Distribution and Habitat Associations of Spotted Ratfish (*Hydrolagus colliei*) in the Monterey Bay National Marine Sanctuary

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Abstract

Improved knowledge of how fish associate with seafloor habitat features is imperative for understanding how species are distributed and for the proper implementation of successful management strategies. The spotted ratfish (*Hydrolagus colliei*), is a deep water species of the Chimaeridae family occurring along the west coast of the United States. The abundance of spotted ratfish and their importance as both a predator and prey species implies they play an important role in deep sea marine ecosystems. However, little knowledge on the life history, distribution, and habitat associations spotted ratfish presents a significant management challenge for mitigating bycatch of the species. Videographic imagery collected within the Monterey Bay National Marine Sanctuary (MBNMS) between 2006 and 2010 using an ROV and towed camera sled provided the opportunity to explore the habitat associations of spotted ratfish. The precise locations of 149 individuals were plotted across four major study areas, including northern Monterey Bay, Point Lobos, Point Sur, and La Cruz Canyon. A habitat selectivity index was calculated to determine positive and negative associations with available habitat types. Spotted ratfish were primarily associated with mud substrates as well as some boulder and ridge habitats. Habitats including cobble and brachiopod beds showed a negative association. Spotted ratfish were also strongly associated with mud habitats in northern Monterey Bay and gradually shifted to a strong association with hard substrates as latitude decreased. Differences in habitat associations between juveniles and adults were also observed. Adult spotted ratfish showed positive habitat associations with hard and mixed substrates and a negative association with soft substrates. Juveniles showed the opposite trend, possibly to avoid competition or predation from adults. Spotted ratfish selectivity for particular habitat types can direct programs for mitigating spotted ratfish bycatch. Changes in habitat associations based on geographic area and age suggests the vulnerability of spotted ratfish to fishing pressures varies based on location. Adaptive management measures are necessary to conserve populations is different regions. Changes in spotted ratfish populations due to anthropogenic impacts may consequently affect the populations of other species, including commercially important fishes. Therefore, understanding where spotted ratfish occur and with which habitat types they associate is essential in preventing population decline through appropriate management strategies.

Introduction

Environmental disturbance and anthropogenic impacts on marine environments have placed significant pressure on ecosystem resources and services (Diaz et al. 2004). As society becomes more reliant on marine resources, knowledge of marine ecosystems is increasingly important. Understanding marine ecosystems and how species relate to features on the seafloor can provide insight into the distribution of such species and inform management actions. Previous research has identified environmental factors that distinguish a habitat, such as depth, relief, rugosity, and substratum type, each of which plays an important role in explaining demersal fish distributions (e.g. Cailliet et al. 1999; Anderson and Yoklavich 2007; Grober-Dunsmore et al. 2008). However, further determination of fish-habitat associations over a variety of spatial and temporal scales is necessary for assessing the importance of habitat types in structuring local and regional fish populations (Anderson and Yoklavich 2007). Therefore, the effectiveness of marine protected areas and the subsistence of marine resources are dependent upon the quantification and classification of suitable habitat components for demersal fish assemblages (Yoklavich et al. 2000; Stoner et al. 2007), particularly in the deep waters of the outer continental shelf where little is currently known.

Marine environments at depths greater than the range of SCUBA (<30m), and the fish assemblages associated with them, have primarily been surveyed using traditional methods, including traps, trawls, and hook and line (Allen 2006). These sampling methodologies have provided broad-scale understanding of demersal fish distributions and the general habitat types over which they are found (Allen 2006). The fine-scale habitat associations of fish assemblages in deep marine environments beyond the depth of SCUBA, however, have not been effectively surveyed due to their remoteness, the financial expenses required to reach these areas, and the limitations associated with traditional gear (e.g. trawl net entanglement on high-relief rocky outcrops) (Cailliet et al. 1999; Yoklavich et al. 2000; Love et al. 2009).

In recent years, new technology including human-occupied vehicles (HOVs), remotely operated vehicles (ROVs), and benthic towed camera sleds have proven to be useful sampling tools for observing *in situ* demersal fish assemblages within these natural refuges (e.g. Stein et al. 1992; Yoklavich et al. 2000; Auster et al. 2003; Stoner et al. 2007; Tissot et al. 2007; Love et al. 2009). For example, Stoner et al. (2007) utilized a towed camera sled to conduct surveys of juvenile flatfish habitats at Kodiak Island, Alaska. Models incorporating fine scale habitat variables (i.e. tube worm densities, structural complexity created by macroalgae and epifauna) observed in videos proved more accurate in predicting juvenile flatfish distributions than traditional sampling methods (i.e. sediment grabs, trawling). These tools also provide evaluation of fish-habitat associations over spatial scales ranging from less that 1m to tens of kilometers which are not apparent through the use of conventional trawls (Anderson and Yoklavich 2007; Stoner et al. 2007). Anderson and Yoklavich (2007) observed changes in fish responses to habitats at different spatial scales (<1m, m's-100m's, km's) using an HOV in Monterey Bay, California. The authors proposed that multi-scale HOV surveys could enhance management success by improving understanding of the functional relationships between fish species and their habitats. Therefore, use of these new technology tools presents an opportunity to better study and define fish-habitat associations within deep marine environments.

Hydrolagus colliei (Lay and Bennett 1839) is a deep water member of the chondrichthyan subclass Holocephali (Grogan and Lund 2004). It is one of 37 described species within the single order Chimaeriformes (Barnett et al. 2009), and is commonly known as the spotted ratfish, white-spotted ratfish, white-spotted chimaera, Pacific ratfish, or angel fish (hereafter referred to as the spotted ratfish) (Fishbase 2009). The spotted ratfish is characterized by a blunt nose, long tapered body, whip-like tail, large luminescent green eyes, open lateral line canals (Ebert 2003), and has a large venomous dorsal spine located anterior to the first dorsal fin (Halstead and Bunker 1952).

Spotted ratfish occur from the southeastern waters of Alaska to the southern tip of Baja California (Allen 2006) and within the northern portion of Gulf of California (Matthews 1975; Allen and Smith 1988). The species occupies a wide depth range from the intertidal to the continental shelf, slope, and rise to a depth of 913m (Alverson et al.

1964; Allen 2006). Along the west coast of the United States, spotted ratfish are one of the ten most abundant groundfish found along the continental shelf between ~50 and 500m (Keller et al. 2006). Based on their relative abundance, it is therefore presumed that spotted ratfish have an ecologically important role within their range as both a predator and prey species (Allen 2006).

As opportunistic feeders, spotted ratfish prey on a variety of food sources such as crustaceans, squids and other molluscs, echinoderms, annelids, and small fishes, and are also known to practice intercohort cannibalism (Johnson and Horton 1972). Consequently, the abundance of spotted ratfish suggests they may play an important function in regulating the population sizes of the prey species they consume. Predators of spotted ratfish include sixgill and sevengill sharks, jumbo squid, giant sea bass, lingcod, rockfishes, and marine mammals (Ebert 2003). They also comprise a significant portion of the diet of commercially important species such as Pacific halibut, soup fin sharks, and spiny dogfish (Johnson and Horton 1972). The variety of species which eat or are preyed upon by spotted ratfish suggest they play an integral role in deep sea marine food webs.

The trophic effects of most chondrichthyans on ecosystems are poorly understood and significant changes in population sizes of chondrichthyans could affect the species composition and structure of lower trophic levels (Fowler et al. 2005). Stevens et al. (2000) examined shifts in community compositions caused by the removal of chondrichthyans as well as their teleost competitors. They found that removal of some chondrichthyans had complex ecological and economic impacts, such as subsequent declines in commercially important teleosts. Since chondrichthyans may prey on teleost predators or competitors, removal of chondrichthyans may increase predation and competition pressures on teleosts and therefore reduce teleost population sizes. In addition, removal of commercially targeted teleosts may remove competitive pressures on chondrichthyans and allow for chondrichthyan population increases. Stevens et al. (2000) cites increases in spiny dogfish abundance due to heavy fishing of teleosts on Georges Bank. The decline of commercial teleost species consequently led fishers to target spiny dogfish. As a result, spiny dogfish populations are in decline and the sustainability of the fishery is of concern. No studies on trophic impacts by spotted ratfish have been conducted. However, the decline of spotted ratfish populations due to anthropogenic impacts could have unpredictable and complex effects on marine trophic webs similar to those seen with other chondrichthyans. Furthermore, increases in spotted ratfish populations due to the removal of predators and the decline of economically important species may increase interest in spotted ratfish as a new commercial resource. The general lack of understanding regarding spotted ratfish ecology and their role in deep sea ecosystems is a serious hindrance to current management.

Currently there is no direct fishery for spotted ratfish; however, they are commonly caught incidentally by recreational fishermen and in trawls and longlines of commercial fishermen (Barnett et al. 2009). In California, 2600kg of spotted ratfish bycatch were reported to the National Oceanic and Atmospheric Administration (NOAA) between 1969 and 2006; however, NOAA advises that bycatch estimates for spotted ratfish are highly unreliable and the species is often categorized as unidentified (Pearson et al. 2008). Therefore, bycatch estimates for California may greatly exceed this amount. Similarly, the British Columbia Groundfish Fisheries (BCGF) reported roughly 650 tons of spotted ratfish bycatch in a single year (2005), placing spotted ratfish as the third highest bycatch species in the area (DFO 2005). As with many chondrichthyans, spotted ratfish exhibit a k-selected life history, maturing later in life and having less reproductive output than most teleosts (Barnett et al. 2009). Because of these traits, the BCGF advises that spotted ratfish resiliency to fishing may be low, which implies populations cannot quickly rebound from decreases due to fishing mortality (DFO 2005).

