An Investigation of Survey Technologies and Modeling Techniques for Improving Deepwater Surveys of Nonindigenous Species in the Northwestern Hawaiian Islands

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For more information

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Cover photo by David Burdick of *Lutjanus kasmira*, a nonindigenous fish species in the northwestern Hawaiian Islands. Photo downloaded from the NOAA Photo library (http://www.photolib.noaa.gov/)

An Investigation of Survey Technologies and Modeling Techniques for Improving Deepwater Surveys of Nonindigenous Species in the Northwestern Hawaiian Islands

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SUMMARY

Nonindigenous species (NIS) are a major threat to marine ecosystems, with possible dramatic effects on biodiversity, biological productivity, habitat structure and fisheries. The Papahānaumokuākea Marine National Monument (PMNM) has taken active steps to mitigate the threats of NIS in Northwestern Hawaiian Islands (NWHI). Of particular concern are the 13 NIS already detected in NWHI and two invasive species found among the main Hawaiian Islands, snowflake coral (*Carijoa riseii*) and a red alga (*Hypnea musciformis*).

Much of the information regarding NIS in NWHI has been collected or informed by surveys using conventional SCUBA or fishing gear. These technologies have significant drawbacks. SCUBA is generally constrained to depths shallower than 40 m and several NIS of concern have been detected well below this limit (e.g., *L. kasmira* – 256 m) and fishing gear is highly selective. Consequently, not all habitats or species can be properly represented.

Effective management of NIS requires knowledge of their spatial distribution and abundance over their entire range. Surveys which provide this requisite information can be expensive, especially in the marine environment and even more so in deepwater. Technologies which minimize costs, increase the probability of detection and are capable of satisfying multiple objectives simultaneously are desired.

This report examines survey technologies, with a focus on towed camera systems (TCSs), and modeling techniques which can increase NIS detection and sampling efficiency in deepwater habitats of NWHI; thus filling a critical data gap in present datasets. A pilot study conducted in 2008 at French Frigate Shoals and Brooks Banks was used to investigate the application of TCSs for surveying NIS in habitats deeper than 40 m. Cost and data quality were assessed. Over 100 hours of video was collected, in which 124 sightings of NIS were made among benthic habitats from 20 to 250 m. Most sightings were of a single cosmopolitan species, *Lutjanus kasmira*, but *Cephalopholis argus*, and *Lutjanus fulvus*, were also detected.

The data expand the spatial distributions of observed NIS into deepwater habitats, identify algal plain as an important habitat and complement existing data collected using SCUBA and fishing gear. The technology's principal drawback was its inability to identify organisms of particular concern, such as *Carijoa riseii* and *Hypnea musciformis* due to inadequate camera resolution and inability to thoroughly inspect sites. To solve this issue we recommend incorporating high-resolution cameras into TCSs, or using alternative technologies, such as technical SCUBA diving or remotely operated vehicles, in place of TCSs. We compared several different survey technologies by cost and their ability to detect NIS and these results are summarized in Table 3.

Data collected during the pilot study was used to investigate spatial predictions. Since limited resources must be focused in habitats were NIS are most likely to establish, spatial predictions can be used to develop maps of where NIS are likely to be found and provide a tool to help effectively allocate resources (e.g., assign monitoring sites, target possible locations for NIS eradication). The spatial distribution of *L. kasmira* was predicted in deepwater habitats of French Frigate Shoals using boosted regression trees. Although the example is limited to a single species and in spatial scope, the methods are applicable to other species and in other areas. Taken together the recommendations for survey technologies and modeling procedures provide a toolset managers can use to efficiently gather NIS data in NWHI.

ACRONYMS

AUV	Autonomous Underwater Vehicle
BASS	Benthic Assessment Sensor System
BB	Biogeography Branch
CRED	Coral Reef Ecosystem Division
FFS	French Frigate Shoals
NIS	Nonindigenous species
NOWRAMP	Northwestern Hawaiian Islands Coral Reef Assessment and Monitoring Program
NWHI	Northwestern Hawaiian Islands
PIFSC	Pacific Islands Fisheries Science Center
PMNM	Papahānaumokuākea Marine National Monument
ROV	Remotely Operated Vehicle
SCUBA	Self Contained Underwater Breathing Apparatus
TCS	Towed Camera System
TOAD	Towed Optical Assessment Device

INTRODUCTION

GOALS AND OBJECTIVES

The goal of this report is to provide the Papahānaumokuākea Marine National Monument (PMNM) information necessary to make informed decisions on how to gather data collected for the purpose of detecting and monitoring nonindigenous species (NIS) in deepwater benthic habitats (>40 m). This information is necessary to support the PMNM management plan and develop a methodology for effective data acquisition in an environment renowned for high operational costs.

To satisfy this goal we (1) conducted a pilot study to assess the feasibility of using towed camera systems (TCSs) for surveying NIS in deepwater, (2) assessed the use of alternative survey technologies, (3) evaluated spatial modeling capabilities using available environemtal datasets and data gathered during our pilot study, and (4) used deepwater data to increase our understanding of species–habitat affinities.

OVERVIEW

PMNM was created to protect the ecosystems of NWHI, which are relatively pristine with few nonindigenous or invasive marine species. Of the 343 NIS found in the marine environment of the Main Hawaiian Islands (MHI), only 13 have been detected in NWHI (Table 1; Eldredge and Carlton 2002; Eldredge 2005; Godwin et al. 2006). This difference is likely due to NWHI's extreme remoteness, relatively low rates of visitation and concerted management efforts. Nonetheless, due to their proximity, the threat of non-indigenous species spreading from the Main Hawaiian Islands to the NWHI and becoming invasive is a serious concern.

Table 1 : NIS of concern in the NWHI

Scientific Name	Common Name	Status
Fish		
Cephalopholis argus	Roi or Peacock grouper	Established
Lutjanus fulvus	To'au or Blacktail snapper	Established
Lutjanus kasmira	Ta'ape or Blueline snapper	Established
Invertebrates		
Pennaria distachia	Christmas tree hydroid	Established
Balanus reticulates	Barnacle	Established
Carijoa riisei	Snowflake coral	Not detected
Diadumene lineata	Orange-striped sea anemone	Unknown, detected
Amathia distans	Bushy bryozoan	Established
Schizoporella errata	Branching bryozoan	Established
Balanus venustus	Barnacle	Likely not established
Chthamalus proteus	Carribean barnacle	Established
Polycarpa aurita	Styelidae, solitary tunicate	Likely established
Cnemidocarpa irene	Styelidae, solitary tunicate	Likely established
Algae		
Hypnea musciformis	Red algae	Unknown, detected
Acanthophora spicifera	Red algae	Not detected

Most NIS currently found in NWHI are in few locations and in low abundances. There is debate as to whether some are invasive (i.e. cause ecological or economic harm), but this is an active area of research (e.g., Schumacher and Parrish et al. 2005). Regardless, invasive species have the potential to dramatically change an ecosystem, shifting the balance of community structure, driving native species to extinction, and altering ecosystem function. More specific impacts include competitive exclusion, niche displacement, hybridization, introgression, predation, and ultimately extinction (Mooney and Cleland 2001). Globally, the number of NIS is increasing at an alarming rate and will likely continue as global commerce increases and ecosystem resilience is eroded by persistent anthropogenic disturbances. not produce pictures of sufficient quality to identify NIS or benthic habitats and thus was unsuitable for this particular application. In addition to cameras, both systems possessed supplementary supporting equipment, including high wattage lights (>300 W) to illuminate the seafloor and increase the probability of NIS detection, pressure transducers to determine platform depth, and ultra-short baseline (USBL) systems to track platform position relative to the support vessel. Appendix A provides technical details of each towed camera system.

PMNM has taken active steps to mitigate the threats of NIS, including the prohibition of ballast discharge, hull inspections and cleaning, snorkel/dive gear treatment and luggage inspection of air passengers. In addition, one of the PMNM's 22 action plans, which address priority management needs, is "to detect, control, eradicate where possible, and prevent the introduction of alien species [NIS] into the Monument".

A prerequisite to control and eradication of NIS is knowledge of their spatial distribution and abundance over their entire geographic range. PMNM uses multiple sources of data to detect NIS and inform management decisions (See 2007), partly because of the immense size of the Monument. Most data is collected using or informed by conventional SCUBA or snorkeling surveys (e.g. NOWRAMP, DeFelice et al. 2002) and thus are limited to depths no great than 40 m. These technologies are commonly used because they are cost effective, can be used to identify diverse taxa simultaneously, have nominal equipment requirements and well-established training programs, and pose little risk to the surveyor or measured system. However, most conventional diving programs specify a depth limit of 40 m and many NIS extend well beyond this limit (e.g., *L. kasmira* – 256 m).

The acquisition of data below 40 m is more difficult and expensive than data collected in shallow water. Most data collected below 40 m in PMNM is gathered using net inspections or fishing gear (e.g. traps, hook and line), but these surveys are tied to the distribution of corresponding items and are highly selective in the species they detect. Consequently, they may not provide a representative dataset for the ecosystem. Further, the fishing gear and inspections do not provide information on behavior, benthic habitat or ecological linkages.

This report examines the utility of various technologies to gather data on the spatial distribution and abundance of NIS in deepwater (>40 m). Much of this report focuses on the use of towed camera systems, but alternative technologies, such as technical diving, fishing gear and remotely operated vehicles are explored. This report also examines the application of spatial modeling techniques which can help to predict NIS distribution and increase the efficiency of NIS surveys.

ABOUT THIS DOCUMENT

This docuement was prepared for the Papahānaumokuākea Marine National Monument and was developed to help achieve desired outcomes outlined in the Monument Management Plan (PMNM 2008), including surveillance and detection of NIS and methodological research to ultimately increase NIS detection and eradication. The basic concepts of this investigation were taken from existing work on invasive species in Hawaii, including Coles and Eldredge (2002), Godwin et al. (2006), See (2007), and data provided by, and discussions with monument staff.

