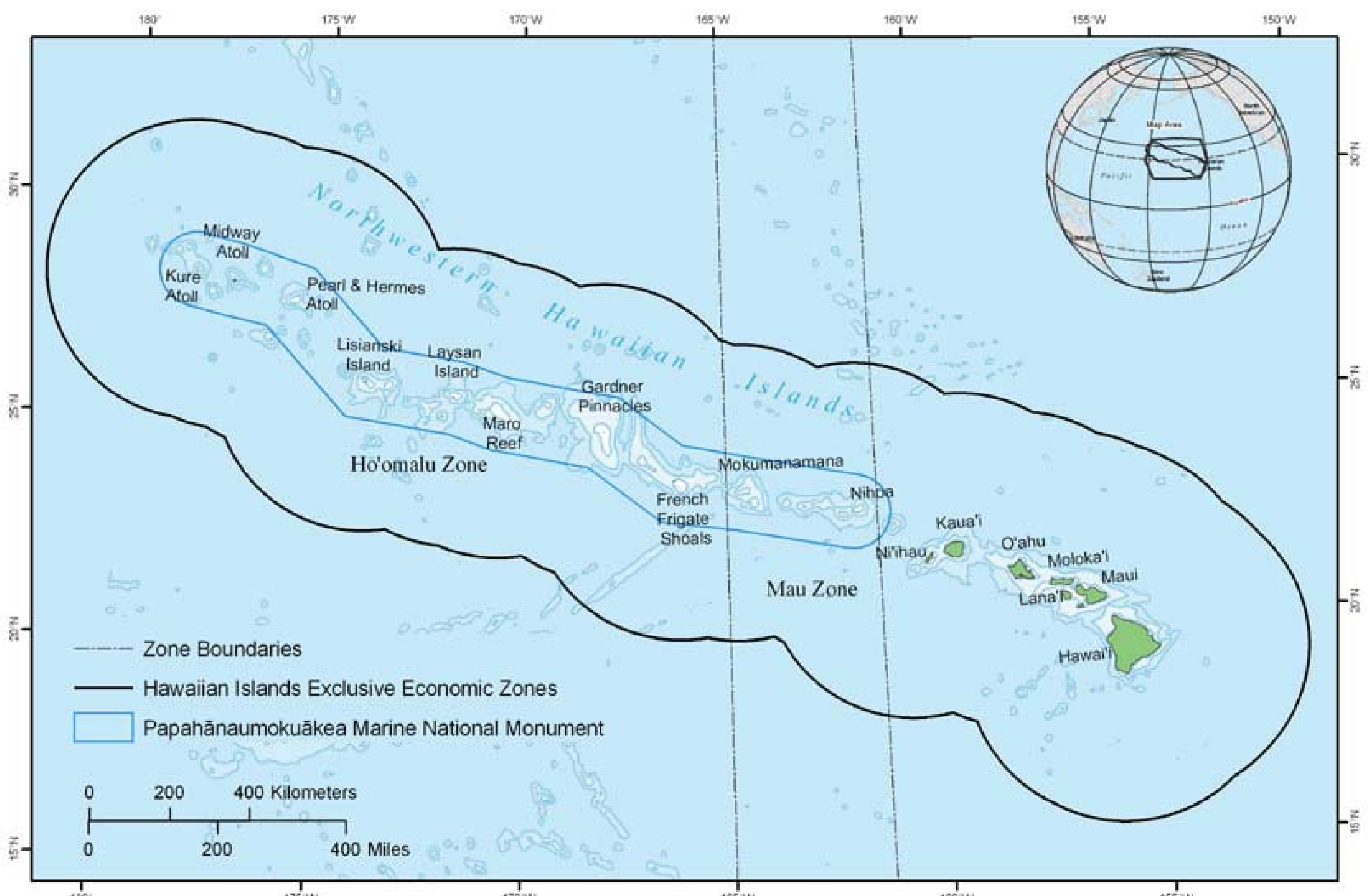


Figure 1. Map of the Northwestern Hawaiian Islands. Source: Papahānaumokuākea Marine National Monument.

The task of the PMNM is to protect the natural and cultural resources in NWHI from a wide variety of environmental and anthropogenic stressors. Aquatic invasive species represent one such stressor, with possible impacts to biodiversity, ecosystem function, habitat structure, and socioeconomics (Ruiz 1997; Selkoe et al. 2008). PMNM has taken active steps to mitigate the threats of invasive species to NWHI, including development of regulations and protocols to reduce the likelihood of transporting invasive species from source populations in MHI, implementation of the Alien Species Action Plan (PMNM 2008) to coordinate management, and investment into threat assessments (See 2007; Selkoe et al. 2008), and ecological and technical research (Menza and Monaco, 2009; this document).

Recent sightings of two invasive species, *Hypnea musciformis* and *Carijoa riisei*, in and near NWHI, respectively (Godwin et al. 2006; Friedlander et al. 2002), have concerned scientists and managers. Both species have demonstrated invasive characteristics in MHI, including outcompeting native species and modifying benthic structure (Smith et al. 2002; Russell and Balaz 1992; Grigg 2003). Their prolific reproduction, rapid range expansion and proven ability to adapt to new habitats underscore the urgency of finding ways to monitor their spread and manage their impacts.

Most of the research involving invasive species in the Hawaiian archipelago has focused on shallow water habitats within the limits of conventional SCUBA (0-30 m). Deeper habitats such as mesophotic reefs are much more difficult to access and consequently there is little information about the distribution of invasive species below 30 m or their impacts. Data from the few studies that exist in deepwater systems (e.g., Grigg 2003) and opportunistic observations (Friedlander et al. 2008) suggest that the distribution of invasive species is expanding and their ecological impacts can be severe. A confounding factor is the lack of baseline ecological information in deepwater ecosystems. Mesophotic reefs, which are found between 30 and 100 m, have recently been prioritized for study in the Monument (PMNM 2009b), but little is known about their ecology, unique marine communities, potential services, connectivity to other ecosystems, and spatial and temporal dynamics.

In response to concerns of invasive species in deepwater habitats, this report describes a surveillance strategy targeting two invasive species of concern. The strategy uses the most up-to-date ecological information available and recommendations from subject matter experts to identify the most appropriate methods for early detection and information useful for future surveys.

General Strategy

The goal of the proposed strategy is to detect invasive species as early as possible while minimizing costs, and working within logistical constraints. Early detection is a critical component of invasive species management (NISC 2008), because the longer an invasive species is established, the more likely it will impact the surrounding habitats and continue to spread. To increase the chances of correctly detecting invasive species when it is rare (i.e. low abundance, minimal impacts to the surrounding environment and heterogeneous spatial distribution) the strategy uses visual surveys in high-risk areas to detect invasive species of primary concern. This approach maximizes the chances of finding an invasive species if it is present.

A large number of nonindigenous species have the potential to invade the NWHI and cause ecological damage. Over 300 species are in the main Hawaiian Islands. To effectively allocate finite resources, it is necessary to concentrate surveillance effort on species with the greatest impacts and those most likely to invade. By concentrating attention on a small number of invasive species, a surveillance program can use basic ecological principals to target areas with the highest propagule pressure and most suitable habitats, and use a survey method with the greatest detection probability.

PMNM has laid the foundation of this surveillance strategy by identifying invasive species of concern and the most likely locations they will invade (Godwin et al. 2006). This report elaborates on past work by compiling the most up-to-date information about potential invasive species in the NWHI and uses the best available ecological and physical data to target specific locations for surveillance. Guidance was provided by local subject matter experts, including scientists and natural resource managers from academia and state and federal agencies [Hawai'i Institute of Marine Biology, the University of Hawai'i at Manoa, the Hawaii Pacific University, the Coral Reef Ecosystem Division in NOAA's Pacific Islands Fisheries Science Center, the Department of Land and Natural Resources and PMNM]. Additional direction was provided by similar invasive species detection and surveillance programs (e.g., McNaught et al. 2006; Culver et al. 2009; Fox et al. 2009).

It is expected that the surveillance strategy will adapt as new information becomes available. Since new and better information is always forthcoming, a strategy must constantly evolve to mitigate new threats and must be part of an iterative process involving risk assessment and invasive species management. For instance, the identification and incorporation of new sighting data is critical to effective allocation of survey effort.

Invasive Species of Most Concern

At least 11 nonindigenous species have been found in the NWHI (See 2007), and many hundreds more nearby in the Main Hawaiian Islands (Eldredge and Carlton, 2002). Many of these species are not considered invasive species, because they do not cause ecological or economic harm and most do not spread far from their original site of introduction. Although unnatural and with the potential to become invasive, these non-invasive nonindigenous species are not the focus of this surveillance strategy. PMNM selected *C. riisei* and *H. musciformis* as species of most concern, because they have been shown to cause the worst ecological or economic harm in MHI, and have a high probability of invading pristine habitats of NWHI (Table 1). A third species, *Avrainvillea amadelpha,* was noted as an additional threat during research for this report.

Table 1. Species of concern.

Primary	**Detected in NWHI**	**Detected below 30 m**
Carijoa riisei	No	Yes
Hypnea musciformis	Yes	Yes
Secondary		
Avrainvillea amadelpha	No	Yes

C. riisei was first detected in the Hawaiian archipelago off O'ahu in 1966, but has since spread throughout MHI (Coles and Eldredge, 2002). Initially, new sightings were among islands south of Oahu (e.g. Maui, Big Island, Molokai, and Lanai). More recently, colonies have been detected among islands north of O'ahu, such as Kaua'i (2002), Ni'ihau (2005) and Five Fathom Pinnacle (2007). These more recent observations suggest *C. riisei* is poised to enter NWHI (see Figure 2).