Since no formal population estimates of spotted ratfish have been performed, it is unclear as to what impact bycatch may be having on the species. There are conflicting reports from previous studies as to whether their population is increasing or in decline and what factors are possible explanations for each. Dunbrack (2008) reported a 75% decrease in spotted ratfish occurrences in the Strait of Georgia, British Colombia between 2001 and 2007 and inferred the decrease was due to perturbations of the continental shelf caused by commercial fishing and changes in temperature regimes. Conversely, Barnett (2008) found spotted ratfish abundance increased in Oregon and Washington but remained fairly constant in California between 1995 and 2007. The author attributes changes in abundance to climate shifts as well as differential fishing mortality and suggests that spotted ratfish populations may be fairly resilient to anthropogenic pressures.

Because the spotted ratfish has a large spatial and depth range, it is listed as a species of least concern according to the International Union for Conservation of Nature’s (IUCN) Red List of Threatened Species (Dagit 2006). The IUCN notes, though, that there are insufficient data on the species’ life history, abundance, and susceptibility to anthropogenic impacts and that further research in these areas is needed (Dagit 2006). As fishing technology improves and stocks of commercially important species become depleted, commercial fishermen move to deeper depths to increase catch yields suggesting that increased bycatch of spotted ratfish is likely. Depletion of teleosts stocks may also raise commercial interest in spotted ratfish. Commercial fisheries for several chimaeroid species already exist with some species declared severely overfished (Barnett et al. 2012). Spotted ratfish and their egg cases have also been observed in aggregations, potentially increasing spotted ratfish vulnerability to fishing pressures (Pirtle 2005, Barnett et al. 2012). Therefore, bycatch mortality and potential commercial exploitation presents a significant strain on the robustness of spotted ratfish populations.

Insight into the habitat associations of spotted ratfish may provide information necessary for mitigating bycatch issues. Previous studies conducted by HOV off Heceta Bank, Oregon (Tissot et al. 2007) and Cordell Bank, California (Pirtle 2005) observed spotted ratfish associated with low relief mud habitats. In general, spotted ratfish are believed to associate primarily with soft substrates (Barnett 2008); however, this may be a factor of the limitations in trawl sampling gear, the primary resource for current spotted ratfish knowledge. Barnett (2008) found a majority of the spotted ratfish collected via trawl surveys were large adults and hypothesized that juveniles may associate with hard substrates not adequately sampled with trawl gear. In light of this, the use of different habitat types at different life history stages may help managers determine essential habitats necessary for sustaining spotted ratfish populations.

At the US federal level, spotted ratfish are managed under the Pacific Fishery Management Council's Pacific Coast Groundfish Fishery Management Plan (PCGFMP) (PCGFMP 2008). The Magnuson-Stevens Fishery Conservation and Management Act (2006), which established the nation's fishery management councils, requires conservation and management programs in all fishery management plans to minimize bycatch and bycatch mortality (PCGFMP 2008). In order to comply with the Magnuson-Stevens Act, the PCGFMP established a Bycatch Mitigation Program (BMP) (PCGFMP 2008). Through monitoring programs and catch data, the BMP supervises annual bycatch amounts and implements methods for minimizing bycatch, for example, through gear restrictions or bycatch limits (PCGFMP 2008). However, the unreliability of spotted ratfish bycatch estimates may impede the BMP's ability to effectively analyze the impacts of fishing on spotted ratfish (Pearson et al. 2008).

The implementation of California's Marine Life Protection Act (MLPA) in 1999 presents a new perspective on the management of coastal ecosystems through ecosystem-based management as opposed to previous single species management perspectives like the PCGFMP. The first goal of the MPLA is protection of California's marine life diversity and abundance, including economically and non-economically important species (MLPA 2008), like spotted ratfish. The MLPA aims to design, implement, and manage a network of marine protected areas (MPAs) to sustain and protect the state's marine life populations, a process that is currently being established (MLPA 2008). MPA functions range from varying levels of conservation, such as no-take reserves, to human restrictions, like seasonal fishing closures (mpa.gov 2010).

In addition to the MLPA, the National Marine Sanctuaries Act designated the Monterey Bay National Marine Sanctuary (MBNMS) in 1992 which covers 6,094mi^2 of ocean from Marin to Cambria, California. The goal of the MBNMS is "to understand and protect the coastal ecosystem and submerged cultural resources of central California" (MBNMS 2009). The combined efforts of the MLPA, the MBNMS, and the PCGFMP present a significant management framework for protecting species, like spotted ratfish, which are ecologically important and that may have or are already potentially at risk from human disturbances. Lack of scientific information for directing management efforts, however, limits the effectiveness of those management bodies. In light of this problem, information on the distribution of and habitat types with which spotted ratfish associate can provide an information basis for advising future management of the species.

The purpose of this study is to expand the current body of knowledge on spotted ratfish by examining fine-scale habitat associations of spotted ratfish within the MBNMS. Previous studies of fish-habitat associations have focused primarily on economically important species, such as rockfishes and flatfishes (e.g. Stoner et al. 2007; Tissot et al. 2007; Love et al. 2009). To my knowledge, no extensive studies have been conducted primarily on the habitat associations of spotted ratfish in any geographic area. Using videographic imagery collected through ROV and towed camera sled surveys, the distribution of spotted ratfish and the habitat type over which they associate was examined. In addition, the relationship between ontogenetic stage and habitat type was examined to determine if spotted ratfish associate with different habitat types based on age.

Methods

Site Selection

The sites established for this study were initially established as ‘areas of interest’ by the MBNMS as part of a larger project aimed at characterizing the Sanctuary, focusing on the deepwater (>100m) zone. This project focused on the spotted ratfish observed within the MBNMS, primarily across the continental shelf and slope in and around the following four study areas (Figure 1). The North Monterey Bay study area includes the Aňo Nuevo and Ascension submarine canyons, the shelf and slope off of Davenport and Santa Cruz, California, and Soquel canyon. Next, the Point Lobos study area encompasses the State Marine Reserve (SMR) and State Marine Conservation Areas (SMCA) at Point Lobos and within Carmel Bay. The Point Sur study area encompasses the wide shelf and slope off of Point Sur as well as the SMCA. Finally, the La Cruz Canyon study area includes La Cruz Canyon and surrounding area as well as the Piedras Blancas SMCA and adjacent areas. Each study area covers roughly 50km from the coastline to the outer continental slope and contains habitat managed under both state and federal jurisdiction. In general, these study sites include a range of habitats within the shallow continental shelf (~55m depth) to the edge of the continental shelf, and down the continental slope to a maximum depth of ~400m as limited by the depth range of the equipment utilized for this study.

Substrate type and abundance differ within and among study areas. The North Monterey Bay study area encompasses a large area, but generally contains a distribution of rock and mud habitats, including canyons with steep-sloping soft sediments and low-relief rocky outcrops (Starr and Yoklavich 2007). The Point Lobos study area is also characterized by a fairly even mixture of hard and soft substrate, but includes high-relief granitic outcrops, extensive cobble fields, and mud expanses (Kennedy et al. 1987; Starr and Yoklavich 2007). The Point Sur study area is dominated by hard substrate, primarily rocky outcrops with intermittent areas of sand (Starr and Yoklavich 2007) as well as deep mud slopes. The La Cruz Canyon study area contains a mixture of hard and soft substrate areas, including rocky outcrops and sand (Kennedy et al. 1987).