This document is part of an evolving Biogeography Branch project which has the goals to conduct invasive speceis research and develop products needed by resource managers to identify, prioritize, and implement management actions for invasive species.

INVESTIGATION OF TOWED CAMERA SYSTEMS

DESCRIPTION OF TECHNOLOGY

Towed camera systems (TCSs) are a relatively inexpensive technology used to collect underwater imagery over a broad range of depths. Typically systems consist of a camera and supporting sensing instruments (e.g., pressure transducer, sonar altimeter, scaling lasers) mounted on a tethered platform. The tether or umbilical is attached to a support vessel and is used to communicate electronic signals, transmit power and tow the underwater platform.

Two distinct towed camera systems were used to collect underwater video imagery: the Towed Optical Assessment Device (TOAD; Figure 1) and the Benthic Assessment Sensor System (BASS). Both systems possessed a downward pointing video camera to obtain imagery, but TOAD also used a forward pointing camera to avoid obstacles and gather additional imagery. To take advantage of the second camera TOAD was used for the majority of surveys. BASS possessed a digital still camera, but it did not produce pictures of sufficient quality to identify NIS or benthic habitats and thus was unsuitable for this particular application. In addition to cameras, both systems possessed supplementary supporting equipment, including high wattage lights (>300 W) to illuminate the seafloor and increase the probability of NIS detection, pressure transducers to determine platform depth, and ultra-short baseline (USBL) systems to track platform position relative to the support vessel. Appendix A provides technical details of each towed camera system.

Figure 1: TOAD's underwater platform (left) and video recording system (right)

STUDY SITE AND METHODS

The NOAA vessel Hi'ialakai was used for support and deployment of the two TCSs at French Frigate Shoals (FFS) and Brooks Banks (West, Middle and Baby; Figure 2) from May 7 to May 26, 2008. The Hi'ialakai's primary objective was to collect multibeam bathymetry data and benthic habitat imagery to use for groundtruthing benthic habitat maps. Assessments of BASS and TOAD and surveys of NIS were a secondary objective of the mission; however imagery were collected in a manner such that all objectives could be satisfied simultaneously. Both objectives required highly resolved imagery of benthic substrate and biota from diverse benthic habitats and over as large a spatial extent as possible.

Most data (31 transects; 96.2 hours; 153.3km) were collected at FFS since this location was a target for multibeam data acquisition and the remaining tows (4 transects; 6.5 hours; 4.2 km) were distributed among Brooks Banks, three submerged banks between FFS and Gardner Pinnacles (Figure 3). At FFS, targeted areas included the western, deeper portion of the lagoon and along outer slopes. At Brooks Banks tows were made on the shallowest portions of the banks (~ 30m) targeting areas with as many different benthic habitats as possible.
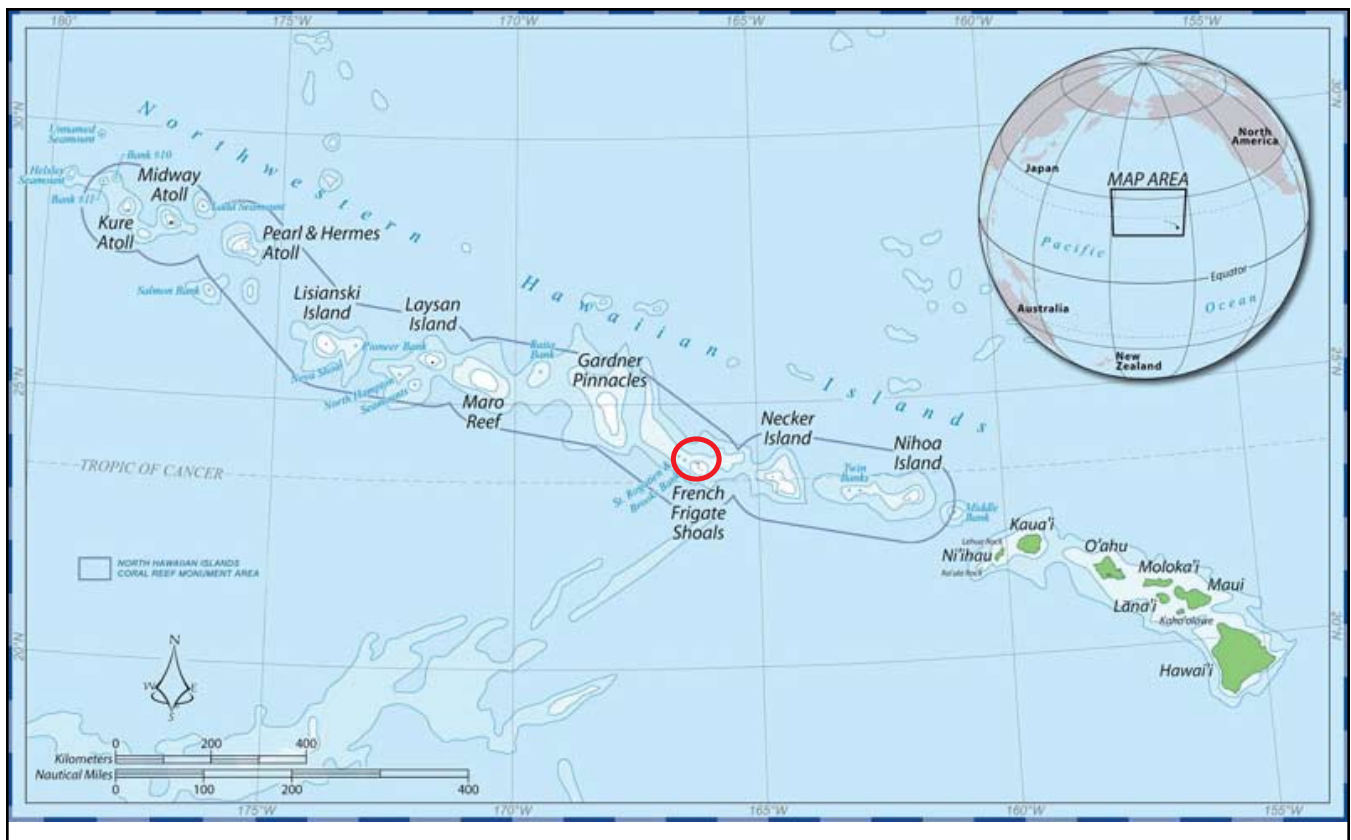
Figure 2: Map of the Northwestern Hawaiian Islands showing study area (red circle). Map taken from PMNM website.

Transects varied in distance from less than 2 km to over 18 km, depending on available surevey time, weather and bathymetry. Most transects were completed by drifting with water currents and thus tow speed and direction was determined by wind and water velocities. The Hi'ialakai did not possess dynamic positioning, which would have allowed more freedom of movement. Occasionally, the Hi'ialakai was used to speed up or alter transect direction by using short bursts of throttle in the desired direction. Bursts of throttle were used to steer toward bathymetric patterns of interest and increase camera speed when less than 0.5 knots. Camera speed averaged between 0.5 and 1.5 knots.

Video from the downward pointing camera was recorded during all dives and used to detect NIS. The camera was oriented downward to increase the probability of detecting invasive algae and sessile invertebrates. These taxa represent the largest group of invasive species of particular concern and were considered the more difficult to detect than larger, mobile NIS such as fish. Occasionally nonindigenous fish were identified in TOAD's unrecorded forward pointing camera. These sightings were noted, but no systematic protocol was used for recording.