Underwater photo of C. riisei. *Photo courtesy of DAR.*

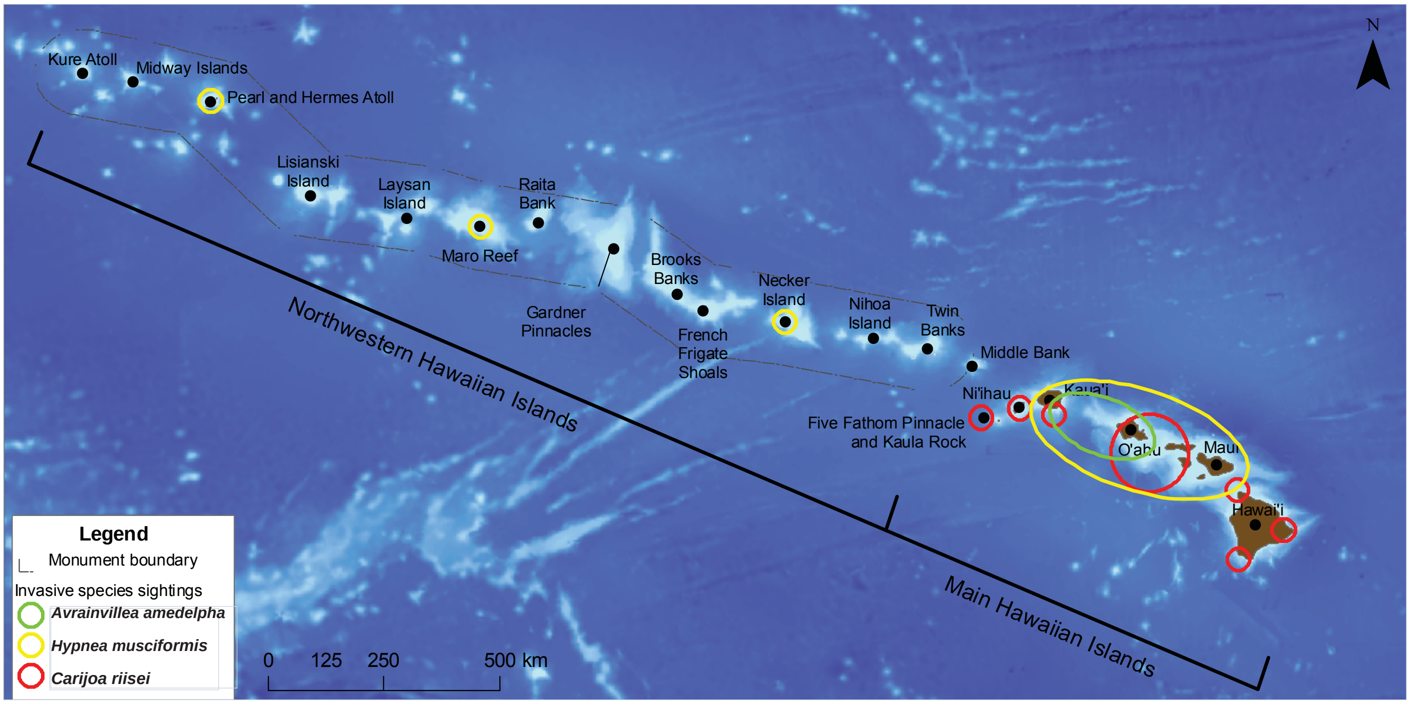
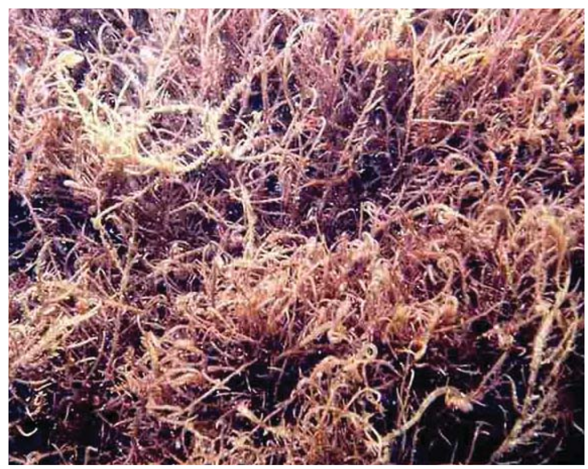


Figure 2. Map of locations where invasive species of concern have been found.

H. musciformis is widely distributed among MHI and has been found at three locations inside PMNM. The alga is typically found in shallow water, but was found entangled in lobster traps soaked at 30 m. Multiple sightings were made on traps at Necker Island between 2002-2005 and at Pearl and Hermes Reef in 2000. Individuals were also identified as part of a drift assemblage at Maro Reef in 2002. None of these sightings offer undeniable evidence of an established colony on benthic habitat, but they do prove propagule pressure. Two explorative deep water surveys at Necker Island after 2005 and an ongoing long-term shallow water monitoring program (NOWRAMP) have not detected the invasive alga.

In addition to *C. riisei* and *H. musciformis*, subject matter experts identified *Avrainvillea amadelpha* as a species of concern for NWHI. *A. amadelpha* is a successful invasive alga on the island of O'ahu and was recently sighted on the island of Kaua'i (Smith et al. 2002). Although it is typically observed in shallow water, recent ROV surveys of deep algal meadows found *A. amadelpha* down to 80 m (Spaulding pers. comm.). *A. amadelpha* is not a target of this surveillance strategy, but should be searched for opportunistically.



Underwater photo of H. musciformis.
Photo courtesy of Jen Smith.

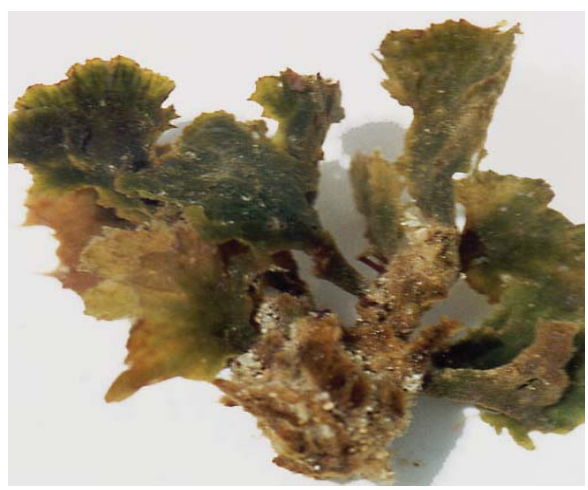


Photo of A. amadelpha.
Photo courtesy of Bishop Museum.

Islands and Banks of Most Concern

PMNM consists of many islands, atolls and submerged banks which stretch for over 2,000 km (1,250 mi.) northwest of the Main Hawaiian Islands. Since this entire area cannot be monitored exhaustively, a strategy which prioritizes areas where invasions are most likely to occur is needed. The proposed strategy prioritizes islands and banks which have confirmed sightings of invasive species or are close to established populations.

Within PMNM sightings of *H. musciformis* have been made at Necker Island, Pearl and Hermes reef and Maro reef (Figure 2). *C. riisei* has not yet been observed inside Monument boundaries, but established populations have been found as close as 150 km from the Monument. It is important to note that *H. musciformis* sightings do not necessarily correspond to established colonies, because individuals were observed on fishing gear and not on benthic substrate. Gear may have snagged individuals moving in water currents or possibly had attached colonies prior to transport into the Monument. The latter is unlikely since the Monument makes a great effort to inspect all gear going into the Monument for invasive species. Even if sightings do not correspond to established colonies they unquestionably are evidence of propagule pressure. Accordingly, the islands where *H. musciformis* has been found have been prioritized for surveillance.

The MHI are the most likely source of invasive species propagules to NWHI (Godwin et al. 2006), because they have established invasive species colonies, potential pathways to NWHI by way of ship traffic and water currents, and are the closest islands with similar ecosystems. Nihoa Island, Twin Banks, and Necker Island (Mokumanamana) are all within (< 500 km) of the Main Hawaiian Islands and are more likely to be invaded by invasive species than islands further up the chain. It is quite possible for invasive species to jump islands, but finite survey effort is well placed in areas closest to potential sources.

Another category of islands which should be prioritized for surveillance are those places outside of, but adjacent to PMNM. Sentinel sites include Five Fathom Pinnacle, Ka’ula Rock, Ni’ihau, Kauai and Middle Bank. *C. riisei* has already been detected at Ni’ihau and Five Fathom Pinnacle. Information on the rate of spread, habitat type and ecological impacts of known invasive species is useful for prioritizing management actions and the placement of surveillance sites in NWHI. The detection of a new invasive species at a sentinel site gives managers forewarning of impending invasions and time to prepare control or eradication strategies before the species moves into NWHI.

Figure 3 shows the relative priority ranking for surveillance of the islands, atolls and banks of NWHI and sentinel sites. Three rankings (high, medium, low) indicate the surveillance priority level. A high level indicates places where *H. musciformis* and *C. riisei* have been sighted. Locations with a medium level are places within 500 km of established invasive species colonies, which does not include where *H. musciformis* was detected on fishing gear. A low level identifies the remainder, places without invasive species sightings and which are greater than 500 km from established colonies.

Habitat Suitability

A habitat suitability model (HSM) was developed to prioritize surveillance sites at individual atolls, islands or banks. The model relied on scientific literature and discussions with subject matter experts to define suitable habitat types for *C. riisei* and the best approaches to identify suitable habitats. The model was not developed to explicitly identify habitats for *H. musciformis* since the alga is found in

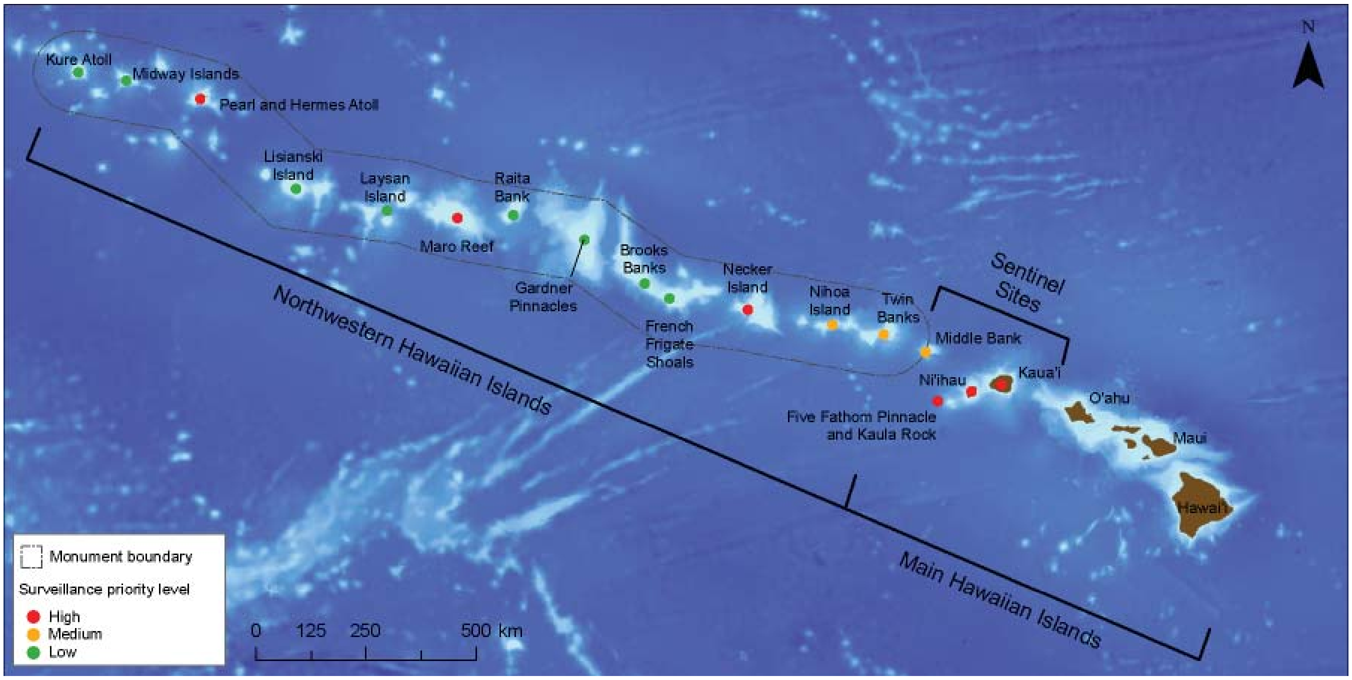


Figure 3. A map showing the relative priority ranking of islands and banks for surveillance of invasive species in deepwater habitats.

many habitats and a corresponding HSM would not adequately focus resources. It is expected that by targeting *C. riisei* habitats, *H. musciformis* can still be detected due to habitat overlap.