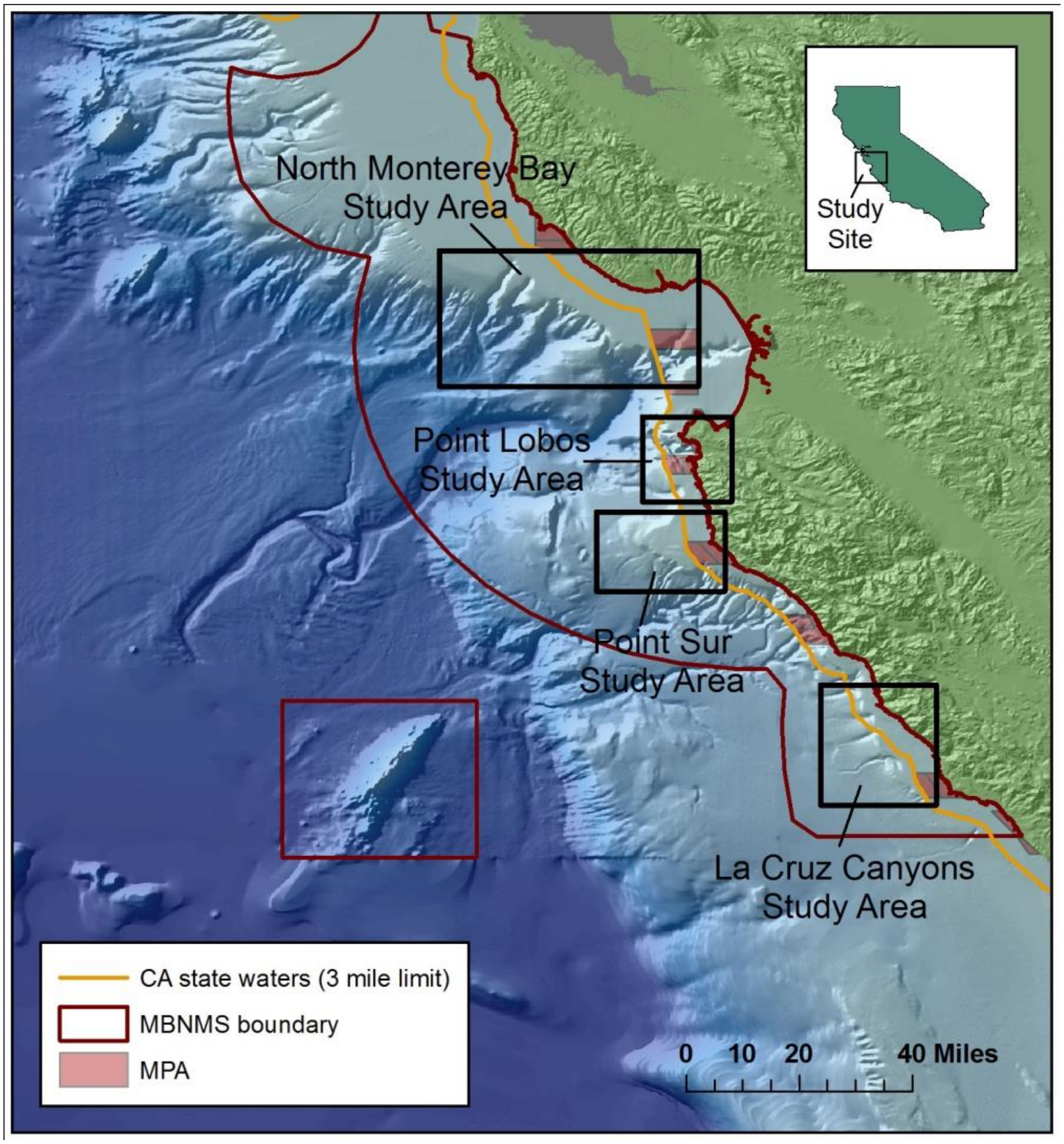


Figure 1. Map of the general study area within the MBNMS, including the four specific study sites (black boxes) where videographic imagery was collected.

Imagery Collection

Videographic imagery was collected from the NOAA vessel the *RV Fulmar* using both an ROV and towed camera sled. The Vector LV4 ROV *Beagle* (owned and operated by Marine Applied Research and Exploration) had five cameras, including forward and downward facing high resolution video cameras, a high resolution downward facing still camera, and two rear facing video cameras (Figure 2a). Only data from the forward facing video camera were analyzed in this study with still images and downward facing video used only to support data collected (e.g. improved sizing accuracy of spotted ratfish). The ROV housed two 200W HMI lights and two 250W halogen lights, two 15mW lasers set 10cm apart, and navigational equipment, including multi-beam sonar. An umbilical data-cable relayed information directly to a topside viewing station where videographic imagery was viewed in real time by observers as well as recorded for later use. Altitude above the seafloor was controlled by thrusters and the ROV had been tested to a maximum depth range of 400m.

The camera sled system was comprised of an aluminum frame which housed a high-resolution video camera, two 250W halogen lights, two 15mW sizing lasers set 10cm apart, and navigational equipment. The video camera was on a mount which could be adjusted (forward-facing to downward-facing) using a control box at the surface. Data was transmitted to the surface via a 300m umbilical data-cable to a topside viewing station where video imagery was also recorded. Altitude above the seafloor was adjusted by a winch. Maximum depth range for the camera sled was 300m, constrained by the length of the umbilical data-cable.

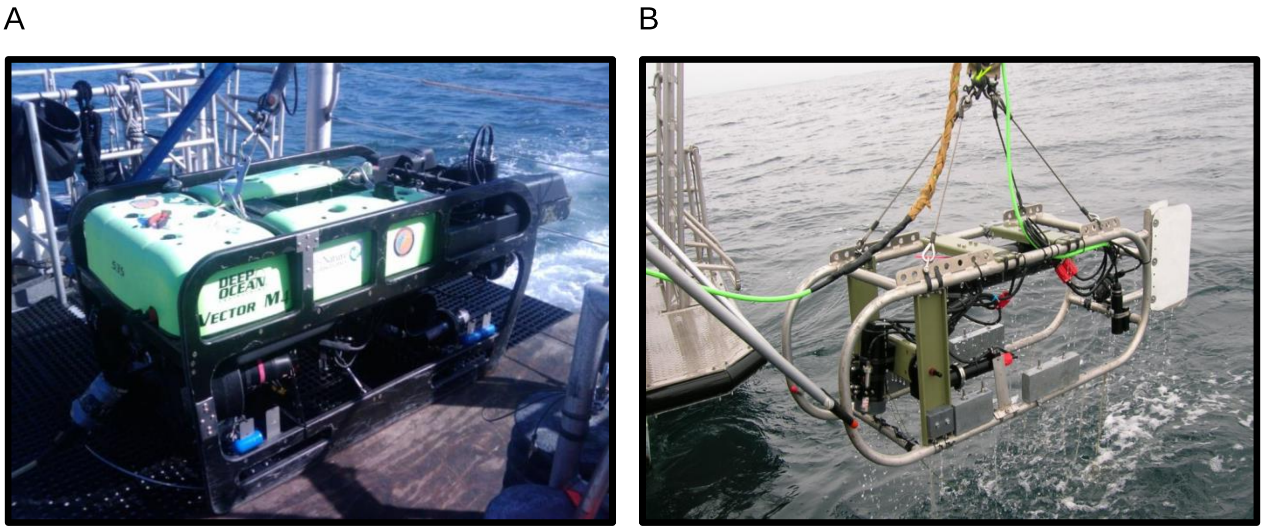


Figure 2. The Vector LV4 ROV *Beagle* (a) and towed camera sled (b), both of which are equipped with video cameras, lights, sizing lasers, and navigation equipment for collecting videographic imagery of the seafloor and associated organisms.

Imagery collection occurred over seven cruises between 2006 and 2010, with two years, 2009 and 2010, having two cruises per year. Each year, between 13 and 51 transects were conducted with a total of 188 transects over the five year period.

Transect length averaged ~1km and 1hr of video time, though boat speed and oceanographic conditions had some influence on transect length. When the ROV or camera sled was deployed, the *RV Fulmar* operated at a speed of approximately one knot, but could vary in speed between 0.5 and 1.2 knots in order to optimize video quality. Both the ROV and camera sled function at ~1m off of the seafloor. Videographic imagery for both tools was overlaid with date, time, and depth information.

Transects in the North Monterey Bay study area were conducted between ~97 and 362m in depth along the interface between the continental shelf and the heads of the Ascension, Año Nuevo and Soquel Canyon systems. Surveys in the Point Lobos study area occurred inside the Point Lobos SMR and SMCA and adjacent areas to the south. Transects occurred between ~83 and 196m depth along the continental shelf. The Point Sur study area consisted of transects ranging from ~54 to 398m in depth along the continental shelf and slope. Lastly, transects in the La Cruz Canyon study area were conducted along the continental shelf at ~90 and 113m depth. Transects were conducted over a variety of habitat types in order to gain a representative sample of habitat types available.

Objectives and Analytical Approach

Objective 1: The first objective of this study was to map the distribution of spotted ratfish within the MBNMS.

All ROV and camera sled transects were viewed for the presence of spotted ratfish. The unique morphology of spotted ratfish rendered them easily identifiable from other species. For each spotted ratfish observation, a video clip was recorded and saved for later analysis. GPS data collected along each transect was used to determine the precise geographic location of each spotted ratfish observed and then plotted within the MBNMS.

Objective 2: The second objective of this study was to characterize the habitat associations of all spotted ratfish observed within the MBNMS.

Research Question 1: Over which habitat types do spotted ratfish associate within the MBNMS?

H_0: Spotted ratfish are randomly distributed over different habitats within the MBNMS.

H_A: Spotted ratfish associate with specific habitat types within the MBNMS.

Substrate type in each spotted ratfish video clip was identified using the methods presented in Green et al. (1999). Hard substrates consisted of ridge (consolidated rock), boulder (unconsolidated rock >24cm in size), cobble (unconsolidated rock between 2.5 and 24cm in size), and pebble (unconsolidated rock <2.5cm in size). In addition to the habitat classifications proposed by Greene et al. (1999), brachiopods (*Laqueus californianus*) were considered a hard substrate habitat type due to their abundance within the MBNMS. Soft substrates consisted of sand (course grain sediment) and mud (fine grain sediment). Both primary and secondary substrate type were determined, where the substrate type comprising 50% of the frame in which the spotted ratfish was observed was considered primary substrate and the substrate type comprising at least 20% of the remaining 50% of the frame was considered the secondary substrate type. The ROV and towed camera sled depth (overlaid onto the video screen) provided an estimate of the water depth at which each spotted ratfish was observed.