All video were reviewed for NIS and when detected, the species, abundance, average size, certainty, time, distance off bottom and several metrics related to habitat were recorded. Not all organisms were identified with complete confidence due to factors such as distance from and orientation to the camera. Thus, certainty of the sighting was noted as either high (>95% certain), moderate (95-50% certain) or low (<50% certain). Benthic habitat measurements included type [patch reef, pavement, algal plain, sand, sand, or scattered coral/rock in sand], dominant biotic cover [macroalgae, crustose coralline algae, coral, or uncolonized], rugosity [high, medium, low], and the presence of habitat ledges and depressions in the substrate within 10 m of the observation.
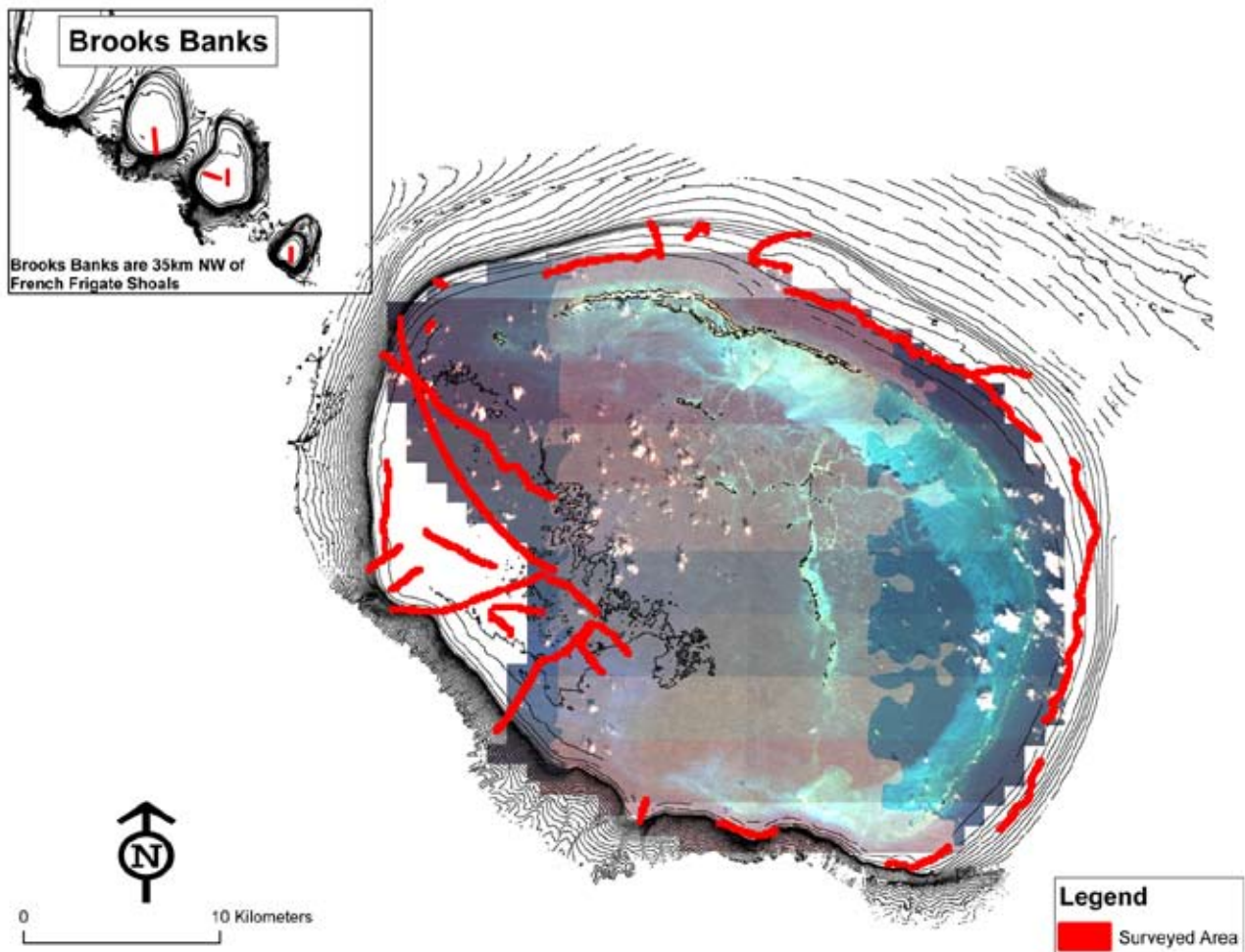
Figure 3: Location of survey transects at French Frigate Shoals and Brooks Banks (inset).

The spatial positions of NIS were defined by comparing a time overlay on the video with geographic coordinates of the camera. Camera position was determined by integrating the TCS's USBL and ship's differential geographic positioning system signals, providing a position with an estimated accuracy of +/- 20 m. Depth of observations was determined by intersecting record position with fine-scale bathymetry models in a geographic information system (during the mission pressure transducers were frequently not working). Bathymetry models were provided by the Coral Reef Ecosystem Division (CRED) and are freely available online (http://www.pifsc.noaa.gov/cred/hmapping/ , last accessed March 11, 2009).

We employed descriptive analyses to examine data, because a non-probabilistic sampling design was used to acquire data and sampling bias would be a problem. We also examined the difference between survey effort and observations to suggest patterns different from random.

FINDINGS

Towed camera systems collected video in depths ranging from 20 to 160 m. Approximately 100 hours of video were examined, in which 124 NIS sightings were detected in TOAD and BASS (Table 2). The vast majority of sightings were *L. kasmira* (97%), although C. argus and L. fulvus were also observed, but at much lower frequencies (1% each). Sightings with a high certainty are discussed below.

Lutjanus kasmira (Blueline snapper or Ta'ape)

L. kasmira was detected at all surveyed shoals and banks except Southeast Brooks Bank. Previous surveys have recorded *L. kasmira* throughout most of the Northwestern Hawaiian Islands, including FFS (e.g., Oda and Parrish 1981) and Middle Brooks Bank (PIFSC fishery data), but not West Brooks Bank. These new data extend the spatial range of *L. kasmira* into new habitats at FFS and establish its presence on West Brooks Bank.

Table 2 : NIS sighting data

Species	Certainty of Sightings			Totals
	High	Moderate	Low	
L. kasmira	76	14	28	118
C. argus	1	0	4	5
L. fulvus	1	0	0	1

At each bank and shoal the spatial distribution of *L. kasmira* was uneven and varied among habitats. At French Frigate Shoals all sightings were made in the lagoon or at its border at the top of adjacent outer slopes (Figure 4). Although a quarter of the survey effort was devoted to acquiring data from along the north, south, and eastern outer slopes, there were no sightings among these habitats. The lack of observations among these habitats is in contrast to recent PIFSC data, which shows *L. kasmira* were found in traps along the eastern slope. At Brooks Banks sightings were on the tops of each bank near the shallowest depths surveyed (Figure 4). PIFSC trap data show *L. kasmira* is also found in deeper habitats along the outer slope edges (Figure 4).

The majority of sightings were made between 25 and 35 m. When considering survey effort, sightings were relatively more frequent at depths between 20 and 65 m (Figure 5). The shallowest limit of this range (20 m) is the shallowest depth the towed camera system could be used and thus should not be confused with a limit or preference in the species' range. Only one sighting was made deeper than 70 m. Our data and those presented by others (e.g., Mizenko 1984, Friedlander et al. 2002) suggest *L. kasmira* is relatively abundant in moderate and shallow waters. This statement must be qualified because as of yet no study has used a standardized methodology to survey the species throughout its entire depth distribution, including this survey which lacks data between 0-20 m. The lack of a systematic protocol for data acquisition is prohibitive to spatial analysis. Data collected using a systematic protocol is needed to make a rigorous description of habitat preferences and thresholds, conduct analysis, modeling and monitoring or calibrate results from different methods.

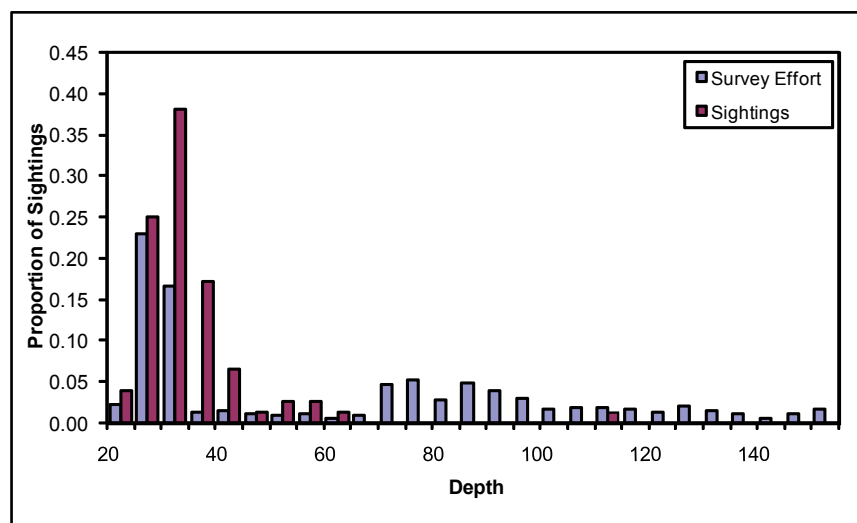Figure 5: Depth distribution of survey effort and *L. kasmira* sightings.

Over 90% of *L. kasmira* sightings were among hard-bottom benthic habitats (Figure 6). Hard-bottom sightings were almost equally split between algal plain and coral reefs. Algal plains
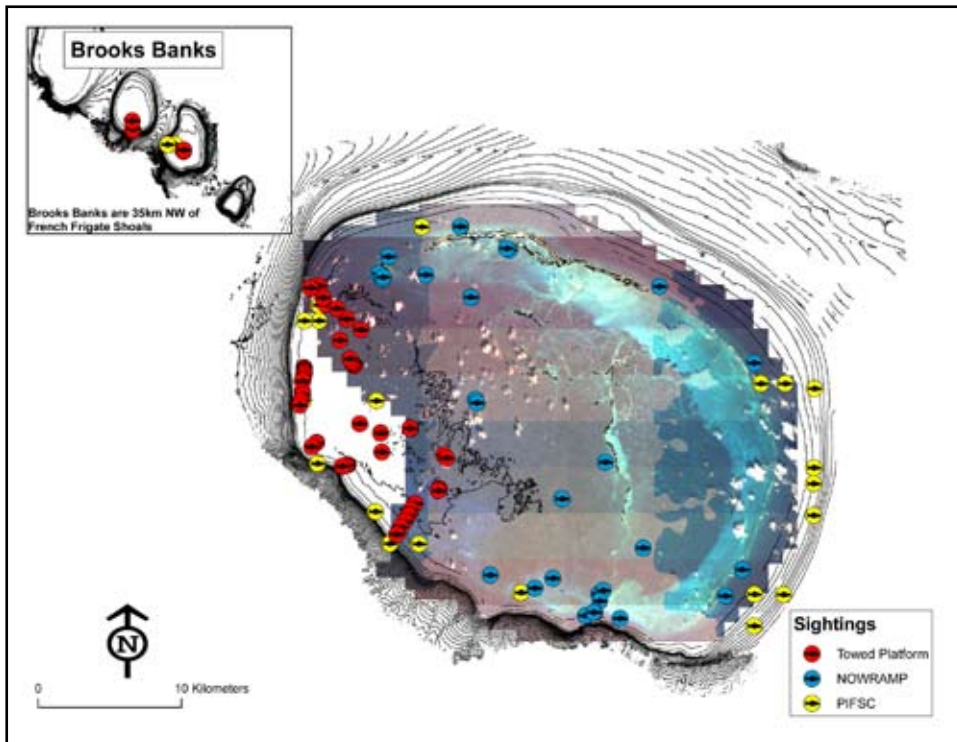
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Figure 4: Spatial distribution of *L. ksamira* sightings at FFS. Contour intervals at 25 m taken from fine-scale bathymetry data available from CRED. Imagery of IKONOS high resolution mosaics.

consisted of hard carbonate substrate or algal nodules covered by macroalgae and crustose coralline algae and with relatively low rugosity. Coral reefs consisted of coral dominated aggregate and patch reefs with moderate to high vertical relief. Observations of *L. kasmira* on reefs are frequent (e.g., Oda and Parrish 1981, Friedlander et al. 2002, Schumacher and Parrish 2005), but we have not found any other study which has shown evidence algal plains are used as habitat. It is believed that fish traps are generally placed in algal plain habitat (Friedlander, pers. comm.) and traps routinely collect *L. kasmira* (PIFSC fishery data), but since the habitat where these traps are placed cannot be visualized this cannot be confirmed. It will be important to determine the function of algal plain habitat. Sightings were also made among sand and scattered rock, and sand habitats, but at significantly lower frequencies.