C. riisei attaches to hardbottom substrate, where there is sufficient water movement to provide adequate food, and is within physiological tolerances of light, salinity and temperature (Kahng 2006). To model the distribution of *C. riisei*, bathymetry data was analyzed to identify benthic habitats which provided shade and hardbottom substrate, and locations within temperature tolerances. Salinity was not used in the model, because salinity levels do not approach ecological thresholds for *C. riisei* in deepwater habitats of NWHI and water movement was not used because data at relevant spatial and temporal scales was unavailable.

Habitat types which provided shade and hardbottom substrate were identified using bathymetric complexity. Bathymetric complexity is a measure of change in depth over a specified distance and was calculated using a nearest-neighbor moving window (3 cell by 3 cell) over a bathymetric surface. Areas with high bathymetric complexity represented habitats with abrupt changes in depth, such as ledges, sharp edges of rugose coral reef, boulder fields and steep slopes. These habitat types are likely to provide shade and consist of hardbottom substrate, which are favored by *C. riisei*. In contrast, areas of low complexity represented flat habitats such as sand, algal plains or carbonate pavement. A similar approach has been used by others (Kendall et al. 2005; Pittman et al. 2007; Dunn and Halpin 2009) to identify habitats such as ledges, patch reefs and aggregate reefs in shallow water ecosystems. Due to differences in the spatial pattern of benthic habitats among islands, different thresholds were used to discriminate high versus low complexity values. The precise thresholds were identified by visual interpretation and were chosen to isolate geomorphological benthic features, such as ledges and reef edges.

Bathymetry surfaces for NWHI and MHI are available from NOAA's Pacific Islands Fisheries Science Center (PIFSC) Coral Reef Ecosystem Division (CRED) and the Hawaii Mapping Research

Group (HMRG). The majority of bathymetry datasets are available online from the corresponding developer, but the 5 m surface for Necker Island was purposely generated by PIFSC CRED upon request for this report. Data is provided for different locations in different resolutions (Table 2), not all of which are appropriate for analysis of benthic habitat. Fine-scale (5 m) bathymetry allowed excellent visualization of underwater ledges and rugose coral reefs and provided a means to easily distinguish these habitats from flat habitats in resulting maps (Figure 4). A cursory comparison of bathymetric complexity using 5 m, 20 m and 87 m resolution surfaces, indicated ledges and patch reefs clearly seen in the 5 m resolution data were absent in the coarser scale data (Figure 5). In addition, steep slopes were much more likely to be incorrectly identified as suitable habitat in coarser scale bathymetry. Consequently, only locations with 5 m resolution data were modeled.

Bathymetric complexity was used to identify suitable habitats only in areas shallower than 65 m. In deeper water, light is sufficiently attenuated in the water column allowing *C. riisei* to grow on exposed flat hardbottom habitats, such as carbonate pavement. As a result bathymetric complexity can't be used to differentiate between suitable hardbottom and unsuitable softbottom habitats. Analysis of multibeam backscatter data can solve this problem, but backscatter data was available for only one location, French Frigate Shoals.

Table 2. Attributes of bathymetric datasets available for the Northwestern Hawaiian Islands. Spatial resolution identifies pixel size in base bathymetry layers. Spatial coverage is the estimated areal coverage within 30-115 m depth range.

Location	Surveillance Priority Level	Spatial resolution (m)	Spatial coverage (%)	Backscatter Available	Modeled
Kau'ai	High	87	100	No	No
Ni'ihau Island	High	87	100	No	No
Five Fathom Pinnacle and Ka'ula Rock	High	87	100	No	No
Middle Bank	Medium	N/A	N/A	No	No
Twin Banks	Medium	20	Unknown	No	No
Nihoa Island and SW shallows	Medium	5	20	No	Yes
Necker Island (Mokumananmana)	High	5	80	No	Yes
French Frigate Shoals	Low	5	75	Yes	Yes
Brooks Banks	Low	5	95	No	Yes
Gardner Pinnacles	Low	20	Unknown	No	No
Raita Bank	Low	20	0	No	No
Maro Reef	High	20	20	No	No
Laysan and Northampton Seamounts	Low	20	Unknown	No	No
Lisianski Island	Low	20	Unknown	No	No
Pearl and Hermes Atoll	High	5	50	No	Yes
Midway Islands	Low	5	95	No	Yes
Kure Atoll	Low	5	100	No	Yes

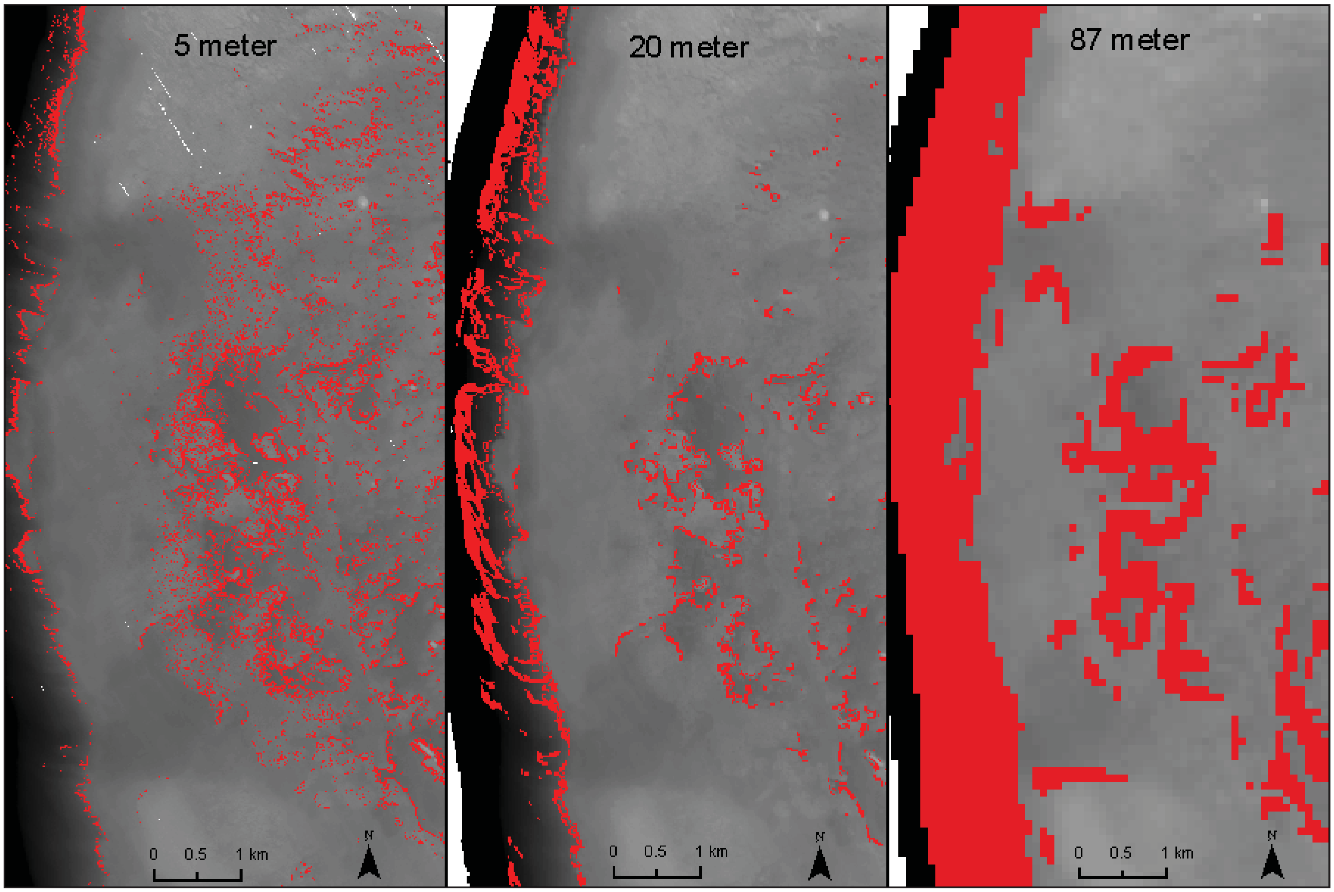


Figure 4. Difference in habitat suitabilty model output (red) with 5 m, 20 m and 87 m bathymetric surfaces. Background bathymetry surfaces reflect changes in depth from deep (black) to shallow (grey). 1.5 meter bathymetric complexity threshold used for all.

Bathymetry surfaces were also used to map areas within temperature constraints. Kahng (2006) showed that the depth limit of *C. riisei* can be expressed by the 23°C isotherm and can be mapped using the temperature-depth structure during the seasonal-high sea surface temperature period from September to October (Kahng 2006). Using temperature-depth profiles provided by Kahng (2006; Table 3) the depth limit of *C. riisei* was mapped at the scale of individual islands.

Decision rules used for habitat suitability model

Bottom substrate and light	Relatively high values of bottom complexity in areas shallower than 65 m
Temperature	Depth of the 23°C isotherm during the seasonal-high sea surface temperature period from September to October

Online Resources for Bathymetry Data

Pacific Islands Fisheries Science Center Coral Reef Ecosystem Division	http://www.pifsc.noaa.gov/cred/hmapping
Hawaii Mapping Research Group	http://www.soest.hawaii.edu/HMRG/Multibeam/

Final model output showing suitable habitats for *C. riisei* was made by intersecting maps of bathymetric complexity and areas shallower than the 23° C isotherm (Figure 5). Output maps are provided in Appendix A.