Habitat associations were examined for the entire MBNMS as well as each individual study area to determine whether spotted ratfish positively associate with certain habitat types. Transects containing spotted ratfish observations were observed in their entirety in order to determine total available habitat types. Primary and secondary substrates were recorded for each habitat patch, or area of continuous substrate type, for each transect. Only habitat patches that spanned 15s or greater of video time were recorded. Because habitat types are not distributed equally throughout the MBNMS, habitat associations were determined using the habitat selectivity index methods provided by Laidig et al (2009). Habitat selectivity was calculated by subtracting the proportional abundance of spotted ratfish over each habitat type from the proportional occurrence of each habitat type. Proportional abundance was calculated for all spotted ratfish and compared to the proportional abundance of all habitat types observed over all transects in which spotted ratfish were found. This provided a broad picture regarding the habitat associations of all spotted ratfish throughout the MBNMS. Proportional abundances of spotted ratfish were also calculated for each study area and compared to the proportional occurrences of the habitat types observed in that study area. This provided insight into changes in habitat associations based on geographic area. Chi-square goodness of fit tests was used to determine whether spotted ratfish were randomly distributed over habitat types. In order to meet statistical test assumptions, habitat selectivity indices were also calculated for broader habitat classes (hard, mixed, and soft substrate) in order to better observe habitat association trends. Hard substrate consisted of hard primary and hard secondary substrates (e.g. ridge and boulder habitat), soft substrate consisted of both soft primary and secondary substrates (e.g. continuous mud habitat), and mixed substrate was classified as a mixture of hard and soft substrates (e.g. boulder and sand habitat, mud and cobble habitat, etc.). The behavior of each spotted ratfish was also recorded, in particular aggregations consisting of >15 individuals within a single transect.

Objective 3: The third objective of this study was to explore the relationship between spotted ratfish ontogenetic stage and habitat type.

Research Question: Are there differences in the distribution of spotted ratfish that are attributable to age cohort?

H_0: Spotted ratfish do not associate with different habitat types based on age.

H_A: Juvenile spotted ratfish associate with hard substrates and adult spotted ratfish associate with soft substrates.

A quantitative analysis of the primary and secondary substrate where spotted ratfish were observed may reveal differences in habitat associations between smaller juveniles and larger adults. Ten centimeter sizing lasers mounted on the ROV and towed camera sled were used to estimate the total body length of spotted ratfish observed. Ebert's (2003) reported a minimum 44cm size at maturity for both males and females and this threshold could be used to distinguish juveniles from adults. Based on total body length, spotted ratfish were classified as juveniles (<44cm) or adults (>44cm) using the laser guides on the ROV or camera sled. Because of low number of adults observed, habitat types were grouped as hard, mixed, and soft and habitat selectivity indices were used to analyze the relationship between spotted ratfish size and habitat. A chi-square goodness of fit test was used to determine if habitat associations were significant.

Results

Spotted Ratfish Distribution

A total of 149 spotted ratfish were observed over 36 transects throughout the MBNMS (Figure 3). The average depth of individuals was 214m but some were witnessed as shallow as 54m and as deep as 398m. Spotted ratfish were seen in all four study areas. In North Monterey Bay (n=43), spotted ratfish were observed along the interface between continental shelf and slope (Figure 4a). Individual spotted ratfish observations were low; however, an aggregation was noted in the southeastern portion of the study area at ~300m. Spotted ratfish were regularly seen over multiple transects in Point Lobos (n=61), primarily within the SMCA (Figure 4c). An aggregation was also noted in this study area at a depth of ~193m. Few spotted ratfish were seen in deeper transects along the Monterey Bay canyon head. In Point Sur (n=40), spotted ratfish were less evenly distributed and were observed in loose groups less condensed than in Point Lobos and North Monterey Bay (Figures 4d). Relatively few individuals were observed in La Cruz Canyons (n=5) despite the number of transects conducted in this area (Figure 4b). No spotted ratfish were seen within the Piedras Blancas SMCA.

In general, three or fewer spotted ratfish were observed per transect, however, lose aggregations of up to 31 individuals were observed in North Monterey Bay, Point Lobos, and Point Sur. These aggregations occurred over both hard and soft substrates and consisted of both adults and juveniles. Two behaviors were observed for all spotted ratfish; resting on the sea floor, usually over soft substrate or in soft substrate crevices between hard substrate (e.g. mud patches between boulders), or swimming less than 1m above the sea floor.

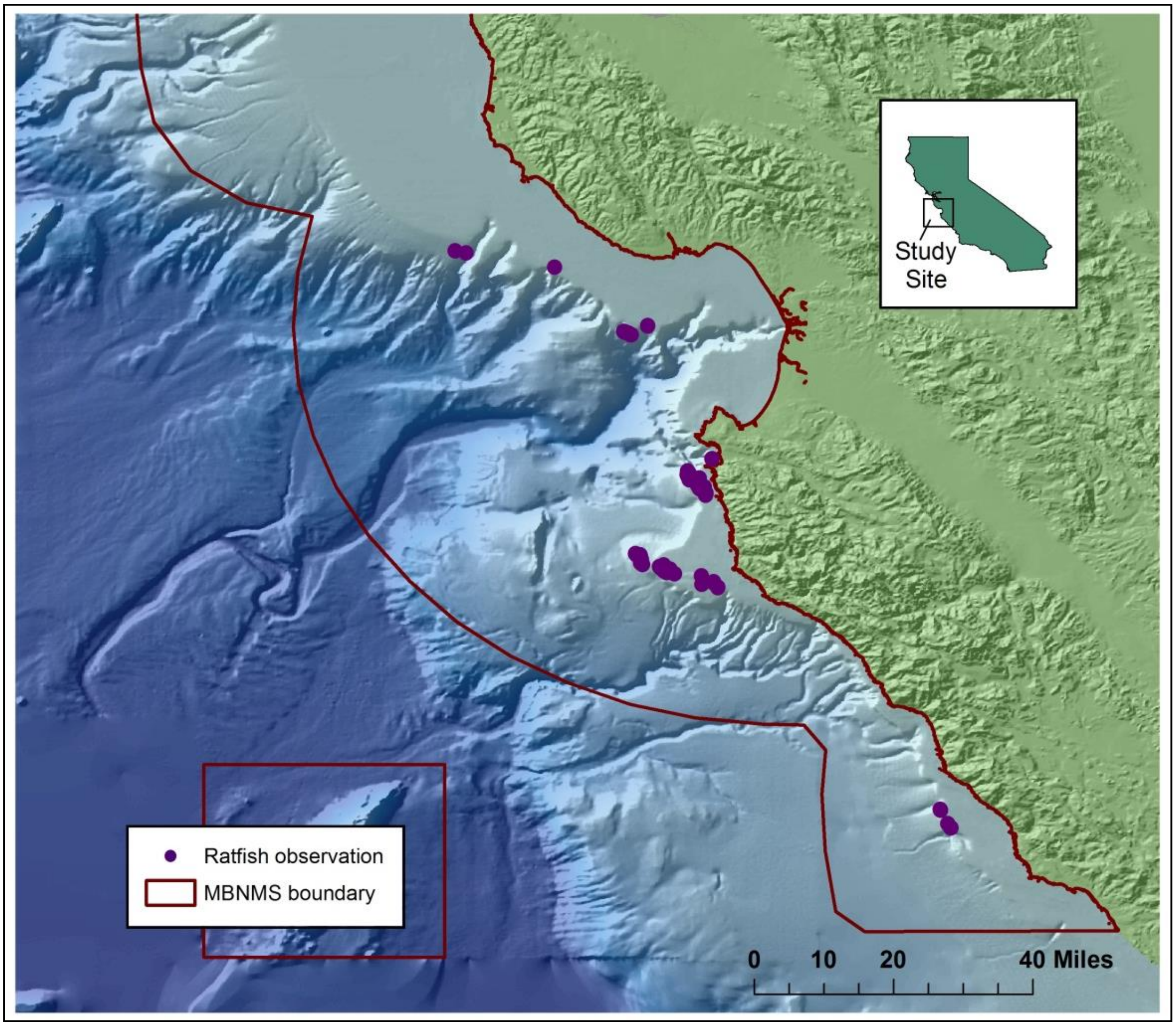
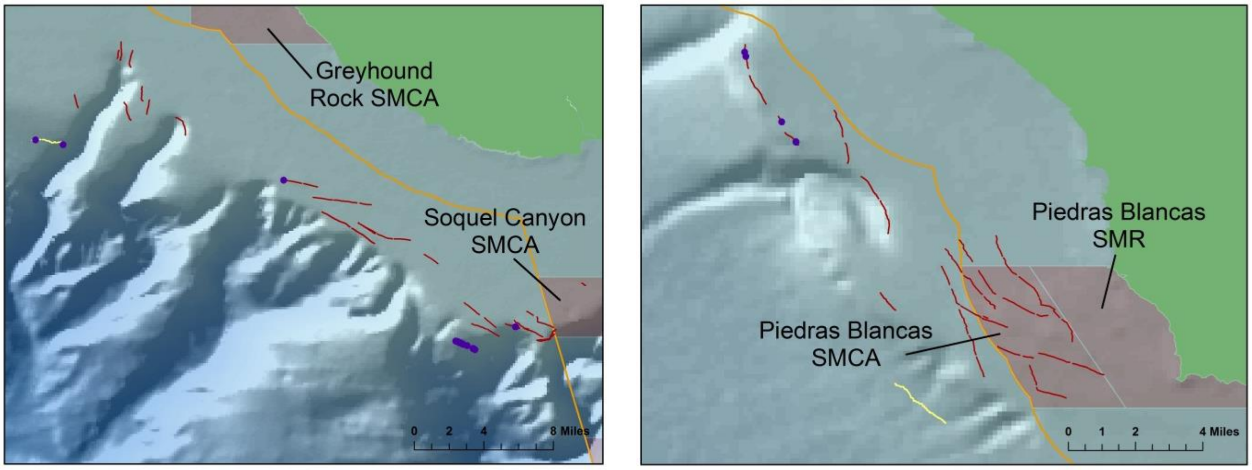
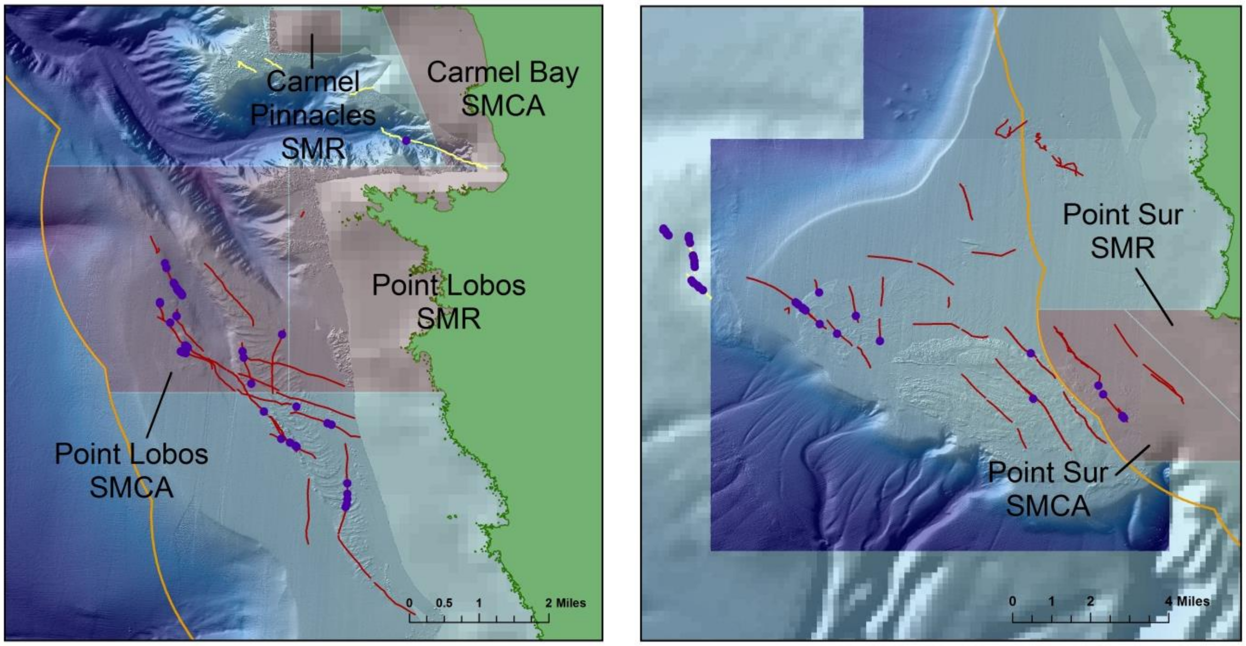