The frequencies of sightings among habitats do not correspond direclty with survey effort. Over 90% of sightings were on hard-bottom substrate, such as algal plain and coral reefs, while only an estimated 50% of the survey effort was in these habitats. A precise estimate of survey effort among benthic habitats is not possible, because a deep water benthic habitat map for the region does not exist and benthic habitat type was not recorded for all video (only where NIS observations were made). The discrepancy between survey effort and sighting frequency, suggests *L. kasmira* predominately used hard-bottom habitats.

The rare sighting frequency among sand habitats (1%) is dissimilar to results presented by others who showed sand habitats were normally used for nocturnal feeding (e.g., Friedlander et al. 2002). Measurement bias may explain this difference. For example, individuals may have been repelled by the towed camera systems more in sand habitats than hard-bottom habitats due to a lack of shelter. Time was likely not a factor since both sand and hard-bottom habitats
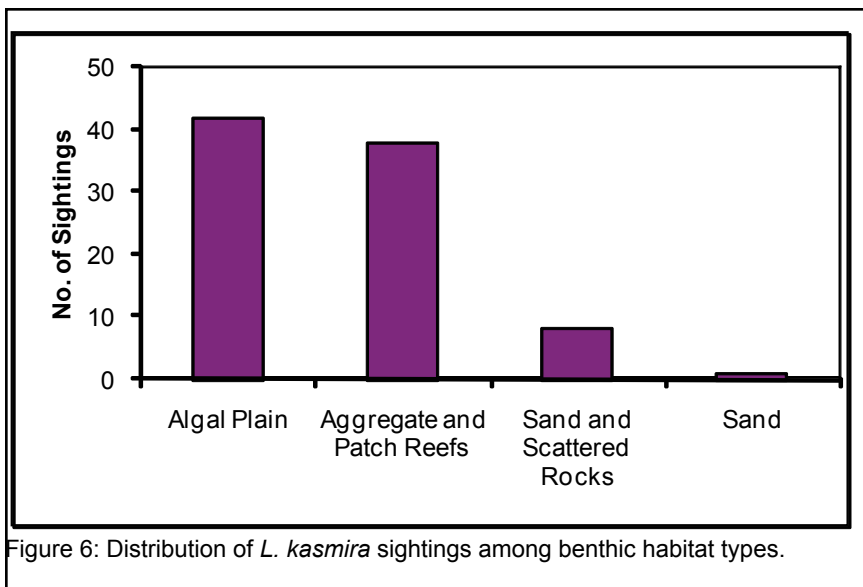
Figure 6: Distribution of *L. kasmira* sightings among benthic habitat types.

We compared the distribution of *L. kasmira* in data provided courtesy of the NOAA Pacific Islands Fisheries Science Center to sightings obtained by the towed camera systems. PIFSC data was obtained using various gear including handlines, traps, pots and nets. At FFS PIFSC data show *L. kasmira* in lagoon and nearby outer slope habitats as did the towed camera system, however PIFSC handline and trap data also show multiple sightings among outer slope habitats on the northern, southern and eastern fringes of FFS (Figure 4). These outer slope habitats were surveyed extensively, by the towed camera system, but no NIS were detected. One reason for this discrepancy may be sampling bias. Since most of the outer slope habitats were open sand or flat algal plain habitat, NIS may have sought shelter from the towed camera system and thus went undetected, whereas traps and handlines actively attracted *L. kasmira* with bait.

In addition to detection data, the towed camera system's video provided information on behavior and fine-scale habitat characteristics. Almost half of sightings were among high relief habitats such as patch reefs, but surprisingly almost 40% of sightings were among low rugosity habitat. Much of the latter was algal plain habitat. Most sightings among algal plains were frequently individuals or small groups seen moving in or near small depressions filled with sand. Individuals appeared to be foraging and at several times plumes associated with disturbed sand were visible. It is possible that these depressions contained food items similar to those found among sand habitats, but this judgment should be confirmed by further study of the overlap between prey availability and diet composition.

Figure 7: Depth distribution of survey effort and *L. kasmira* sightings.

Schooling, a strategy to increase security and commonly used during periods of inactivity (e.g., Radakov 1973) was examined. Schools consisting of groups of more than 3 individuals were observed 14 times (15.7%); in one case a school of more than 100 individuals was observed. Most schools (64%) were observed under ledges with recesses and appeared to be resting. All

schools which were not under ledges were actively swimming. Schooling did not show a prominent diel cycle, but did occur most

frequently from 12:00 to 16:00, part of the period snappers are expected to be inactive (Figure 7). Few schools were observed 08:00 - 12:00 and 16:00 - 20:00, which are also time periods expected to be a period of inactivity. Schooling was observed in all habitats, including the one observation made in sand habitat. There was insufficient data to asses a temporal trend among habitats.

Cephalopholis argus (peacock grouper or Roi)

C. argus was observed only once with certainty using the towed camera system. Four other sightings with low certainty were logged, but the individuals were too far from the camera to make an irrefutable record. The one certain sighting was made in the lagoon at FFS about 5 km WSW of La Perouse Pinnacle (Figure 8). Water depth was 27 m and habitat was characterized as aggregate reef with moderate rugosity and a nearby transition to sand. NOWRAMP surveys detected C. argus at La Perouse and three other sites near the edge of the lagoon in shallow water (<30 m). The PIFSC has not detected C. argus in monitoring traps.

The relatively low sighting frequency of C. argus with the towed camera system makes spatial analysis impractical. One of the reasons for this rarity may be their preferred depth habitat is outside the limits

Figure 7: Spatial distribution of *C. argus* sightings at FFS. Contour intervals at 25 m taken from fine-scale bathymetry data available from CRED. Imagery of IKONOS high resolution mosaics.

of our survey domain. Although Heemstra and Randall (1993) report distribution is down to 40 m, which is well within our domain, they also reported preferred habitat is less than 10 m which is too shallow for the towed camera system. Other reasons for infrequent detection could be associated with sampling selectivity and animal behavior.

Few studies have been conducted on the ecology of the species to determine or forecast ecological impacts and function. Work on these aspects is currently being done by the University of Hawaii.

Lutjanus fulvus (blacktail snapper or to'au)

L. fulvus was sighted only once in the lagoon at FFS (Figure 9). The sighting was made in 31 m of water on aggregate reef with high rugosity and a nearby transition to sand. Multibeam data indicate the habitat near the sighting was along a border of a complex high-relief reef and low rugosity habitat (probably scattered coral/rock in sand). The border was characterized by a 2.5 m ledge. Many other fish were observed in the area and it was seen swimming away from the camera.