Table 3. Parameters used in habitat suitability model and area of model output.

Location	Bathymetric complexity threshold (m)	Depth of 23° C isotherm (m)	Area of suitable habitat (km^2)
Nihoa Island and SW shallows	1.5	110	4.22
Necker Island (Moku-mananmana)	2	110	8.52
French Frigate Shoals	1.5	105	8.44
Brooks Banks	1.5	100	3.35
Pearl and Hermes Atoll	2	60	3.2
Midway Islands	2	60	2.2
Kure Atoll	1	60	5.53

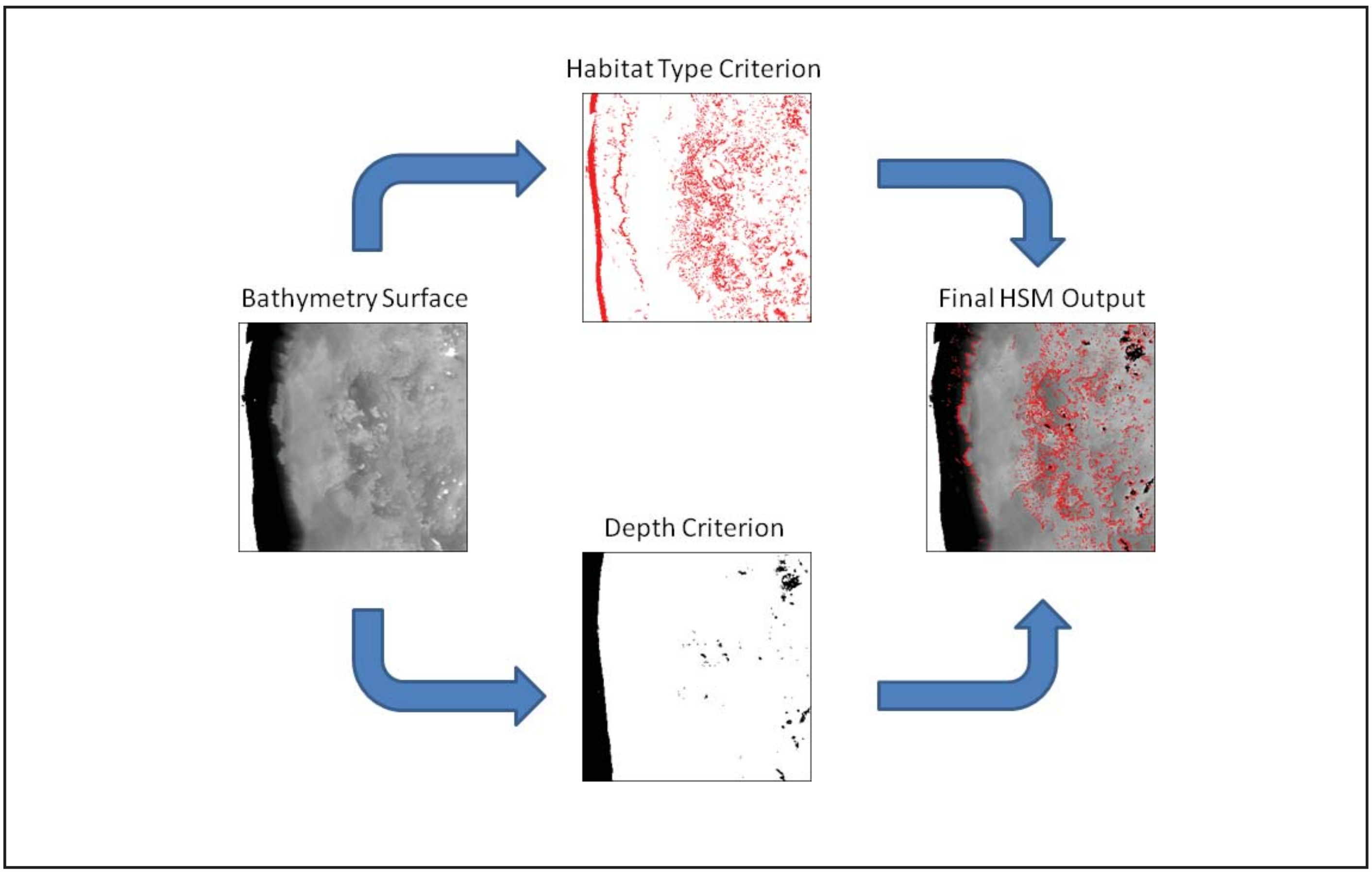


Figure 5. Flowchart showing process and data used in habitat suitability model development.

Site Selection Using Habitat Suitability Maps

HSM output was used to select survey sites for a mission exploring the mesophotic coral reefs of NWHI. The mission had multiple objectives including surveys for *C. riisei* and *H. musciformis*. Survey sites were selected by choosing the locations identified in the output maps which were clearly recognizable geomorphological features such as the edges of rugose coral reefs and ledges. Locations of suitable habitat which were isolated and/or consisted of small areas were not chosen for surveys. This judgmental process using visual interpretation of HSM output maximized the chances surveys would be completed over suitable habitat. The selection of larger features had additional positive benefits. Targeting large features provided divers with more area to survey during a dive, and increased the probability divers could find suitable habitats, even if they were displaced during deployment or descent.

Selection of survey locations was accomplished manually in a geographic information system (GIS). Site coordinates are freely available at http://ccma.nos.noaa.gov/stressors/invasivespecies/monitoring.html. Numerous sites were chosen for each island, bank and atoll to ensure sufficient quantities for several days of diving. Sites were positioned in order to maximize survey efficiency by clustering (see Figure 6 for an example at French Frigate Shoals). Multiple sites formed a cluster to decrease travel time and, if diving regulations permitted, allow multiple dive teams to be used simultaneously. Clusters were distributed around an island, bank or atoll so that if one cluster could not be surveyed due to weather or wave conditions another one might be.

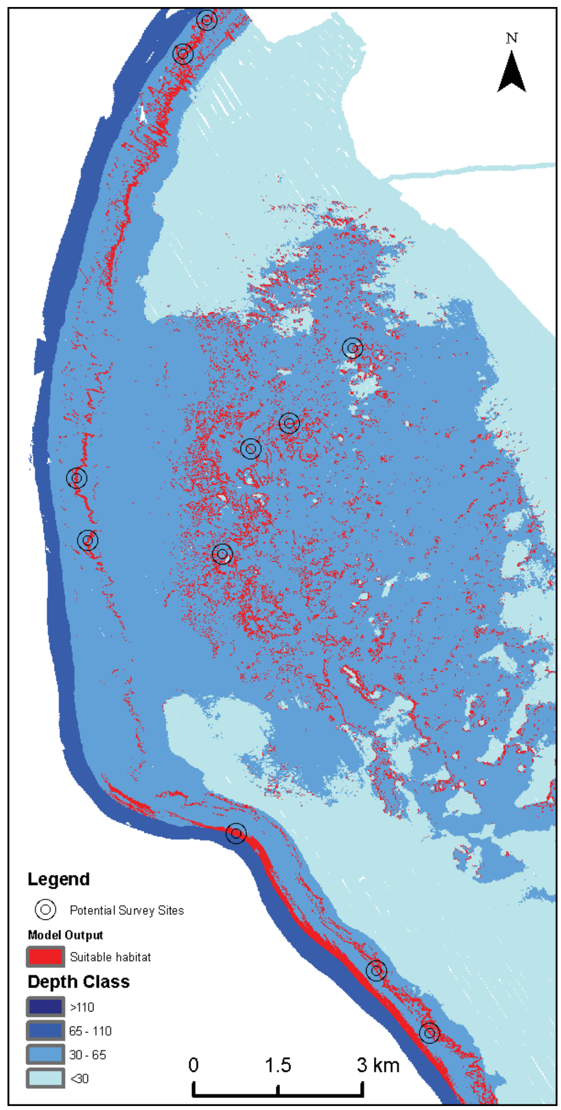


Figure 6. Map of potential survey sites around French Frigate Shoals. Note the placement of sites on suitable habitat.

At each site, the survey consisted of a visual census by a technical diver. Visual surveys were chosen because divers can identify species by sight and swim over to inspect or collect suspect organisms. Alternative measurement methods which employ remotely operated vehicles, submersibles or fishing gear have more uncertainty associated with detection probability and are generally more expensive (Menza and Monaco, 2009). A standardized protocol developed for visual surveys by divers is presented in Appendix B. The protocol was developed to increase the efficiency of surveys, maximize the probability of detection, identify important information relevant to future surveys and standardize results.

Findings

The surveillance strategy was assessed during a field mission to NWHI from August 10 to September 5, 2009. PMNM was given predefined survey site coordinates and the survey protocol (Appendix B). Visual surveys were conducted using technical diving at depths ranging from 15 m (50 ft) to 82 m (270 ft). Sites were distributed at Ni’ihau, Nihoa, Necker (Mokumananana), Laysan, Midway, and Pearl and Hermes.

Predefined survey sites were used only once, because suitable habitat was not found at the first investigated site. As suggested in the survey protocol, reconnaissance using multibeam sonar was used to choose future survey sites. Reconnaissance consisted of using multibeam sonar to find abrupt changes in bathymetry and was identical to the method used for habitat suitability modeling, except that it was accomplished using real-time heads-up display and was visualized at a finer (<5 m) spatial resolution.

A disincentive for using predefined surveys sites was the lack of habitat suitability maps. The absence of a map meant survey planners who were unfamiliar with the methods used to choose sites did not know the type of benthic features targeted and did not have a broader seascape perspective. In the future, provision of the model output maps may give surveyors more confidence to use predefined coordinates to plan dives.

The visited site at Necker (Mokumanamana) which caused the field team to stop using predefined coordinates is at the center of Figure 7. The site appears to be located at an underwater ledge. These ledges surround much of the islands at regular depth intervals, and are considered suitable habitat for *C. riisei*. It is unknown why divers did not find suitable habitat at this site. The site is located on a relatively thin ledge and is isolated from other features. The cause of this error is unknown, but imprecise diver position or map inaccuracy are possibilities.