Figure 3. Distribution of spotted ratfish observed throughout the MBNMS between 2006 and 2010.



a. North Monterey Bay b. La Cruz Canyon



c. Point Lobos d. Point Sur

Figure 4. Distribution of spotted ratfish found within each study area. Red lines depict transect conducted via towed camera sled and yellow lines depict ROV transects. Purple dots represent each spotted ratfish observation.

Habitat Associations

Thirty-one substrate combinations consisting of hard, soft, and mixed substrate types were observed within the MBNMS (Figure 5). Habitat classification codes are available in Table 1. Uniform sand, uniform mud, mud and cobble, and mud and boulder habitat accounted for 67% of all habitats available. All other habitats accounted for less than 5% of the remaining habitats and were considered rare. Soft substrates comprised 55.4% of the habitats viewed. Mud was the most abundant substrate type covering 50% of all habitats. Hard and mixed substrates, 23.0% and 21.6% respectively, comprised the remaining substrate types. Of the 31 substrate combinations, spotted ratfish were found over 12, with 64.4% of spotted ratfish observed over soft substrates, 23.5% over hard substrates, and 12.1% over mixed substrates. Results from the habitat selectivity index show spotted ratfish positively associated with uniform boulder, ridge, and mud habitats (Figure 6). The strongest association was for uniform mud habitat. A negative association with most mixed substrates, generally those containing cobble, and sand substrates was also noted. When considering broad habitat classes (hard, soft, and mixed), spotted ratfish showed a negative association with hard and soft substrates and a positive association with soft substrates (Figure 7).

Table 1. Habitat classification codes for assessing habitat types within the MBNMS. Codes were also combined to represent primary and secondary substrate.

Habitat Type	**Code**	**Description**
Ridge	R	Consolidated rock
Boulder	B	unconsolidated rock >24cm in size
Cobble	C	unconsolidated rock between 2.5 and 24cm in size
Pebble	P	unconsolidated rock <2.5cm in size
Brachiopods	Br	*Laqueus californianus* beds
Sand	S	Coarse grain sediment
Mud	M	Fine grain sediment

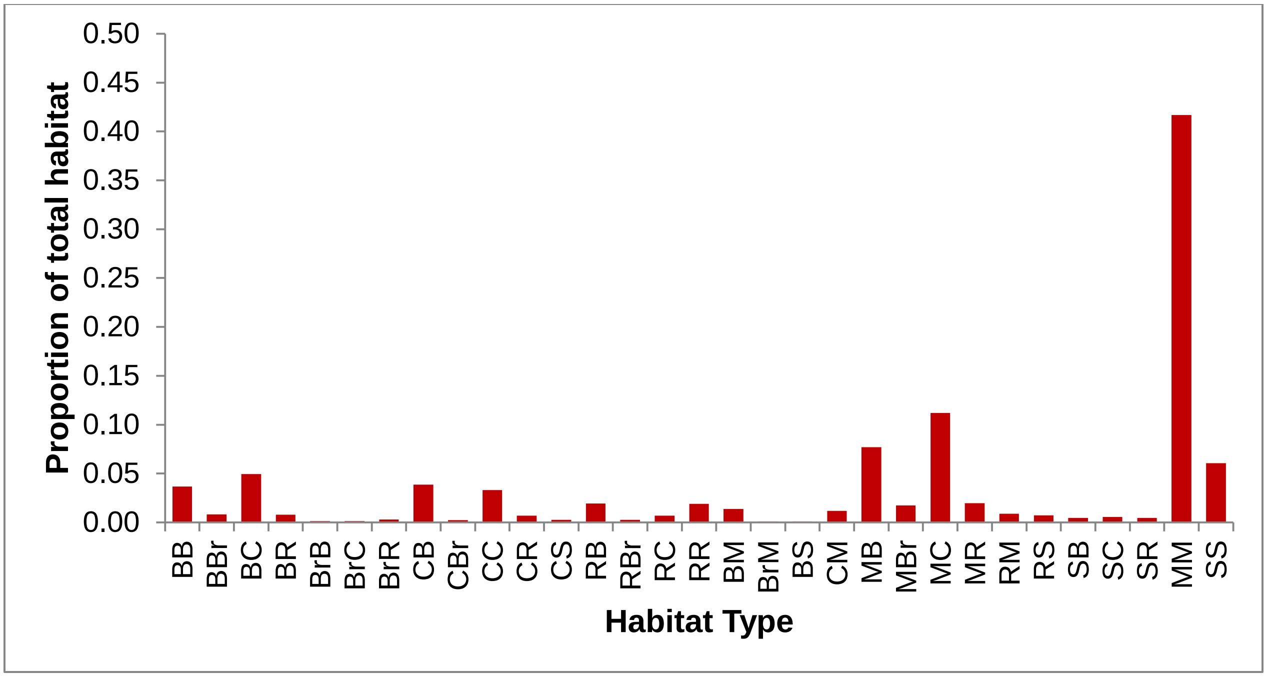


Figure 5. Proportion of each habitat combination observed over 36 transects. Consistent mud habitat represents the greatest proportion of habitat observed. Several habitat types were considered rare (<0.05).