The habitat in which it was observed at FFS has preferred characteristics. In the Indo Pacific, L. fulvus has been observed in lagoons and semi-protected seaward reefs and prefers areas with shelter or high rugosity (Lieske and Myers 1994, Myers 1999).
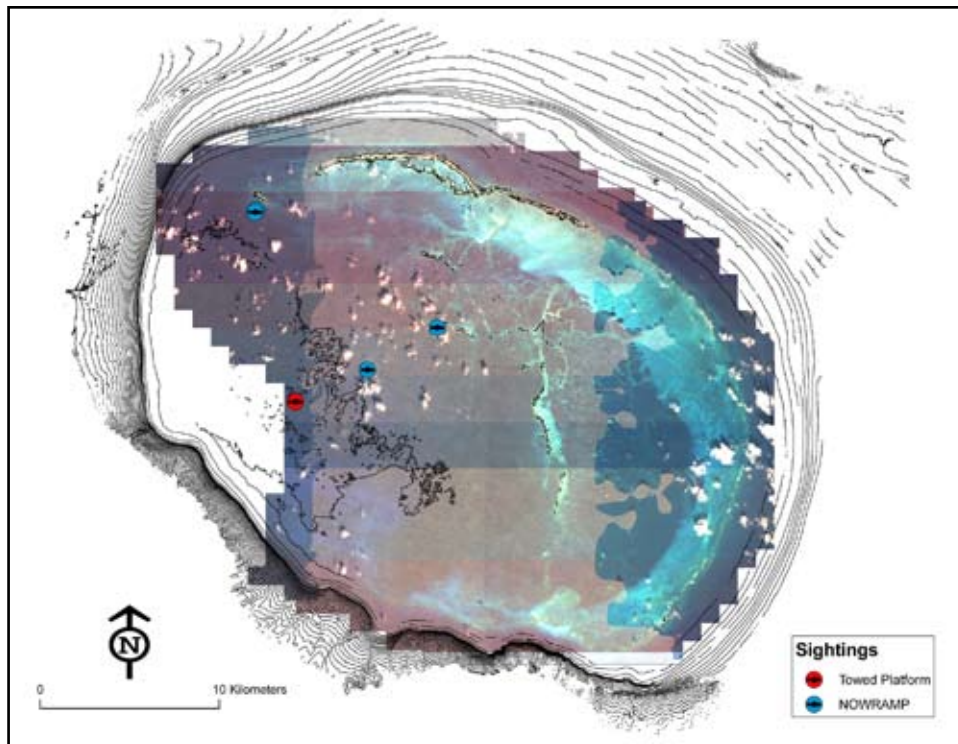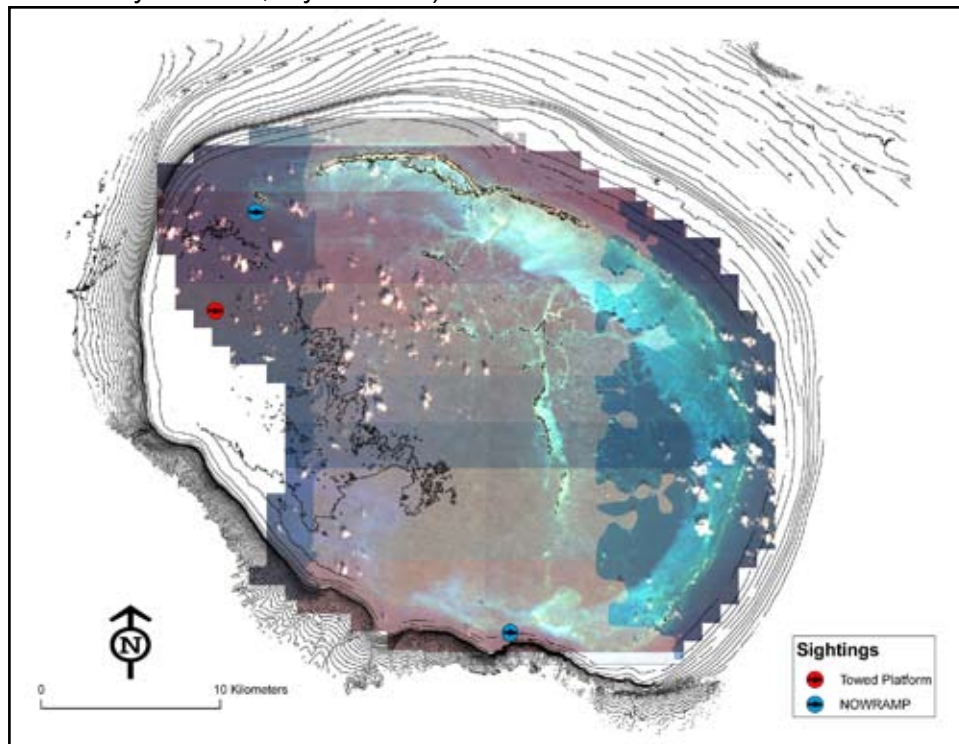

Figure 8: Spatial distribution of *L. fulvus* sightings at FFS. Contour intervals at 25 m taken from fine-scale bathymetry data available from CRED. Imagery of IKONOS high resolution mosaics.

Similar to C. argus there are too few data to conduct a spatial analysis and too little is known about their ecology to forecast impacts. In the NWHI L. fulvus is sighted less frequently than *L. kasmira*. NOWRAMP has only had two sightings of L. fulvus at FFS.

ASSESSMENT

BASS and TOAD provided a simple, cost effective means to identify several NIS of particular concern in NWHI; however its application to all NIS is suspect. BASS and TOAD easily identified three nonindigenous fish species, but NIS with small or cryptic distinguishing characteristics such as algae, barnacles, bryozoans, hydroids or anemones were not observed or were observed with only low certainty. For instance, the flattened broad hooks on the tips of branches used to identify H. musciformis cannot be detected in collected video.

Sensors

Detection is one of, if not the most important variable to consider when choosing a survey technology for NIS, especially for rare taxa. A technology which cannot accurately detect NIS will lead to many false negatives and impede effective NIS management since no action will be taken.

The video cameras used on both BASS and TOAD had moderate video resolutions (380-460 TV lines). This resolution is considered insufficient to detect small or cryptic distinguishing characteristics. Video cameras with increased resolution (preferably high-definition) or high-resolution still cameras would increase the resolution of imagery and the probability of species identification. Black and white low-light cameras are not recommended as color was an important distinguishing character for many NIS.

Sensor orientation has an impact on NIS detection. An examination of sensor orientation on NIS detection rate was conducted on a single transect using forward and downward pointed cameras. Frequency of NIS occurrence and relative abundance was highest among the forward looking camera (only *L. kasmira* were observed). These results agree with those by Auster et al. (2007) who examined sensor orientation on multiple camera sleds, ROVs and AUVs. They recommended that designers accommodate forward looking cameras and associated lighting in order to increase the detection of mobile fauna. Our observations corroborate their conclusion that mobile organisms are detected less in downward pointing cameras due to organism avoidance. The impact of camera orientation on immobile benthic organisms is less certain. On one hand texture and height are more apparent in orthogonal images, but on the other hand organisms cannot hide behind benthic structures.

Platform Movement
The inability of the towed camera system to direct their movement towards a habitat or specimen of interest is a major disadvantage of the technology. A lack of directed movement meant many observed organisms could not be thoroughly inspected and thus could not be identified. This was a major problem for Hypnea sightings, because flattened broad hooks on the tips of branches couldn't be seen.

The lack of directed movement also has implications on sampling designs which require repeated measures. For instance a TCS could not be used to for long-term monitoring at permanent sites, since the same areas could not be easily revisited. Random probabilistic sampling designs would not have such a problem.

Auxiliary Visual Information
Imagery, like direct observations, provides information on behavior, habitat characteristics and community. Alternative technologies, such as fishing gear do not provide such data, because they are "blind". Behaviors associated with feeding, schooling, and avoidance offer powerful insights into the ecology of a species. In conjunction with additional information such as habitat and community diversity, behavior can also help identify ontogenetic shifts and essential fish habitat.

Knowledge of where NIS are likely to occur can aid in NIS detection. Video from TCSs can provide information on benthic habitats and community covariates such as species with environmental niches similar to NIS of concern. Thus auxiliary visual information in the video can identify locations where NIS are likely to be found. Habitat information can be used in conjunction with other data (e.g. bathymetry) to develop benthic habitat maps using extrapolation or can be used in conjunction with other survey technologies (e.g. ROVs, technical divers) to inspect preferred habitat.

Measurement Bias
In a recent review of 48 demersal marine fish taxa, Stoner et al. (2008) showed that almost all taxa react in one way or another to underwater vehicles. During the pilot study we witnessed several taxa adjust their behavior within the cameras field of view. Generally species with small body sizes, most of which could not be identified, avoided the cameras and could be seen swimming away or finding shelter in holes and cracks within hard substrate. Some species, such as large bodied jacks (e.g., Caranx hippos), were attracted, presumably to the lights. Still other species such as *L. kasmira* did not appear to react at all. These behaviors do not necessarily translate into sampling bias if they are consistent, but more information is needed to investigate this connection and generate bias adjustments if needed.

We expect there to be a detection bias among different habitat types for both mobile and immobile species. For instance, we were able to identify and detect taxa more easily among low-relief habitats than among rugose coral reefs, because of unimpeded line of sight and differences in behavior. Precise bias measurements require further study, but our observations suggest bias associated with attraction and avoidance behaviors will affect absolute abundance, distribution and diversity measures and should be considered when these measures are computed.

Spatial Scope

Most biological data in NWHI are collected or informed by conventional SCUBA. The principal drawback of this method is that effective research is constrained to depths shallower than 40 m and to short bottom times. A technology which increases the spatial scope or extent of a survey is advantageous because new habitats can be surveyed. The ability of TCSs to reach depths up to 250 m means they can fill a void left by SCUBA surveys. The pilot study proved towed camera systems complement NOWRAMP sightings based on SCUBA by extending NIS detections into deeper habitats (e.g., Figure 4). In addition, a technology which is not constrained by bottom time can collect more data, increasing collection efficiency. TCS were only limited by the amount of time available for surveying, not by the equipment itself. The collection of over 100 hours of imagery is much greater than what could have been accomplished with divers. This divergence increases as surveys get deeper.

Costs

The cost of a towed camera system can be considerable and varies according to the platform's capabilities (i.e. type and quality of cameras and auxiliary sensors). A simple towed camera system consists solely of a normal camera in an underwater housing tethered to a surface support vessel. Such a system is relatively inexpensive and is commonly used in shallow systems (<50 m). To survey depths below 50 m costlier and more sensors are needed. The need for more equipment is generally intended to reduce the risk of equipment loss, for basic navigation and ensure usable data. BASS (max. depth 300 m) and TOAD (max. depth 250 m) possessed a platform to accommodate and protect multiple sensors, special instrument housings to withstand pressure at depth, strong umbilical cables to withstand high drag, umbilical cable reels to efficiently raise and lower the platform, lights to see in darkness and an ultra-short baseline system to position the system underwater. All of these components add to the overall price, but increase the quality of data. Implementation of a towed camera system will incur a significant startup cost (approx. $75-250K), but this is less than similar technologies such as remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs) and human occupied vehicles (HOVs) and requires little in terms of maintenance costs.

Operational costs related to items such as vessel charges and crew wages are exceptionally high for survey operations in NWHI. Decisions which increase data acquisition efficiency and lead to a reduced number of days at sea or cost per survey are highly desirable. This pilot study was performed in concert with benthic habitat mapping activities, which meant ship time, and equipment and operation costs were shared. This strategy proved extremely cost effective and should be adopted whenever possible. In addition, the towed camera systems were used at times when other survey operations could not, thus increasing mission efficiency. For instance, towed system operations were conducted at night, when diving operations were suspended due to increased risk of injury.

The towed camera system was capable of surveying many locations relatively quickly. This capability increased the number of samples (i.e. video frames) used to detect NIS and somewhat offsets its moderate ability to detect NIS per sample. For example a technology which has a 50% detection probability and can sample 100 sites, is better than a technology that has a 80% detection probability but can only sample 10 sites.