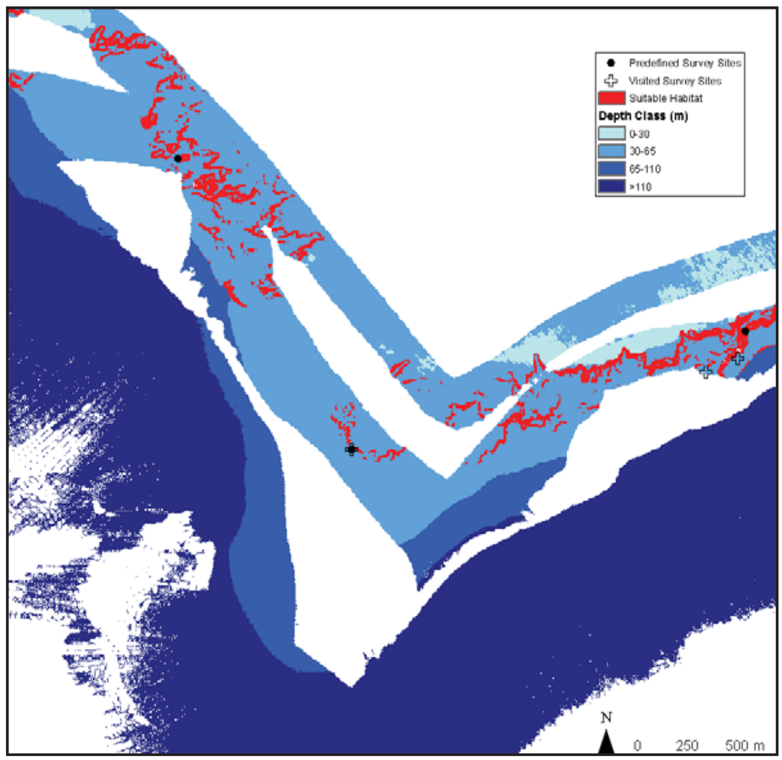


Figure 7. Map showing location of predefined and visited survey sites southwest of Necker Island. White patches represent locations where bathymetry was not collected.

To better understand model accuracy, habitats at sites surveyed in the 2009 field mission and their location with respect to HSM map output were compared. This was not a comprehensive accuracy assessment of the map, since sites were not chosen randomly, the precision of diver position is unknown, and the habitat suitability model was developed to identify the best suitable habitats (i.e. tallest ledges, most rugose reefs), not all suitable habitats. Nonetheless, the assessment provides some degree of confidence that the map is identifying suitable habitat.

The assessment showed a strong spatial correspondence between survey sites chosen using real-time multibeam reconnaissance and suitable habitat identified by the HSM. Over 95% (23 of 24 sites) of sites chosen for surveys in 2009 were defined as either suitable habitat or can be considered "likely" suitable habitat (Table 4) given the potential for survey sites coordinate imprecision. Sites which were considered likely within suitable habitat were relatively near (<25 m) suitable habitat, or were outside the spatial extent of the model map (e.g. too shallow, too deep, no bathymetry) but were adjacent to benthic features which would likely extend out to where the sites were located (e.g.

Table 4. Correspondence of model output with visited sites during 2009 field mission.

Location	Inside suitable habitat	Likely inside suitable habitat	Outside suitable habitat	Outside extent of model
Ni'ihau	0	4	0	2
Nihoa	0	2	0	1
Necker	4	0	1	2
Laysan	0	0	0	4
Pearl and Hermes	6	0	0	1
Midway	4	0	0	1
Kure	3	0	0	1
Total	**17**	**6**	**1**	**12**

linear terrace). The one site which was not within suitable habitat was within 20 m of the map edge and therefore may have been close to suitable habitat.

Data Gaps and Future Considerations

The proposed surveillance strategy was developed using the best information available, but there is room for improvement. Much of the information that would benefit the proposed strategy is discussed by Godwin et al. (2006). Data gaps include accurate knowledge of invasive species distributions and abundances, a comprehensive baseline taxonomic database, and accurate fine-scale bathymetry data or benthic habitat maps.

Benthic habitat maps, such as those developed for shallow water habitats in the NWHI (NOAA 2003), are useful tools to identify the distribution of organisms. They serve as integrators of multiple environmental variables like substrate, habitat type, water movement and depth and can be used to pinpoint suitable habitat for invasive species when these variables are known (e.g. *C. riisei*). Shallow water benthic habitat maps use aerial imagery to identify benthic habitats, but at depths deeper than 30 m, the development of benthic habitat maps and habitat suitability models relies on accurate fine-scale bathymetry data. We found the 5 m resolution bathymetric surfaces easily identified many different habitat types important to invasive species of concern, while coarser scale bathymetric data did not have sufficient spatial resolution to identify ledges and patch reefs.

Fine-scale (5 m) bathymetry data has been collected for seven of the islands and banks of the NWHI, but spatial coverage was incomplete at many locations (see Table 2 for details). Ten islands and banks do not have bathymetry data with resolution required for accurate benthic habitat mapping, and of these, five have a "high" or "medium" surveillance priority level. PIFSC CRED has been collecting bathymetry data in the region and is continually chipping away at the vast area which needs to be mapped. As new bathymetry data becomes available, new data should be used to update the habitat suitability maps, especially those areas where the surveillance priority level is "high".

Another major obstacle for this report was the potential distribution of *H. musciformis* in deepwater habitats. *H. musciformis* is found in many different habitat types, making it difficult to prioritize one habitat over another. Several subject matter experts agreed that *H. musciformis* may prefer areas with high nutrient levels. Additionally, early detection may be easier at sites with high levels of nutrients since increased algae growth would make populations more conspicuous. At the time of this report water nutrient data at fine spatial scales, was unavailable, but future work should consider such data. An investigation of chlorophyll content or sea surface temperature using satellite sensors may provide suffice as good a proxy for nutrient levels over broad spatial scales. It would be important to assess inputs from upwelling, internal waves and resident bird population guano, as well as seasonal variability.

The surveillance strategy described herein is based on assumptions from a preliminary risk assessment. This basic assessment identified two species of concern and their major source of propagules, but these data may be incomplete or there may be comparable risks for other invasive species. For instance, *A. amadelpha*, was identified as a potential threat by Heather Spalding, a marine botanist interviewed for this report. Other unidentified taxa may also pose significant threats. The elaboration on the preliminary risk assessment provided in this report should not take the place of a comprehensive risk assessment. A complete risk assessment for invasive species is a systematic comprehensive analysis of transport, establishment and/or impact (e.g. ANSTF 1996; Colnar and Landis, 2005) and the work done to date is not systematic.

The strategy was constrained to technical diving due to the diverse objectives of the 2009 field mission, but separate methods may be better for individual species. For instance, Dr. Celia Smith, another marine botanist, indicated settling plates may be a useful technique for detecting *H. musciformis*. Plates can be placed in locations with nutrient pulses or nutrients can be supplied artificially to ensure optimum growing conditions.

Surveillance is only one component of the work needed to manage invasive species. Other components include prevention, rapid response, control and eradication. PMNM has invested into prevention and surveillance, which is a good approach, but basic information and protocols for other components will prepare PMNM if an invasive species is detected. Corresponding information and protocols include:

- Rapid risk assessment protocols
- Rapid response action protocols
- Development of a rapid response fund
- Eradication and control method libraries

This document was developed to help PMNM regardless of other resources, but its usefulness will be maximized if it is well connected to other survey and monitoring programs. All types of opportunistic surveys should be included in a comprehensive surveillance program to maximize detection probabilities and reduce costs. PMNM has gathered important sighting information from opportunistic surveys and will likely continue to do so. It was outside the scope of this report to assess their application, but it may be worth investigating how to maximize the usefulness of these opportunistic surveys.

Habitats and invasive species in shallow water were also outside the scope of this document. It is important to note that all species of concern in deepwater habitats have also been found in shallow systems. Any deepwater surveillance strategy should be tightly linked to shallow water counterparts, such as those conducted by the Bishop Museum in shallow water ports and reefs.

The compilation of information presented in this report will help PMNM with dedicated surveillance of invasive species. To ensure continued usefulness the tools should be revised as new information becomes available.

References

ANSTF (Aquatic Nuisance Species Task Force). 1996. Generic Nonindigenous Aquatic Organism Rick Analysis Review Process. Report to the Aquatic Nuisance Species Task Force.

Coles, S.L., R.C. DeFelice and L.G. Eldredge. 2002. Nonindigenous marine species in Kane'ohe Bay, O'ahu, Hawaii. Bishop Museum Technical Report No. 24

Culver, C.S., S.L. Drill, M.R. Myers and V.T. Borel. 2009. Early Detection Monitoring Manual for Quagga and Zebra Mussels. California Sea Grant. Comprehensive, well-illustrated guidebook with detailed instructions for volunteer monitors. 40 pp.

Dunn, D.C. and P.N. Halpin. 2009. Rugosity-based regional modeling of hard-bottom habitat. Marine Ecolgy-Progess Series 377: 1-11.

Eldredge, L.G. and J.T. Carlton. 2002. Hawai'i marine bioinvasions: a preliminary assessment. Pacific Science 56(2): 211-212.

Fox, J.C., Y.M. Buckley, F.D. Panetta, J. Bourgoin and D. Pullar. 2009. Surveillance protocols for management of invasive plants: modelling Chilean needle grass (*Nassella neesiana*) in Australia. Diversity and Distribution 15(4) 577-589.

Friedlander, A.M., J.D. Parrish and R.C. DeFelice. 2002. Ecology of the introduced snapper *Lutjanus kasmira* (Forsskal) in the reef assemblage of a Hawaiian bay. Journal of Fish Biology 60: 28-48.

Friedlander, A.M., G. Aeby, S. Balwani, B. Bowen, R. Brainard, A. Clark, J. Kenyon, J. Maragos, C. Meyer, P. Vroom and J. Zamzow. 2008. The state of coral reef ecosystems of the northwestern Hawaiian Islands. pp. 263-306. In: J. Waddell (ed.). The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for coastal monitoring and assessment's biogeography team. Silver Spring, MD. 567 pp.

Godwin, S., K.S. Rodgers and P.L. Jokiel. 2006. Reducing potential impact of invasive marine species in the northwestern hawaiian islands marine national monument. Report to: Northwest Hawaiian Islands Marine National Monument Administration.

Grigg, R. 2003. Invasion of a deep black coral bed by *Carijoa riisei* off Maui, Hawai'i. Coral Reefs. 22:121-122.

Kahng, S.E. 2006. Ecology and ecological impact of an alien octocoral, *Carijoa riisei*, in Hawaii. PhD. Thesis, University of Hawaii. 284 pp.