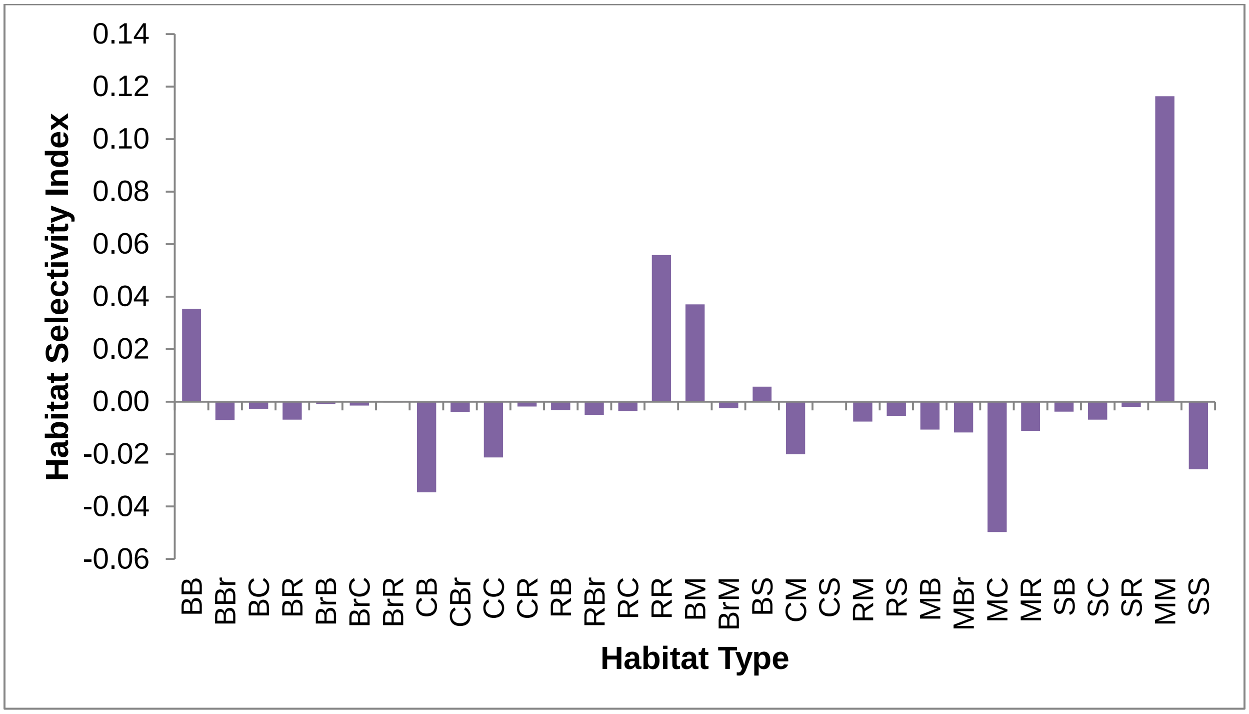


Figure 6. Habitat selectivity index for all spotted ratfish (n=149) over 31 substrate combinations. A positive value suggests a positive association with the substrate type whereas a negative value suggests a negative association with that substrate type.

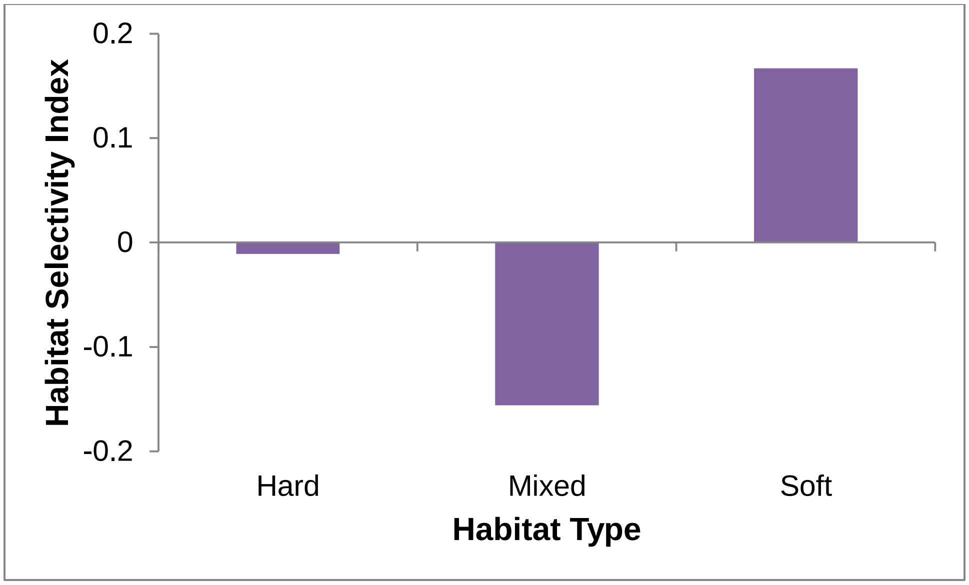
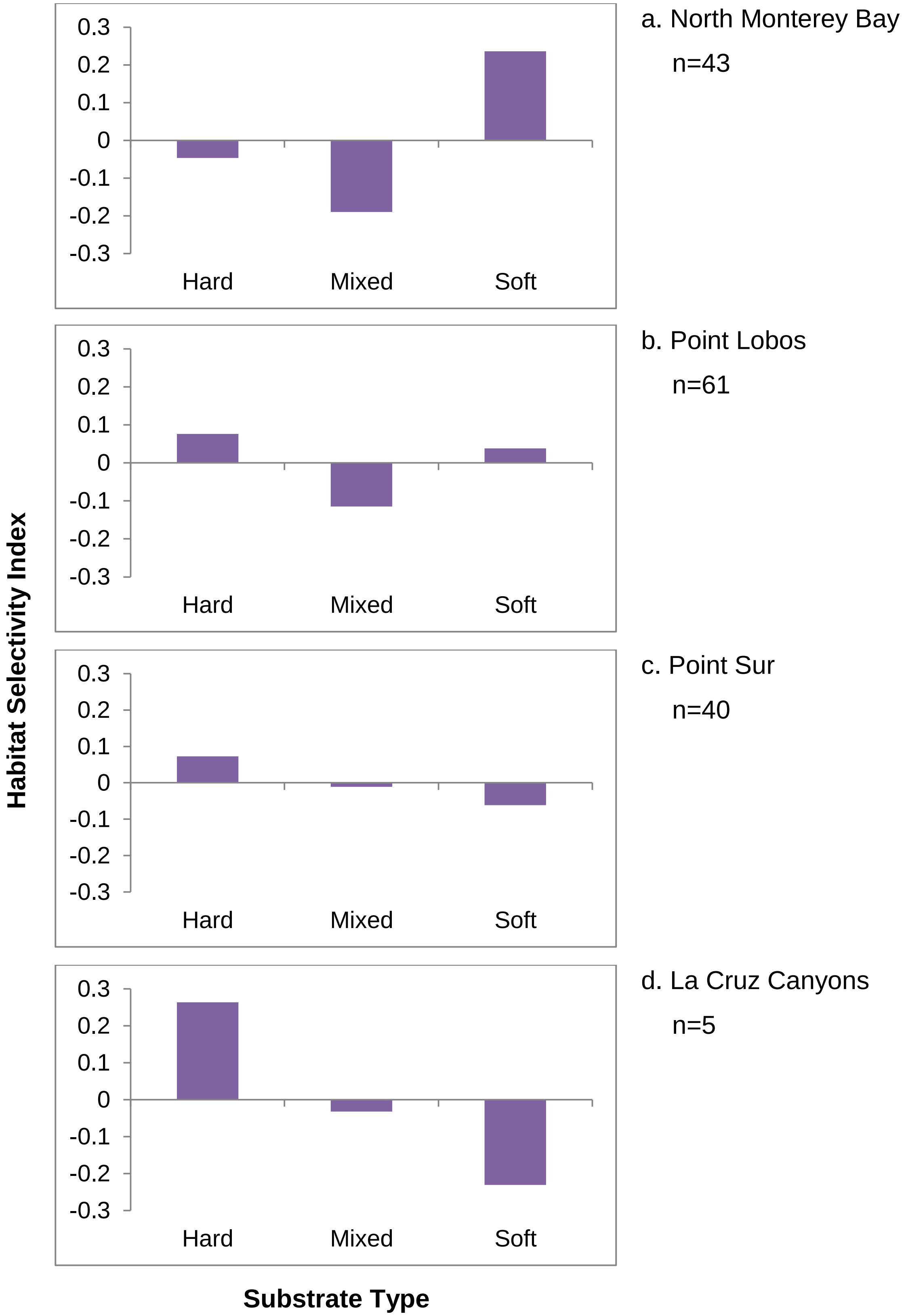


Figure 7. Habitat selectivity index for all spotted ratfish (n=149) over broad substrate categories. A positive value suggests a positive association with the substrate type whereas a negative value suggests a negative association with that substrate type.

Different habitat association trends were observed when habitat selectivity was analyzed by individual study area. Due to the lack of spotted ratfish observations over all substrate combinations, habitat was classified as hard, mixed, or soft in order to meet statistical test assumptions. In North Monterey Bay, spotted ratfish showed a positive association with soft substrates and negative associations with hard and mixed substrates (Figure 8a). In Point Lobos, spotted ratfish were positively associated with hard and soft substrates and negatively associated with mixed substrates (Figure 8b). In the Point Sur study area, a positive association with hard substrates was observed compared to mixed and soft substrates (Figure 8c). In both Point Lobos and Point Sur, habitat selectivity was weak compared to North Monterey Bay and La Cruz Canyon. A similar trend to Point Sur was observed in La Cruz Canyon (Figure 8d). Differences in habitat associations between study areas were significantly different (X^2=36.9, p<0.001).



a. North Monterey Bay
n=43

b. Point Lobos
n=61

c. Point Sur
n=40

d. La Cruz Canyons
n=5

Figure 8. Habitat selectivity indices for spotted ratfish in each study area over hard, mixed, and soft substrates.