Additional uses

Data collected using towed camera systems has many additional uses other than NIS detection and

consequently can satisfy multiple objectives simultaneously. For instance, the data collected during this pilot study will also be used to ground-truth benthic habitat maps being developed by NOAA PIFSC. For this purpose, video imagery will be used to identify benthic habitat types. Further, imagery can be used to identify substrate characteristics (e.g., coral cover coral disease) and enumerate organisms (e.g. crown of thorns, apex predators, urchins, and coral). All of these data are important ecological measures and are readily apparent in video imagery.

Recommendations

The inability of TCS to identify smaller taxa is a serious concern. Many of the nonindigenous species in the main Hawaiian Islands, which are a serious threat to NWHI, are small invertebrates and would likely go undetected. We recommend to courses of action. At a minimum, sensors on towed camera systems should be augmented so that they are capable of detecting smaller taxa. These augmentations can take the form of telephoto lenses, higher resolution video cameras or addition of high resolution still cameras. Another and preferred recommendation is to use the less costly data obtained from TCSs to focus sampling effort of alternative survey technologies capable of inspections, such ROVs or technical divers. This recommendation will likely be more costly in terms of equipment and time than the first, but would also likely have a higher probability of detecting NIS with high certainty. The following sections describe technologies and modeling methods which can aid in focusing sampling effort.

ALTERNATIVE DEEPWATER SURVEY TECHNOLOGIES

Several alternative technologies are compared in this section. The alternatives are divided into three broad survey categories (indirect observation, direct observation, and extractive), because technologies in each category share many of the same costs and produce similar data. Two factors are paramount when deciding on a suitable technology: (1) data quality or its ability to satisfy survey objectives; and (2) the cost of equipment and operation. Table 3 identifies several technologies which can be used to conduct NIS surveys in NWHI and compares variables associated cost and data quality. Although there is some discussion about cost in the next paragraphs, we focus our attention on data quality.

For this report data quality is measured by a technology's ability to identify NIS. It should be noted that NIS of interest to the PMNM cover diverse taxonomic categories and any single technology may not be suitable for all taxa. It is possible that multiple technologies may be required to survey all species of particular concern.

Direct Observation

The most common method of species identification is through direct observation (i.e. visual census) and in the marine environment this is most often accomplished using a diver. Human occupied vehicles are also used for direct observation, but are much more costly and consequently used much less frequently. Direct observation is generally preferred over indirect observation or extractive technologies because it produces high-quality datasets at low cost and with little attenuation caused by sensors. Further, direct observation allows rigorous inspections and thus reduces uncertainty when identifying NIS.

Technical Diving

Technical diving describes various technologies and methods which extend the bottom time and/or depth limit of divers when compared to conventional SCUBA. It is accomplished by mixing inert gases such as helium into breathing gas, using a rebreather, decompression-diving or saturation diving. Technical divers can reach depths approaching 100 m and thus can fill a gap left by conventional SCUBA divers.

Technical divers are more versatile than technologies employing indirect observation for the same reasons conventional SCUBA divers are employed in shallow water systems: surveys are generally less expensive and data is of higher quality. Divers can perform rigorous inspections and collect organisms, thus greatly increasing the confidence with which detections are made. Another advantage is that similar

measurement protocols used in shallow water can be used in deepwater. The resulting standardized output it useful in NIS detection surveys, but critical when data will be used to model species distributions or monitor NIS over time.

However, one of the principal drawbacks of technical diving is low sample size. In general, only one or at most two 20-30 minute dives (depends on depth) can be completed by a single diver in a day. This is much less than the 5-10 dives a single diver using conventional SCUBA can accomplish or the amount of time a TCS can spend underwater collecting imagery. Although the probability of detection is higher than any other deepwater survey technology, the probability should be tempered by its capacity to only survey a small area. One approach could be to combine technical diving with remote technologies thus providing complementary data that could be used to fill in the gaps that otherwise occur when used separately.

At least one technical diving mission has been accomplished in NWHI to survey deep water fish (NOAA 2002). Although this particular mission focused on fishery species, technical diving is being used successfully by NOAA researchers in other areas (coastal North Carolina) to conduct ecosystem based research on the invasive lionfish in water depths from 35-50 m (Whitfield pers. comm.). There is no reason to believe the technology cannot be used to detect NIS from diverse taxonomic groups. A future technical diving mission to detect NIS is planned for FY09 and methods to increase the probability of NIS detection are currently being considered.

Submersibles

Submersibles offer another method to detect NIS below 40 m, but they are such an expensive tool that they are typically only used when alternative methods are unsuitable, such as in very deep habitats (>300 m) or when precise manipulation is required. The use of submersibles for NIS surveys is unlikely in NWHI unless a NIS is considered extremely harmful or the survey is tied to another project which requires a submersible.

Indirect Observation

In some circumstances, such as in deep water, direct observations cannot be made because they are prohibitively costly or risky. One possible solution is the use of technologies which employ a sensor for indirect observation. By far the most common sensor is a camera, but technologies employing sonar (e.g., DIDSON) are more frequently being used especially in environments with low visibility. Since the NWHI is characterized by clear high-visibility waters, we will focus the assessment on technologies employing cameras.

Cameras provide two varieties of output: video and still photos. Either can be used to detect NIS, but they possess different advantages. Video generally provides better perspective. A 3-dimensional representation of a species is more easily made using video. Further the ability to view species movements, whether it is a fish swimming or algae swaying in a current, increases the likelihood of accurate species detection and identification. The principal drawback of video cameras is image resolution. The video resolution (380-460 TV lines) and lens quality of video cameras on BASS and TOAD were moderate. Resulting images were insufficient to detect small organisms or distinguishing characteristics. A major camera improvement is the development of high-resolution video, but these cameras are more costly, data is much larger and transmission in real-time is more difficult.

Still photos generally possess higher resolution than video, but lose perspective. The additional resolution allows observers to see physical characteristics on an organism which can aid in species identification which may go unnoticed in video imagery or even by a diver using direct observation. Cameras capable of producing 3-10 megapixel still photos are common and have been used extensively to identify species in the marine environment, even small species ().

The quality of data from a camera is inherently a function of image quality and positioning, whether

Technology	Cost	System complexity	Sample size	Probability of NIS detection	Taxonomic Selectivity	Type	Advantages	Drawbacks
Towed camera system	Medium	Medium	High	Low	Low	Indirect observation	Simplicity; sample size	Lack of agility
Remotely operated vehicle	High	High	High	Medium	Low	Indirect observation	Maneuverability, sample size	Cost
Autonomous underwater vehicle	High	High	High	Low	Low	Indirect observation	Sample size	Cost, lack of reaction
Stationary camera	Medium	Medium	Low	Low	Medium	Indirect observation	Simplicity	Lack of movement, taxonomic selectivity
Human occupied vehicle	Very High	Very High	Low	Medium	Low	Direct observation	Direct visual assessment	Cost, complexity, sample size
Technical diving	Medium	High	Low	High	Low	Direct observation, extractive	Direct visual assessment, voucher specimens	Diver risk, sample size
Fishing gear / settling plates	Medium	Medium	Medium	Variable	High	Extractive	Voucher specimens	Highly selective, extractive

Table 3: Comparison of survey technologies for NIS surveys in deepwater environments

it is video or still photos. Cameras which provide sharp, consistent images in a variety of underwater environments (e.g., coral reefs, algal plains) are critical. Further, good image positioning is important. A high-quality image which misses a specimen cannot satisfy the objective of NIS detection. One of the main drawbacks of TCSs was there inability for directed movement which resulted in poor image positioning. Three alternative camera platforms which offer improved image position are discussed below.

Remotely Operated Vehicles
ROVs are similar to TCSs in many respects, but differ in their ability for directed movement. Commonly, real-time video is used by operators to direct ROVs to specimens of interest, established NIS colonies or long-term monitoring sites. The capacity for directed movement makes ROVs especially useful for close-up inspections and fine-scale photographic surveys.

ROVs have been used in numerous ecological studies to observe fish, coral and benthic habitats. For example, several studies have used ROVs to collect basic ecological information on deep water macroalgae (Spalding et al. 2003; Verbruggen et al. 2006). Recently, studies have begun using ROVs for quantitative surveys and numerous technologies and methods have been implemented to increase probabilities of identification and accurate enumeration such as scaling lasers (Pilgrim et al. 2000), stereo-vision (Hegahdaripour and Firoozfam 2006) and red lights (Widder et al. 2005). In a suitable case in point, Whitfield et al. (2006) used ROVs to assess the distribution and abundance of invasive lionfish off the southeast coast of the United States. They used conventional linear survey methods to collect data and showed lionfish could easily be detected and enumerated. Taken together, past reports suggest ROVs are a capable tool in the detection of mobile and sessile species. Their principal drawback is cost and maintenance. Not only do they require a significant startup cost (greater than all other technologies listed in table 3, except a HOV), but they also require regular maintenance costs and a dedicated operator / technician.

Autonomous Underwater Vehicles
AUVs differ from TCS and ROVs in several major respects. First, they are not tethered, which gives AUVs much more freedom of movement. Second, AUVs operate autonomously based on commands uploaded prior to deployment, limiting their ability to react. Early AUVs could not react to gathered data or send large amounts of data (i.e. video) to the surface in real-time, but recently work has been done to accomplish these tasks. Yoerger et al. (2007) describe an AUV capable of surveying an area, analyzing the data while in the water and then returning to sites of interest for more detailed inspections. With current technology a similar method could be used to survey for benthic habitat types using bathymetric measures and then return to habitats with the highest likelihood of possessing invasive species (e.g., inspections targeting ledges for C. riseii). The ability to pre-direct the AUVs sampling area would also allow repeated surveys of the same area which would allow researchers to design more statistically robust sampling designs over longer time periods. A problem currently outlined in this report for the TCS system.