Kendall, M.S., O.P. Jensen, C. Alexander, D. Field, G. McFall, R. Bohne and M.E. Monaco. 2005. Benthic Mapping Using Sonar, Video Transects, and an Innovative Approach to Accuracy Assessment: A Characterization of Bottom Features in the Georgia Bight. Journal of Coastal Research, 21(6), 1154–1165.

McNaught, I., M. Thackway, L. Brown and M. Parsons. 2006. A field manual for surveying and mapping nationally significant weeds. Bureau of Rural Sciences, Canberra.

Menza, C. and M. Monaco. 2009. An Investigation of Survey Technologies and Modeling Techniques for Improving Deepwater Surveys of Nonindigenous Species in the Northwestern Hawaiian Islands. NOAA Technical Memorandum NOS NCCOS 95. Silver Spring, MD. 25 pp.

NISC (National Invasive Species Council). 2008. National Invasive Speceis Management Plan 2008-2012. 35 pp.

National Oceanic and Atmospheric Administration (NOAA). 2003. Atlas of the Shallow-Water Benthic Habitats of the Northwestern Hawaiian Islands. Center for Coastal Monitoring and Assessment, Silver Spring, MD. 160 pp. Available online at http://ccma.nos.noaa.gov/ecosystems/coralreef/nwhi_mapping.html, last accessed Nov 18, 2009.

Pittman, S.J., J.D. Christensen, C. Caldow, C. Menza and M.E. Monaco. 2007. Predictive mapping of fish species richness across shallow-water seascapes in the Caribbean. Ecological Modelling 204(1-2): 9-21.

PMNM (Papahānaumokuākea Marine National Monument). 2008. Papahānaumokuākea Marine National Monument Management Plan. Available online at http://papahanaumokuakea.gov/management/mp.html, last accessed Nov. 18, 2009.

PMNM (Papahānaumokuākea Marine National Monument). 2009a. Draft Natural Resources Science Plan. Available online at http://papahanaumokuakea.gov/research/plans/draft_natressciplan.pdf, last accessed Nov. 18, 2009.

PMNM (Papahānaumokuākea Marine National Monument). 2009b. Request for authorization and approval to issue a Papahānaumokuākea Marine National Monument Research permit to Dr. Randall Kosaki, NOAA, PMNM, for access to State Waters to conduct surveys of deep coral reefs.

Ruiz, G.M., J.T. Carlton, E.D. Grosholz and A.H. Hines. 1997. Global invasions of marine and estuarine habitats by non-indigenous species: mechanism, extent and consequences. *Amer. Zool.* 37: 621-632.

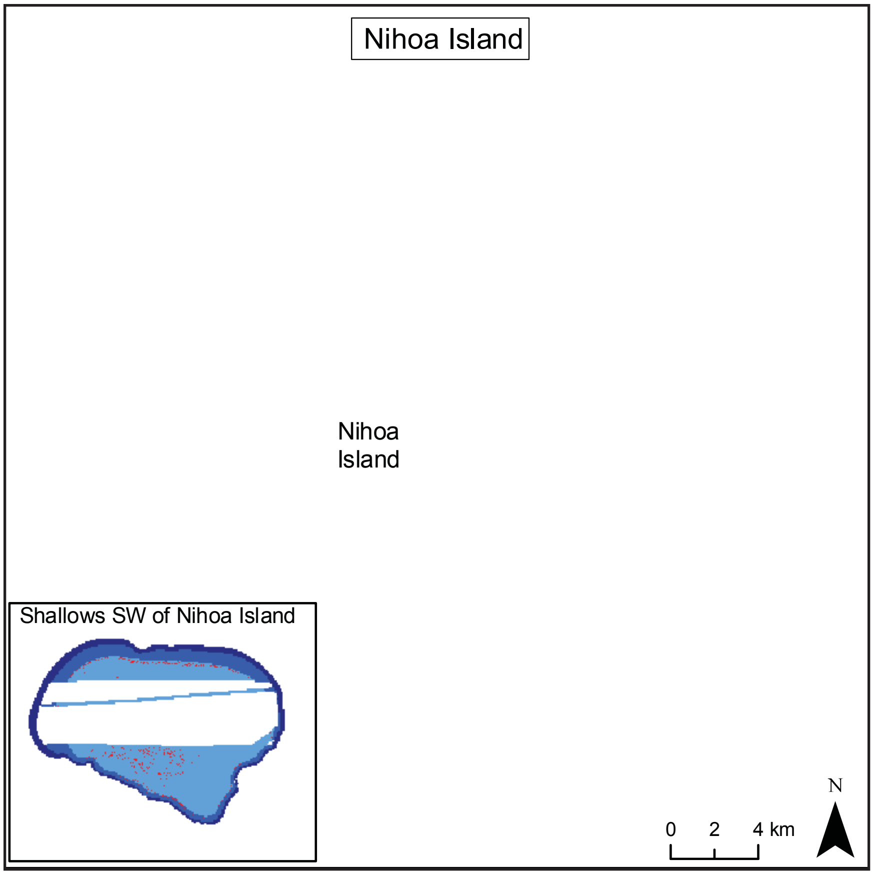
Russell, D. and G. Balaz. 1992. Colonization of the alien marine alga *Hypnea musciformis* (Wulfen) J. Ag. (Rhodophyta: Gigartinales) in the Hawaiian Isalnds and its utilization by the green sea turtle, *Chelonia mydas* L. *Aq Bot*. 1994: 53-60.

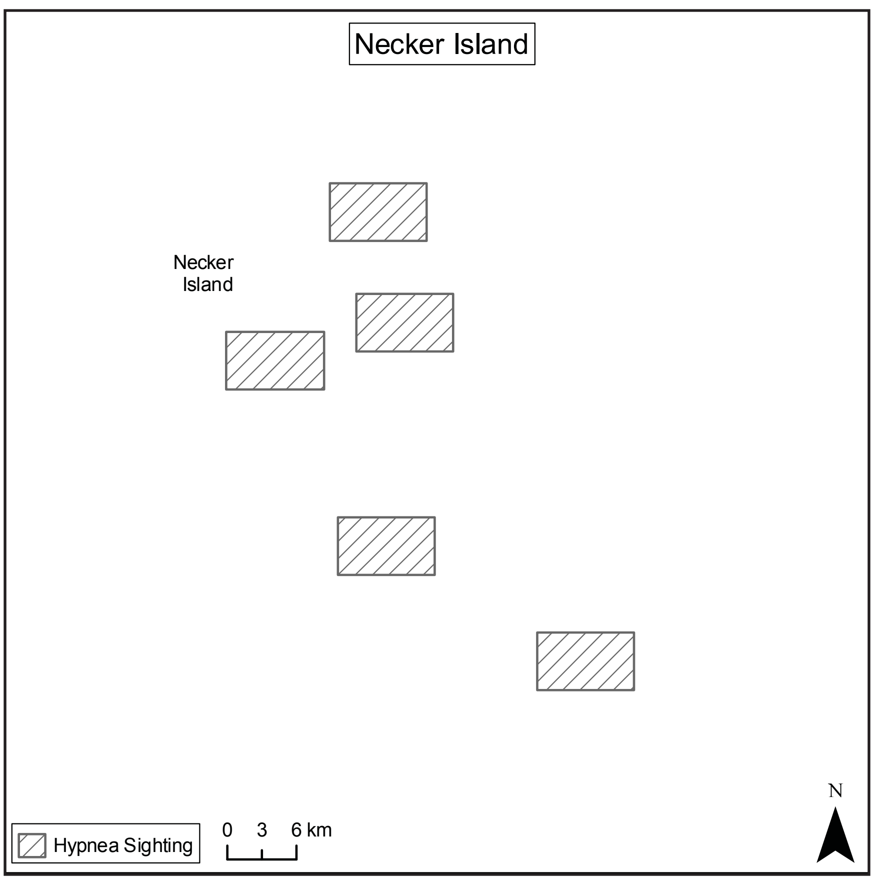
See, K. 2007. Report on the Marine Invasive Species in Papahānaumokuākea Marine National Monument.

Selkoe, K.A., B. Halpern and R. Toonen. 2008. Evaluating anthropogenic threats to the Northwestern Hawaiian Islands. Aquatic Conservation: Marine and Freshwater Ecosystems 18:1149-1165.

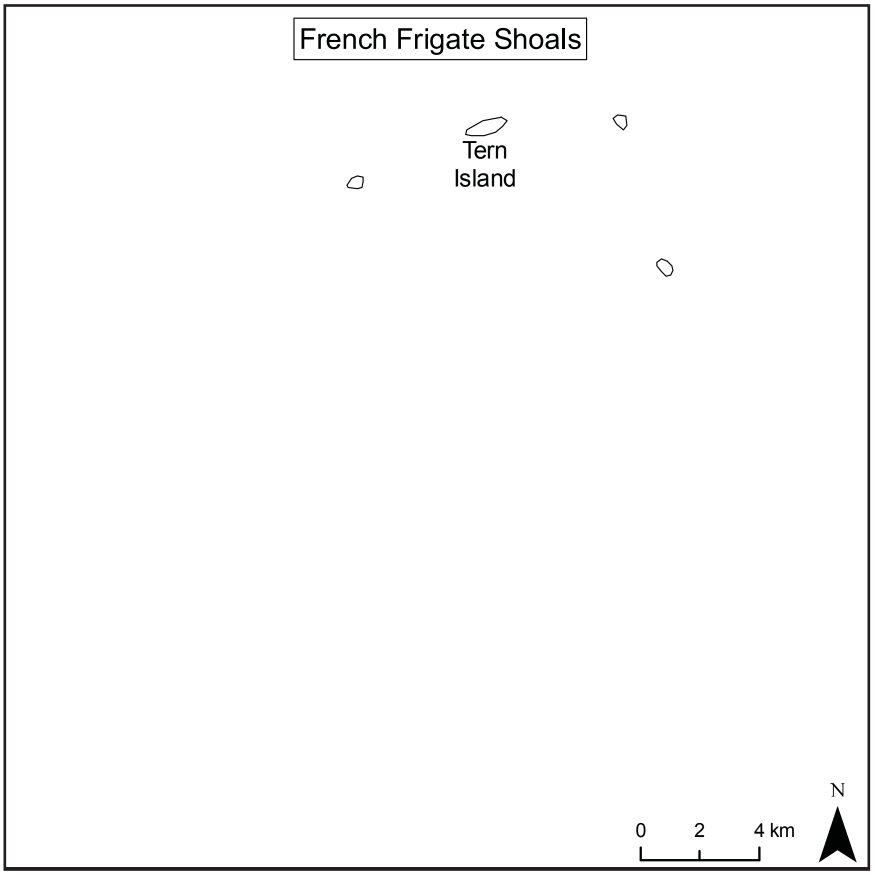
Smith, J.E., C.L. Hunter and C.M. Smith. 2002. Distribution and Reproductive Characteristics of Nonindigenous and Invasive Marine Algae in the Hawaiian Islands. *Pacific Science*, vol. 56, no. 3: 299-315.