Habitat Associations and Life History Stage

Of the 149 spotted ratfish observed, 25 were adults based on the size classification proposed by Ebert (2003). Ninety-six spotted ratfish were less than 44cm in length and were classified as juveniles. The remaining 28 individuals could not be sized due to poor lighting or only partial view of the subject. Spotted ratfish size varied from ~10cm to as large as 87cm with more than 50% of individuals under 33cm. Adult spotted ratfish showed a positive habitat association with hard and mixed substrates and a negative association with soft substrates (Figure 9). Juveniles showed the opposite trend with a positive association toward soft substrates and negative associations toward mixed and hard substrates. Juvenile associations with soft substrates were fairly strong compared to negative habitat associations (Figure 10). The opposite was true for adults, were negative association with soft substrates was stronger than positive associations with hard and mixed substrates. Habitat association differences between adults and juveniles were significantly different ($X^2=21.9$, $p<0.001$).

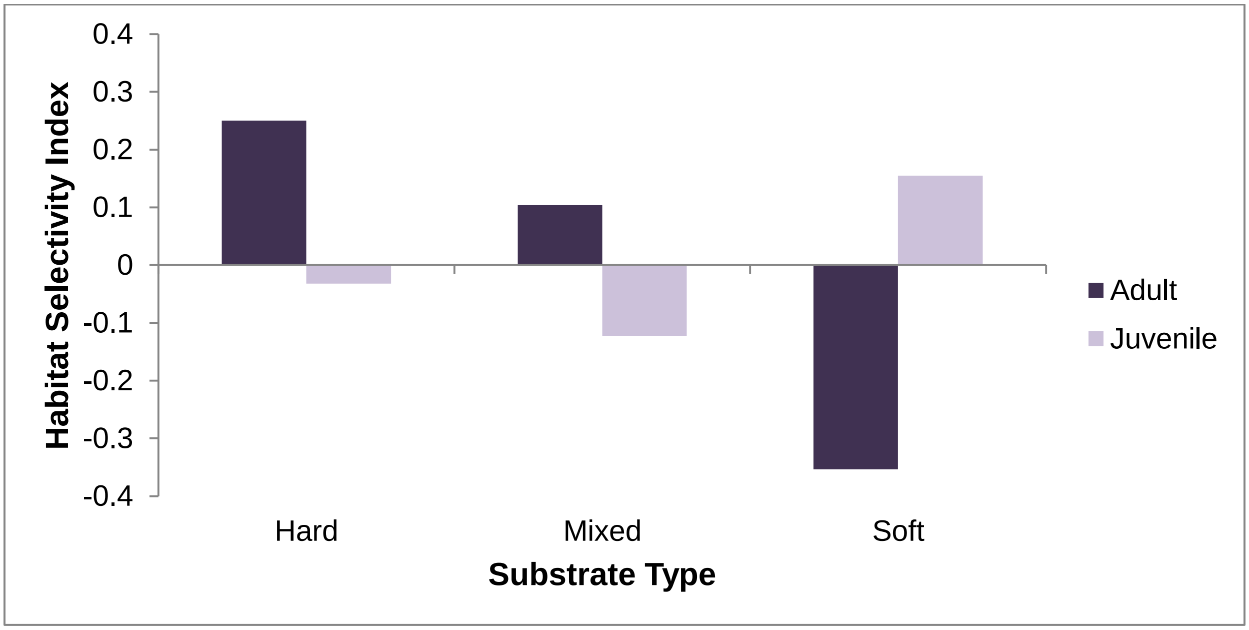


Figure 9. Habitat selectivity indices for adult (n=25) and juvenile (n=96) spotted ratfish. A positive value suggests a positive association with the substrate type whereas a negative value suggests a negative association with that substrate type.

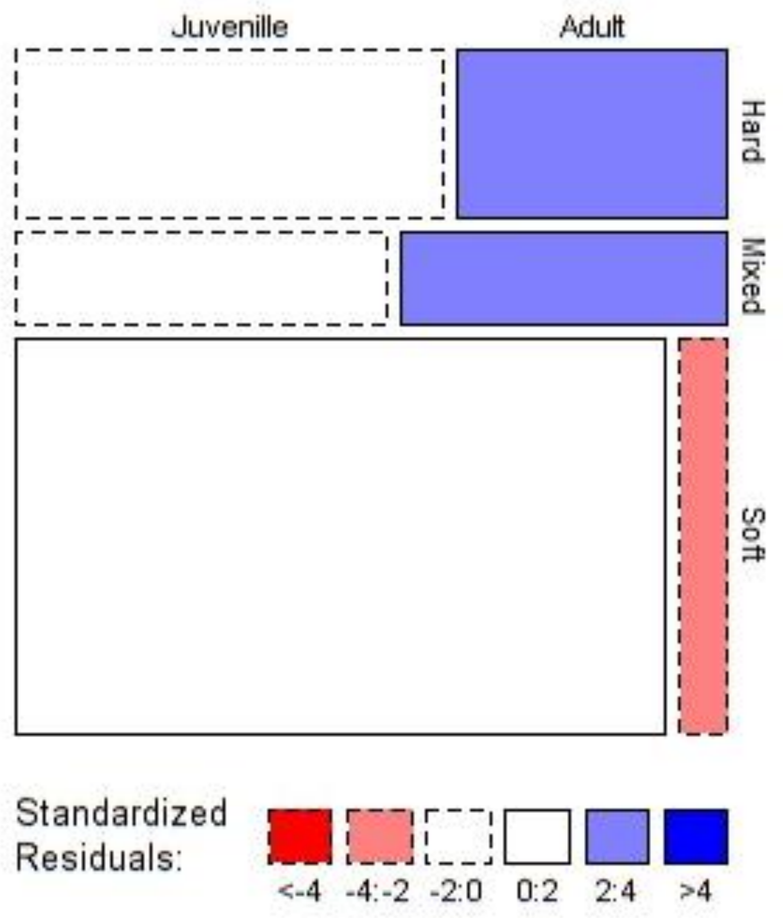


Figure 10. Chi-square mosaic plot of juvenile and adult spotted ratfish associations with hard, mixed, and soft substrates. Blue squares depict strong positive associations between spotted ratfish size classes and habitat types. Red squares depict strong negative associations. White squares depict weaker positive and negative associations.

Discussion

Spotted Ratfish Distribution

Spotted ratfish were found throughout the continental shelf and slope of the MBNMS. Abundances were highest in the northern portion of the MBNMS and decreased to the south. This is consistent with other studies where higher abundances of spotted ratfish were found around prominent physical features along the California coast including Monterey Bay, Cape Mendocino, and Cape Flattery and decreased abundances in surrounding areas (Barnett et al. 2012). The lack of observations in the La Cruz Canyon study area may be explained by differences in oceanographic conditions further south, such as upwelling regimes. Overall, spotted ratfish cover a wide range within the MBNMS though their abundances appear relatively low compared to other species. This suggests spotted ratfish populations may be able to withstand fishing pressures in concentrated areas; however, overextraction and fishing mortality may present a problem if the overall population size is small. Improved knowledge of spotted ratfish population sizes and densities is needed.

Two aggregations of spotted ratfish were seen over two separate transects, one located in the Point Lobos study area consisting of at least 31 individuals the majority of which were juveniles. The second aggregation was observed in the North Monterey Bay study area and was comprised of 29 individuals, primarily adults. Lose groups of up to eight individuals, both juveniles and adults, were also seen in Point Sur. Spotted ratfish aggregations were consistent with aggregations observed in other studies off Cordell Bank and in Alaska (Pirtle 2005, Yoklavich and O'Connell 2008). However, a previous study in Monterey Bay, Yoklavich and O'Connell (2008), did not see spotted ratfish aggregations and few juveniles were found. Since observations in this study differ with observations in the same region in a previous study, predicting the location and composition of aggregations may be difficult. Adult aggregative behavior may be due to reproduction and access to mates. High densities of prey may explain non-breeding juvenile aggregations. However, more research into the factors that drive aggregative behavior is necessary if aggregations are at higher risk of fishing mortality, particularly trawling, since individuals are condensed. Age segregation within aggregations places age groups at risk from fishing mortality as well.

Resting behavior and slow swimming speed of the individuals observed suggests the ROV and camera sled did not negatively impact spotted ratfish counts. However, the lights on these instruments appeared to stun or blind some individuals, causing them to bump into nearby structures and appear disoriented. Therefore, light sensitivity should be considered in behavioral observations of spotted ratfish.

Habitat Associations

Analysis of available habitats showed a variety of substrate types within the MBNMS. Spotted ratfish were found utilizing less than 39% of all substrate combinations available suggesting that not all habitat types are favorable. This may be due to the rarity of many substrate combinations; however, some rare substrates, such as continuous boulder and ridge, and boulder and mud habitat were selected for. Selection for boulder and ridge habitat despite their rarity suggests these are important habitats for spotted ratfish, possibly due to the protection they provide from predators or the prey resources they support. A number of individuals were observed resting on the sea floor between boulders and in ridge crevices. Spotted ratfish were observed in greatest proportion over mud habitat. Both spotted ratfish aggregations were over mud habitat as well. A high positive association with mud habitat is also consistent with past bycatch observations. As opportunistic durophages, mud habitat may provide abundant epifauna and infauna prey for spotted ratfish. Cobble and brachiopod beds had the most negative associations, a trend observed in other species such as some rockfishes and flatfishes (Laidig et al. 2009). Brachiopod beds and cobble habitats may not support suitable prey types or provide adequate protection from predators. These types of habitat may also change frequently in turbid conditions (e.g. are covered with mud) and are therefore not consistently available.