Another advantage of an AUV is the ability to gather vast amounts of data with little or no surface support. Generally, AUVs are used to acquire data at large spatial-scales which are then used to direct other technologies for more detailed surveys. There is a synergy between AUVs and other technologies such as TCSs and ROVs. This synergy can be exploited to increase the yield of cruises. Principal drawbacks are price, complexity and maintenance due to the need for advanced technical systems.

Stationary Underwater Platforms
Stationary underwater platforms are dropped from a ship onto the seafloor and used to collect imagery of nearby species. To increase the probability of detection they commonly use attractants specific to a species or taxa of interest. Since these platforms commonly rely on attraction, they are only suitable for mobile NIS.

In 2006, BOTtomfish digital stereo-CAMera bait systems (BotCam) were deployed at 14 sites on

southern slopes of West and Middle Brooks banks (Cruise Report HI-06-12). Several species of fish and invertebrates were identified, but not any NIS.

Specimen Extraction

Technologies that extract specimens, such as fishing gear and settling plates, offer the highest probability of identification; however these are generally destructive (i.e. organisms are stressed, killed or removed), highly selective (i.e. only a component of the population is surveyed) and spatially biased. Technical divers are also capable of extracting specimens and have much less selectivity.

Extraction allows researchers to thoroughly inspect each specimen, and if needed, to contact taxonomists, use microscopy or perform DNA analysis to eliminate doubt. Another advantage is that collection gear can be retrieved hours or days after deployment, thus integrating survey effort over a long period of time. Such a strategy increases the probability of detection for species which possess a heterogeneous spatiotemporal distribution. Extractive methods are not foolproof. Their ability to comprehensively census an area is not guaranteed and their census area is variable. Consequently, data is not standardized and this impacts analyses examining population and spatial distribution change.

The PIFSC uses handlines, pots, nets and traps to collect data on deepwater fishes and mobile invertebrates from the NWHI. These gear typically use bait to increase probability of capture and have been useful in detecting the presence of *L. kasmira* in habitats as deep as 256 m. They have also detected L. fulvus, but at much lower frequencies. Another application of these gears is to detect algae and other attaching or encrusting organisms. For instance, since 2002 H. musciformis has been detected at Mokumanamana (Necker Island) attached to lobster traps hauled up from 30-90m.

Conclusion

The preceding paragraphs describe a diverse selection of technologies capable of deep water NIS surveys. Unfortunately, there is no clear correct selection. The decision will depend on the particular NIS of concern, funding and the availability of trained personnel. It is likely that multiple combined technologies will be required to satisfy all objectives related to NIS detection and monitoring in the PMNM.

As a broad generalization, ROVs and technical diving seem the best options if they can be afforded and trained personnel are available. They provide comprehensive assessments of deepwater communities, can be standardized by area and time, and allow inspection of specimens to increase certainty of taxonomic identification.

SPATIAL MODELING

The high costs associated with underwater surveys below 40 m means a comprehensive, systematic spatial dataset of deepwater NIS is difficult to acquire. A targeted survey approach which focuses effort in specific areas or for certain species or both is desirable. Common methods of allocation include concentrating survey effort in essential habitat, edges of known spatial distribution, or on the most invasive (i.e. destructive) species.

This section examines datasets and methods able to help maximize the likelihood of detecting target species such as *L. kasmira*. The goal was to develop a map which could be used to focus monitoring effort. We use boosted regression trees to illustrate how presence-absence data can be used to identify suitable habitats and show the utility of data provide by towed camera systems. The example predicts the spatial distribution of *L. kasmira* at FFS using a straightforward spatial modeling technique and freely-available bathymetry datasets. We intend this approach to serve as an illustrative example and be instructive for similar analyses of other NIS and in other locations (e.g., Midway, Kure, Nihoa). Taken together these types of output can form a core deliverable of an invasive species risk assessment and early warning system.

Boosted regression trees were used to generate the spatial model because they are capable of handling different types of predictor variables (continuous, nominal), can fit complex non-linear relationships, automatically model interactions among predicators, can provide valuable ecological insight and have been used with good results in past distribution studies (e.g., Elith et al. 2008). Distribution data used to form the model were taken from the 2008 towed camera system pilot study were both presence and absence data was available.

Ten predictor variables were taken from or informed by bathymetry data collected by NOAA Pacific Islands Fisheries Science Center CRED (Table 4). A 20-meter resolution bathymetric surface was used for most derivations, but a 5-m resolution bathymetric surface limited to depths shallower than 100m was used to help guide decisions of habitat type (i.e. ledge, pinnacle) whenever possible. Bathymetry data was collected using multibeam sonar systems and exhaustively covers the entire survey domain (marine habitat 20-250m at FFS). Bathymetry datasets and descriptions of instruments and methodologies are available on the PIFSC-CRED website (http://www.pifsc.noaa.gov/cred/, last accessed January 23, 2009). Slope, variability of slope and slope of slope were programmatically derived from the 20m resolution bathymetry surface using the Spatial Analyst extension in ArcGIS (ver. 9.2). The remaining predictors, ledge and pinnacle, were derived using visual examination of the bathymetry surface.

Table 4: Description of predictor variables used in spatial modeling of *L. kasmira*

Variable	Description	Range	Code
Depth	Average depth (m)	22-294	Bath_avg
Slope	Average first differential of depth (°)	0-45.6	Bath_slope
Variability of depth (Fine-scale)	Standard deviation of depth (m)	0-34.2	Bath_std
Variability of depth (Coarse-scale)	Standard deviation of depth (m)	0-130.0	Bath_std_lg
Slope of slope	Average second differential of depth (°)	0-40.1	Bath_slofsl
Ledge	Presence of ledge	Yes, no	Ledge
Pinnacle	Presence of pinnacle	Yes, no	Pinnacle
Slope Aspect	General location relative to cardinal directions	East, West, North, South, Flat	Aspect

Data for most sets of predicator variables were aggregated into a survey grid consisting of mutually –exclusive and exhaustive 100m X 100m square elements. The application of a survey grid allowed diverse datasets to be compiled within a standardized spatial framework and decreased processing time. In the future such a grid will allow the addition of alternative environmental predictors, such as sea surface temperature, water current data or marine debris presence, even if they are in dissimilar spatial formats. A coarser survey grid (1km by 1km) was used to map coarse-scale habitat. It may also be possible to integrate such a grid into a probabilistic sampling design for monitoring or early detection.

The presence of ledges and pinnacles was determined by identifying distinguishing spatial patterns in the bathymetry. A ledge was identified by a linear change in bathymetry of more than 2m and a pinnacle by a round local high protruding from the surrounding habitat by more than 5m. Aspect was used along outer slopes to indicate relative spatial position around the atoll. Several variables were thought to be correlated with aspect, including current strength and turbidity, although these relationships were not investigated.

Data was randomly split into two independent datasets, one for training the model (75%) and the other for testing (25%). Models were fit in R (version 2.4; R Development Core Team) using the gbm package

version 1.5 (Ridgeway 2006) and custom code provided by Elith et al. (2008). To balance model fit and predictive performance the relationship among the number of trees (1000-10000), learning rate (0.01-0.005) and deviance reduction was examined and the combination which achieved minimum predictive error using 10-fold cross validation (number of trees = 2000, learning rate = 0.001, tree complexity=5) was identified.

Two models were developed to assess the impact of predictor number and overfitting on prediction. The first, model A, utilized all predictor variables, whereas the second, model B, utilized only 5. The predictors used in model B were those with the greatest relative importance in model A. Predictor influence was measured using relative importance, which is described by Elith et al. (2008) and developed by Friedman (2001). Figure 10 provides partial dependence functions of each model. In both cases depth [bath_avg] was the principal predictor and accounted for over 50% of the relative importance.

Model validation was accomplished by comparing model predictions to the testing dataset using map accuracy and Cohen's Kappa statistic. Since model output is in the form of a continuous variable, model predictions were first modified into a Boolean surface (i.e. presence-absence map). The cutoff point with highest sensitivity (cutoff=0.04316) on a receiver operating curve was used to divide model output into presence or absence.

Table 5: Results from accuracy assessment

|	Map Accuracy	Kappa
Model A	82%	0.43
Model B	82%	0.45

Map accuracy for both models was high (greater than 80%), but much of this accuracy can be attributed to the rarity of sightings. Cohen's kappa statistics were moderate and Model B was slightly higher suggesting the addition of mode variables in Model A may be overfitting the data. Output from model B was exported into a geographic information system to visualize spatial patterns (Figure 11). It is this type of output which could be used by natural resource managers to choose sampling sites and develop a monitoring program for *L. kasmira*.

In general, the models show the probability of *L. kasmira* presence is greatest along the terrace and in the lagoon where ledges occur or fine-scale rugosity is high. The probability of presence below 60m and in flat areas is very low. The model also reveals an interesting ecological interaction between fine-scale rugosity and coarse-scale rugosity. The interaction suggests *L. kasmira* are found in high-relief habitats which are also near low-relief habitats as would be expected for a species which seeks shelter in reefs during the day and feeds among sand habitat or other low rugosity habitats at night.

A major caveat of this model is that the assigned absence is not necessarily true absence, but rather non-detection. Since all input data were acquired using the same technique (towed camera system) the absence output may reflect sampling bias. Additional data collected by means of alternative technologies will likely alter predictions, but to what extent cannot be known.