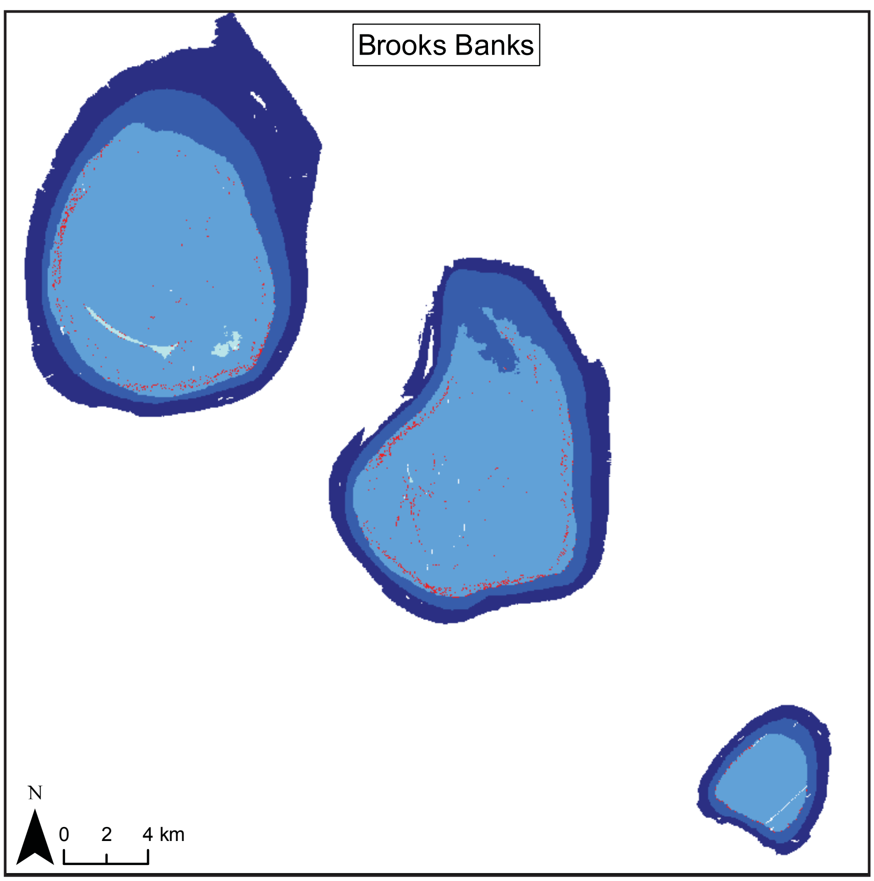
APPENDIX A: HABITAT SUITABILITY MAPS





APPENDIX A (CONT.)





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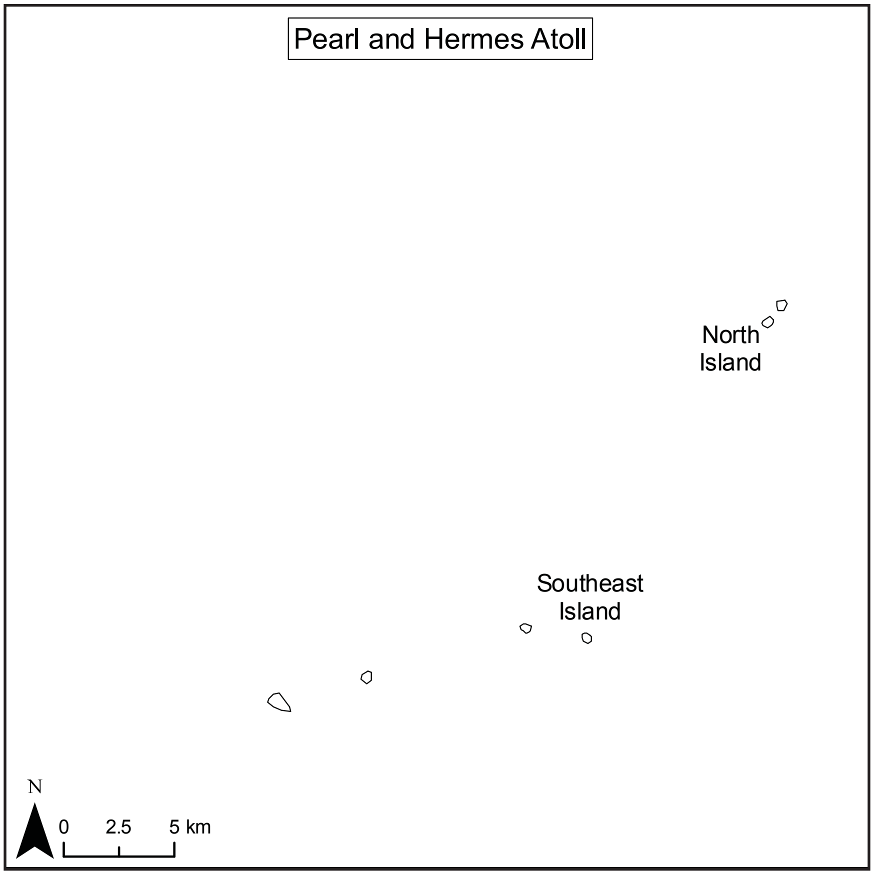

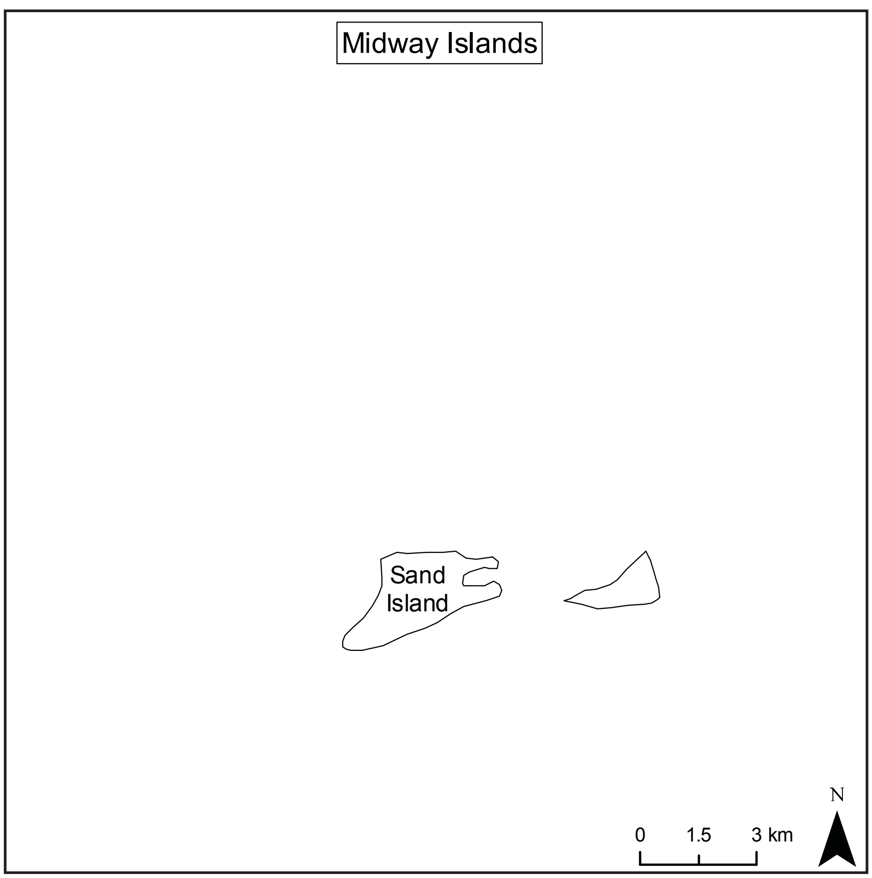

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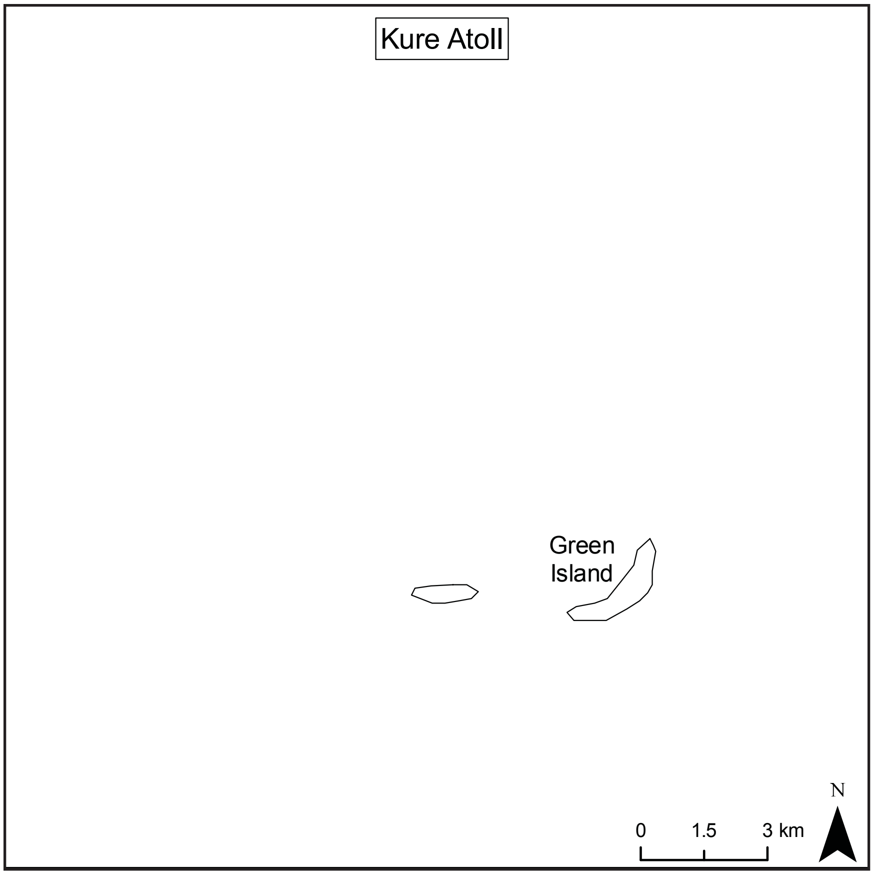

APPENDIX B: SURVEY PROTOCOL TO DETECT DEEPWATER INVASIVE SPECIES OF CONCERN IN THE NORTHWESTERN HAWAIIAN ISLANDS

Objective

Detect *Carijoa riisei* and *Hypnea musciformis* in deepwater habitats using visual surveys by technical divers.