Assessment of habitat associations within each study area suggests a latitudinal trend where spotted ratfish associate more with soft substrates in the northern portion of the MBNMS and then shift to hard substrates in the south. Strong positive associations with soft substrates in North Monterey Bay shift to weak positive associations with soft and mixed substrates in Point Lobos and then weak positive associations with mixed and hard substrates in Point Sur. These weak associations imply that spotted ratfish in these areas are not selecting for particular habitat types. Abundance of prey and habitat availability could explain these weak associations. In La Cruz Canyon, spotted ratfish have strong positive associations with hard substrates despite abundant soft and mixed substrates. However, prevalent hard substrate was also observed in transects in the nearby Piedras Blancas SMCA yet no spotted ratfish were observed in these transects. Changes in habitat associations may be due to changes in epifauna and infauna prey type and abundance due to upwelling, productivity, and coastal runoff (Johnson and Horton 1972), particularly since the Piedras Blancas SMCA is closer to shore. Similarly, limited ranges for prey species and changes in climate may influence food type and availability.

Habitat Associations and Life History Stage

Juvenile spotted ratfish accounted for ~80% of all individuals observed. Previous studies in Monterey Bay observed few juvenile spotted ratfish (Yoklavich and O'Connell 2008). Abundant juvenile spotted ratfish may suggest changes in annual recruitment strength or loss of adults due to fishing pressures. In addition, spotted ratfish may undergo ontogenetic shifts where juveniles utilize shallower depths as nursery habitats and adults move to deeper habitats with age. Similar ontogenetic shifts have been observed in other species, such as habitat shifts from boulder reef to cerianthid anemone habitat in Acadian redfish (*Sebastes fasciatus*) in Stellwagen Bank (Auster et al. 2003). These shifts may not be apparent in transect surveys until spotted ratfish movement patterns are better understood. Depth may also play a role in adult and juvenile distributions if adults move to deeper depths particularly beyond the range of sampling instruments. However, the lack of adults is concerning in terms of reproduction and population sustainability within the MBNMS.

Juvenile and adult habitat associations observed in this study contradict Barnett's (2008) hypothesis that juveniles may associate with hard substrates due to their decreased presence in trawls. However, the decreased abundance of adults over soft substrates may be a direct result of bycatch especially outside of state waters. The difference in habitat associations between juveniles and adults may be a result of differences in diet or avoidance of competition and intercohort cannibalism. Adults showed stronger positive and negative habitat associations than juveniles which may be a result of the smaller sample size for adults or may suggest a stronger association with or avoidance of particular habitat types. Adults may be more selective in the prey types they eat and have a refuge in size that reduces predation risk and allows for increased foraging time. The weaker associations seen in juveniles may be a direct result of avoidance of adult competition and predation where juveniles utilize less favorable habitat types or select for less favorable prey in order to avoid predators or competition.

Implications for Management

Underwater observations via ROV and towed camera sled prove valuable for studying the relationships between organisms and surrounding habitats compared to extractive methods (Yoklavitch et al. 2007, Stoner et al. 2007). The use of these instruments has recently begun to shed light on the distribution, abundance, life history, population dynamics, and habitat associations of deep water species, like the spotted ratfish. Considering our poor understanding of many deep water species and ecosystems, *in situ* observations are invaluable, particularly in terms of management.

Spotted ratfish associations with mud habitats leave the species particularly vulnerable to trawling. In previous studies, large aggregations of egg cases, juveniles, or adults have been observed over mud (e.g. Pirtle 2005). The high number of juveniles and observed over mud habitats in the MBNMS could result in high juvenile mortality from bycatch. Therefore, the population's susceptibility to trawling is greatly increased if mud habitat is vital to spotted ratfish reproduction and as a potential nursery for juveniles. The loss of juveniles potentially compounds the low abundances of mature adults observed in the MBNMS. Therefore, subsistence of spotted ratfish populations may be in jeopardy if few reproductive adults are present and few juveniles survive to reproductive age. Because spotted ratfish play such a prominent role in deep sea food webs, decreases in their populations could have negative impacts on teleost predators. The populations of economically important species, such as California halibut, could decline if spotted ratfish prey decrease. In addition, recovery of critically endangered species, like giant sea bass, could be hindered if spotted ratfish prey is removed. Control of prey populations by spotted ratfish could also be at risk of spotted ratfish populations decline. These shifts in lower trophic levels could have detrimental impacts on high trophic levels which, in turn, could negatively impact fisheries for economically important species. Knowledge on these trophic interactions is critical for better understanding the spotted ratfish's place in this system. In light of this, understanding where spotted ratfish occur and with which habitat types they associate may be an important step in maintaining the deep sea communities of which they are an integral part.

In general, chondrichthyan populations are thought to be highly susceptible to overfishing and as bycatch (Stevens et al. 2000) with deep water species considered particularly vulnerable (Garcia et al. 2008, Simpfendorfer and Kyne 2009). Slow population growth due to late maturity and low fecundity could prevent populations from rebounding from past, present, or future overexploitation. Though spotted ratfish currently have no commercial value, increased interest in chimaeroid liver oil and as a food source leaves the population open to future exploitation (Brennan and Gormley 1999). Similar interest in liver oil is occurring for other chimaeroids, including the rabbitfish (*Chimaera monstrosa*) in Norway, as demand for human dietary supplements increases (Calis et al. 2005). New and potential fisheries for chimaeroids, including spotted ratfish, are severely data limited. Without sufficient information on spotted ratfish with which to regulate a new fishery, spotted ratfish could face the “boom and bust” pattern many other chondrichthyan fisheries have experienced. The aggregative nature of spotted ratfish and their life history traits are further cause for concern if large numbers of same age individuals are removed. Therefore, preemptive management, aided by scientific information, is critical in preventing population decline for this potential resource.

Results from this study can inform managers on the propensity of spotted ratfish to utilize particular habitat types and therefore limit fisheries mortality and bycatch. For example, in North Monterey Bay where spotted ratfish were observed to have a high positive association with soft substrates, the potential reopening of halibut trawling in this area could result in excessive bycatch of spotted ratfish. With this information, fisheries managers can implement bycatch mitigation measures before overextraction irreversibly impacts the population. In addition, understanding the latitudinal and geographic trends in habitat associations of spotted ratfish can help managers discern areas of high abundance and association with multiple habitat types, such as Point Lobos and Point Sur. These areas may house populations that are more robust to anthropogenic pressures or changes in climate regimes. Several spotted ratfish were observed within the Point Lobos and Point Sur SMCAs. These areas already offer protection for spotted ratfish under the MLPA. In contrast, areas like La Cruz Canyon do not appear to be ideal for maintaining spotted ratfish populations considering the few individuals found despite the high abundance of multiple habitat types. This information provides an essential foundation from which management measures, such as MPAs, and policy can be developed.

MPAs are more frequently being used to support the sustainable growth, protection, and improvement of marine resources (Williams and Bax 2001, Halpern 2003, Lubchenco et al. 2003). Biological consideration into the design and implementation of MPAs, though, has generally seceded to social and political expectations (Halpern 2003). However, there is limited scientific knowledge on species-habitat associations, distribution, abundance, and life history with which to aid MPA placement and design. Therefore, our lack of understanding of marine ecosystems presents a serious challenge for successful management. Presently, fish-habitat associations are more frequently being used to direct management across the globe (Perry and Smith 1994, Williams and Bax 2001). In California, the network of MPAs established under the MLPA will need scientific input on species-habitat associations quickly and efficiently in order to assess the effectiveness of MPAs and manage them adaptively.

The methodology used in this study could provide a relevant picture of the habitat types utilized by marine species. The MBNMS Management Plan to characterize the continental shelf and slope within the MBNMS has collected extensive data over multiple years. These data provide an excellent opportunity to explore the habitat associations of multiple species with which to build a foundation for management. Habitat characterization and habitat selectivity indices do not require extensive training or knowledge of marine ecosystems and can be collected easily and quickly. In this study, no discernible difference was observed between the videographic imagery collected via the ROV and camera sled, therefore either instrument could be considered based on financial support. Depending on the scale of data collected, species-habitat associations could paint a detailed picture of habitat associations and trends in associations of a significant number of economically and ecologically important species. Similar studies have already been conducted to inform and develop Australia's National Representative System of Marine Protected Areas (NRSMPA) (Williams and Bax 2001).

Future Work

Continued data collection to increase sample size would improve the clarity of this study. In addition, fine-scale habitat data on the available habitat types throughout the MBNMS would help to better determine habitat selectivity for spotted ratfish. Estimates of spotted ratfish densities and population size are also necessary. A detailed assessment on the diet of spotted ratfish and differences in juvenile and adult diet would provide more definitive conclusions on how prey type and availability may influence habitat associations of spotted ratfish. Similarly, tracking and tagging studies on the movement patterns of spotted ratfish are necessary to determine ontogenetic, seasonal, or diurnal movements in relation to habitat associations. Most importantly, this methodology should be expanded to other species to determine habitat associations, particularly economically important species and species sensitive to anthropogenic impacts, to aid management strategies.

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