The models show that bathymetry data which is freely available for all of the shoals, banks and atolls of NWHI can be used to model an invasive species adequately if there are moderate levels of presence-absence data. Unfortunately, the availability of invasive species data is commonly very limited
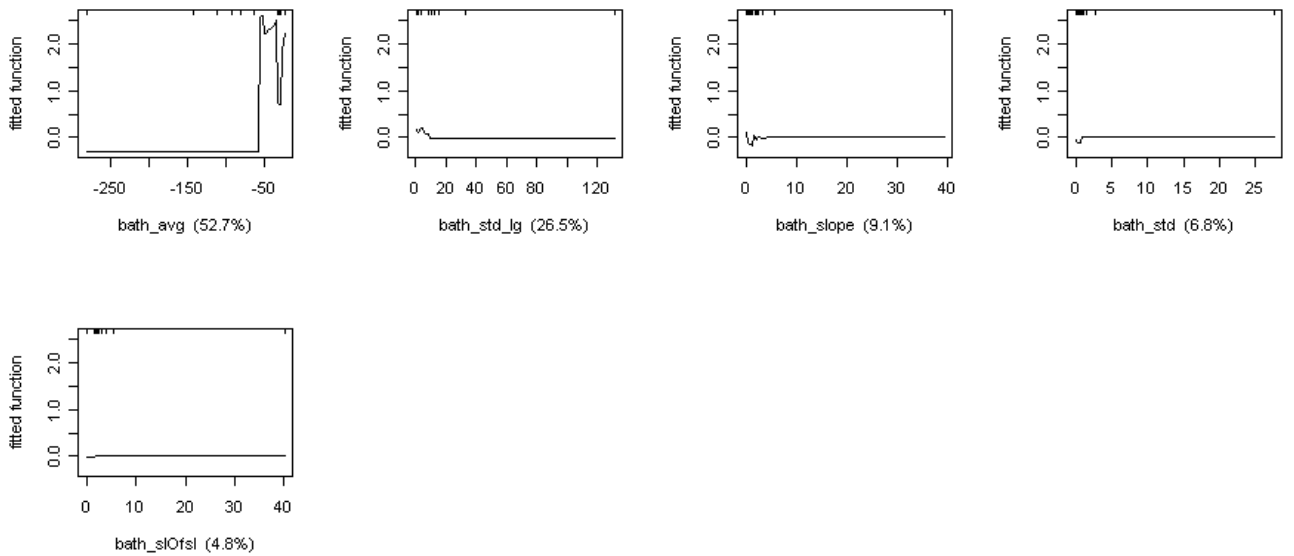
Model A
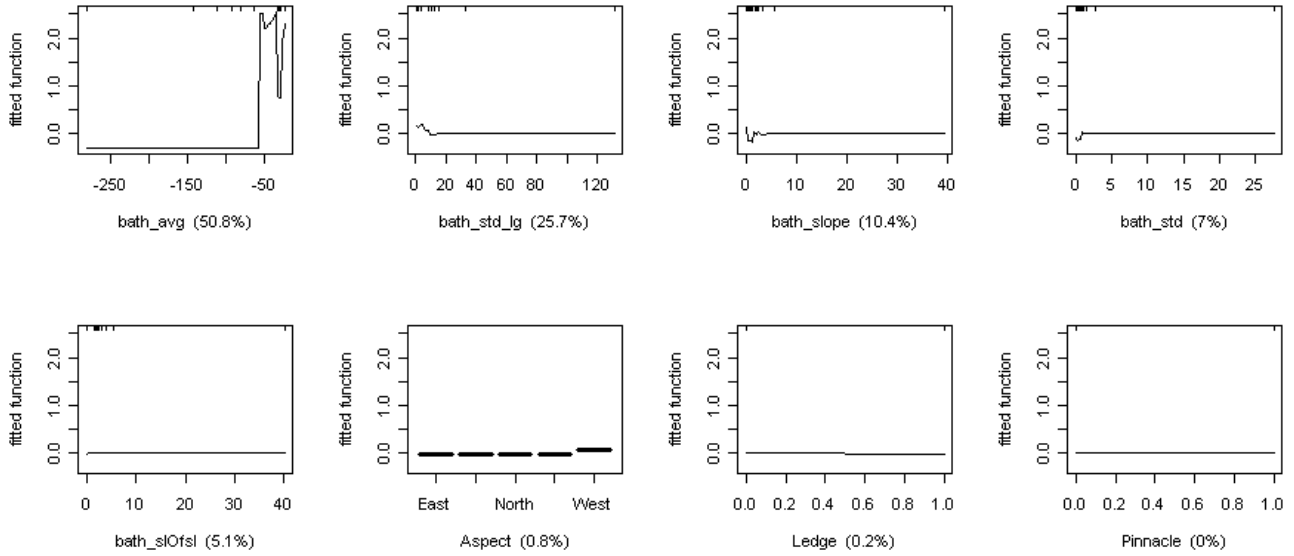
Model B

Figure 10: Results from models using all predictors (A) and a subset of 5 predictors (B). Graphs show effect of predictor variables on *L. kasmira* distribution and relative importance to model (expressed as a percentage). Predictors described in table 4.
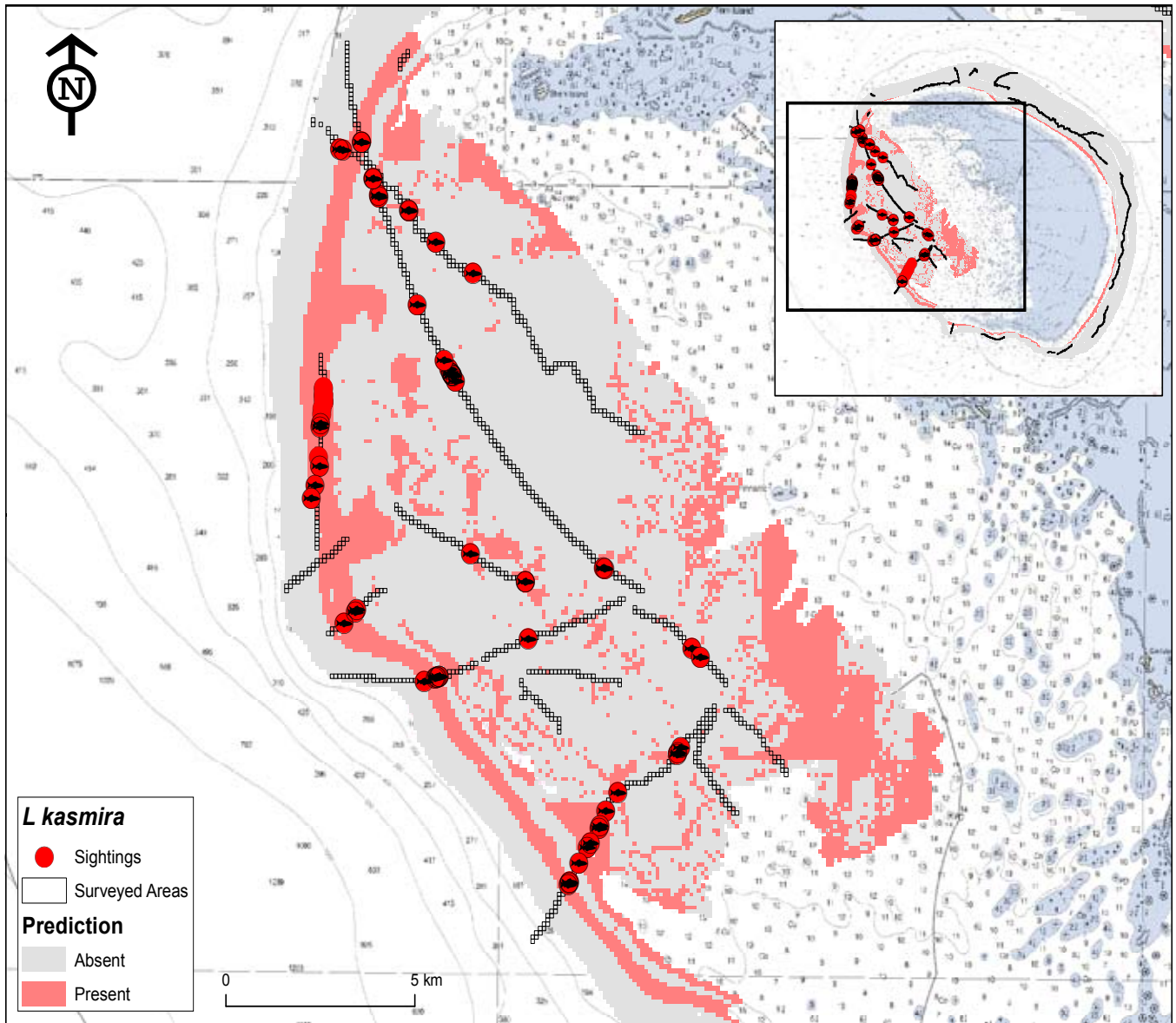
Figure 11: Results of presence-absence model for *L. kasmira* at French Frigate Shoals, NWHI. Model based on boosted regression trees and data collected during pilot study. Location of surveys and actual sightings overlaid on top of model results.

APPENDIX A

System	BASS	TOAD Camera Sled
Frame	Custom stainless steel cube	Modified Phantom ROV body
Digital Still Camera	SharkEye SC-3 Digital Still Camera	N/A
Still Resolution	1 MP	N/A
Forward Video Camera	Shark Marine SV-16R Digital Video Camera	Deep Sea Power & Light Multi SeaCam 2060 low-light color video camera
Video Resolution	380 TV lines horizontal	460 TV lines horizontal
Downward Video Camera	N/A	Deep Sea Power & Light Multi SeaCam 2060 low-light color video camera
Video Resolution	N/A	460 TV lines horizontal
Ultra-short Baseline System	TrackLink 1500 MA	TrackPoint II
Estimated Spatial Accuracy	20m	20m
Additional Equipment	Scaling lasers, 300W flood lights, laptop, contained cable reel, pressure transducer, compass	Scaling lasers, 500W flood lights, DeepSea Power and Light SeaArc2 HMI light, laptop, contained cable reel, pressure transducer, sonar altimeter, compass

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