Note: This protocol is designed to detect the presence or absence of invasive species. A distinct protocol is required to collect information on abundance and impact, or monitor changes over time.

Critical Actions

1. Develop search image for species of concern
2. Conduct reconnaissance at potential survey sites
3. Collect pictures and voucher specimens of potential invasive species

Permits and Permission

Necessary permits and permissions must be obtained before implementation of surveillance in NWHI. Permits must include provisions for access and voucher specimen collection. In addition to permits from the Monument, if data will be collected at Necker Island or sentinel sites in the Main Hawaii Islands, permits from the State of Hawaii must be obtained as well.

Site Planning

Determining where to survey before a field mission will help organize effort and ensure needed information is available and understood.

Habitats most likely occupied by invasive species should be surveyed to maximize the probability of detection. A benthic habitat map or habitat suitability map are useful tools to locate appropriate survey sites. This method contrasts with probabilistic designs which attempt to infer from samples to a larger population, but which are ill suited to survey “rare events” such as an invasive species colony.

Distribution of surveys at two spatial scales will aid logistics and minimize the likelihood sites cannot be surveyed due to weather conditions. At short spatial scales, clustered sites will decrease travel time among sites and possibly allow multiple dive teams to be used simultaneously. At longer scales, clusters distributed around an island, bank or atoll can minimize the likelihood all sites are inaccessible due to weather conditions or travel distance. For instance, a cluster in the lee of an island may be accessible while others are not due to wave height.

Training

It is important for all divers to have sufficient training to effectively identify species of concern, and be familiar with the methods and data reporting requirements. These items are important to make effective use of very limited bottom time, support subsequent management actions, reduce the likelihood of false reports and lessen effort spent collecting extraneous information.

To detect *C. riisei* and *H. musciformis*, divers must have a clear search image of both species. A search image represents information that will help identify an organism, including morphology, behavior, habitat and organisms with similar habitat preferences. The search image helps paint a mental picture of what to look for. Special consideration should be given to develop a search image

APPENDIX B (CONT.)

for *C. riisei* when polyps are open and closed. Taxonomic keys, morphological descriptions, and pictures will help develop search images.

Divers should be well trained, and familiar with all methods and equipment to be used for data acquisition. A dive at a familiar site can help train new surveyors.

Equipment

Data entry forms and writing utensils
Lights
Camera
Metal clippers
Specimen bag
Cooler with ice
Geographic positioning system on support vessel
Materials and equipment for preservation

Reconnaissance

It is highly recommended to collect reconnaissance data before sending divers to any survey sites. Reconnaissance is used to locate suitable habitat and thus decrease the probability of conducting a survey on habitat unlikely to harbor species of concern. Reconnaissance is especially important when information about a survey site is lacking or uncertain. For instance, uncertainty can arise in sites selected using remotely sensed data because of interpretation error or changes over time.

Reconnaissance data can be collected using a variety of equipment, such as remotely operated vehicles (ROV), autonomous underwater vehicles (AUVs) or multibeam sonar. Visual data in the form of video or still images are optimal for reconnaissance, because they provide data in a format that can be recorded, and used for multiple objectives, and have been used effectively in the past to groundtruth remotely sensed data. Alternatively, soundings from multibeam sonar at a resolution finer than 5 m can be useful in verifying or pinpointing benthic features of interest.

During reconnaissance, it is a good idea to identify specific benthic features to be surveyed by divers. Geographic position, as well as notable seascape features in the immediate vicinity, will assist in finding the feature at a later time. Features should be prioritized according to habitat type and survey area when multiple features are identified. High priority habitat types include hardbottom benthic structures such as:

- terraces
- ledges
- large plate corals
- boulders
- pinnacles
- crevices
- exposed hardbottom substrate (deeper than 65 m)

Reconnaissance data also provides information for dive planning. Helpful data includes depth on bottom, and profiles of temperature, light, current speed and current direction.

It is unlikely that data collected using an ROV or drop camera will detect invasive species, and the effort needed to inspect under ledges and in cervices can take a considerable amount of time, consequently invasive species detection should not be a priority. Rather, reconnaissance should cover as much area as possible while still collecting sufficient information to identify important features.

APPENDIX B (CONT.)

Diver Planning

The use of technical diving is necessary due to the need for visual surveys, and depths and bottom time required for deepwater surveillance. All divers should have sufficient training and adhere to pertinent regulations of governing authorities. If technical diving will be completed under NOAA auspices they must conform to the regulations of the NOAA Dive Center.

Expect a dive team to conduct a single or at most two dives a day due to the depths and decompression requirements involved.

Dives should be planned and executed in such a manner as to avoid gas shortages and in-water decompression times greater than 120 minutes. The “rule-of-thirds” (one third to get to the dive site, one-third to reach the first decompression stop, and one-third reserve) should be followed on all decompression dives. Consequently, divers should be prepared to complete surveys in 25 minutes or less.

A buoy carried by at least one member of the dive team is recommended if weather conditions permit. The buoy can be used by surface support vessels to safely track diver movements, and the dive team can use the buoy to communicate with the support vessel.

Visual Surveys

The probability of detection is maximized by concentrating search effort on the species and habitats of interest. Other species of concern should be searched for opportunistically.

Shallower than 65 m (213 ft) divers should focus attention on crevices, overhangs, holes and ledges or any other habitats likely to provide shade. Deeper than 65 m, divers should also inspect exposed hard substrate. If time permits, inspections of algae communities should include attached, drifting and epiphytic algae.

Surveys should attempt to include as much area as possible over the most important habitats while minimizing the chances an invasive species is overlooked.

Critical Data Collection

It is important to gather information that will help locate the survey in geographic space and define survey effort, especially if an invasive species or probable invasive species is detected. The survey site coordinates may be inadequate due to diver movement and inaccuracies in deployment. At a minimum, record the depth of the survey. If possible, communicate with the surface support vessel using a buoy so that the support vessel can then take a GPS fix to record geographic position. One method of communication is to pull a surface buoy line using a predetermined signal. Survey effort can be estimated using elapsed time during the survey.

The field data sheet provided at the end of this protocol was developed to help record important information. Printing the data sheet on water proof paper allows its use underwater.

Pictures of the survey site provide information to locate the survey, identify benthic habitats and communities, and assess baseline conditions. Take pictures in four cardinal direction and closeups of suitable habitats.

APPENDIX B (CONT.)

If an invasive species or probable invasive species is detected additional information is needed for authoritative identification, assessment of impact and identification of habitat. Voucher specimens and in situ photographs are essential for authoritative taxonomic identification. If there is any uncertainty, pictures and a voucher specimen should be collected. Still pictures provide a tangible record of invasive species and can provide information on substrate and community not recorded by the diver. Suspect organisms should be photographed in situ along with some sort of identification label so that specimens can be related to particular photographs. Multiple pictures taken at multiple distances from the target are recommended. Pictures taken at multiple distances provide information at multiple spatial scales. Pictures which can be used to describe the community and benthic habitat are desirable to quantify affected area, better understand the ecology of invasive species and refine survey methods.

Specimens should be collected from probable individuals and prepared for transport. Specimens can be collected by hand or with metal clippers, placed in sealed bags, carried to the surface by divers and put into a cooler with ice. Upon return to the support vessel specimens must be preserved and labeled with site information. All macroalgae must be drained of water and put into the laboratory freezer. Each macroinvertebrate sample should be divided into two sub-samples, with one being preserved in 95% Ethanol and the other in Dimethyl Sulfoxide (DMSO).

Auxiliary Data Collection

If an invasive species is detected, auxiliary data which can be used to assess the local community and environment are useful. Several types of auxiliary data are described below.

Area of coverage can provide information important to quantify impacts to the community and can be used to assess change over time. Area of coverage refers to a visual estimate of the planar area inhabited by invasive species. In cases where invasive species are patchily distributed, areas should be divided into separate sites if there is a gap of more than 10 m between colonies (or individuals) or where there is a useful and obvious benthic boundary (e.g., patch reef, edge of substrate, isolated boulder). If a single individual or small colony (<100 cm^2) is observed the area of coverage can be defined as a point. If the area of infestation is one-dimensional (i.e. linear ledge), the area of coverage can be defined by a distance. If the limits of an infestation cannot be determined, provide a minimum area or distance (e.g., > 100 m^2).

The benthic habitat on which an invasive species is established can be used to refine habitat suitability models and diver search images, as well as assess impact. Benthic habitat type integrates multiple environmental parameters such as geomorphology, substrate and water movement. To be helpful, benthic habitat types must be mutually-exclusive, and consistently recorded among surveyors. Examples of benthic habitat types and their respective definitions are provided below.

Ledge - an abrupt descent at the edge of a relatively flat surface. Ledges are common at the edge of terraces created from former sea level stands and consequently are common along circumferential isobaths on insular shelves.

Reef – hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms (relict or ongoing).

APPENDIX B (CONT.)

Boulders - a large, detached, worn rock or piece of bedrock. Typically found at the base of ledges or steep slopes.

Pavement – exposed flat, low-relief solid carbonate rock. Generally pavement is colonized by macroalgae, sponges, coral and other sessile invertebrates.

Algal Plain – an area supporting a rich algal community, consisting of macroalgae, crustose coralline algae and rhodoliths.

Sand – area composed of unconsolidated coarse sediment typically found in depositional areas with weak currents or low wave energy.

Information on the community in close proximity to invasive species can identify communities at risk and help refine diver search images. Identification of organisms to the lowest possible taxonomic level and/or pictures of nearby organisms are useful.

Reporting

Hardcopy reports of all data collected should be retained for permanent record keeping. It is important to report findings even if invasive species were not found during a dive; these can be used in the future to identify baseline conditions. The datasheet on the next page was developed specifically for this protocol and can be used to collect and catalog data.

APPENDIX B (CONT.)

Date			Name		Station	
Location			Buddy(ies)			

Survey Information (circle all that apply)

Benthic Habitat	Terrace	Reef	Boulders	Pavement	Algal Plain	Sand		
Start time		Min Depth						
End time		Max Depth						
Notes								

Specific Sighting Information

Species	Time	Depth (ft)	Habitat Type	Area of Coverage	Notes

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