An approach for assessing essential fish habitat for coral reef species in Hawai'i

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Introduction

The Sustainable Fisheries Act of 1996 mandates that Fishery Management Councils describe and identify essential fish habitat (EFH), defined therein as "those waters and substrate necessary for fish for spawning, breeding and growth to maturity" for all species managed under a fisheries management plan (WPRFMC, 2009). One straightforward approach to determining essential fish habitat for a species of interest is to compare its relative abundance between available habitats. In fact, in its guidelines to fishery management councils for implementing EFH, the National Marine Fisheries Service (NMFS) acknowledges that having habitat-specific relative abundance or densities for a given species is a critical metric of habitat data quality (50 CFR Pt. 600.815). A species can be elevated from level-1 habitat data quality (knowing only which habitats a species occurs in based on its distribution in all or part of its range) to level-2 if it has habitat-related density or relative abundance data. This paper outlines how available fish survey data can be combined with remotely sensed benthic habitat data to provide a first-order approximation of habitat-specific relative abundance. In this context, the strengths and weaknesses of the available fish abundance and benthic habitat data for the Main Hawaiian Islands (MHI) are discussed. Finally, using the pilot species 'manini' (*Acanthurus triostegus sandvicensis*), habitat-specific density was combined with bathymetric data using a geographic information system (GIS, in this case ArcGIS) to delineate EFH. The purpose of this exercise is to provide the Western Pacific Regional Fishery Management Council (WPRFMC) with a cost-effective approach for designating EFH for coral reef species in Hawai'i, and to demonstrate the kind of outputs such an approach can offer for fishery managers.

Methods

I. Derivation of Habitat-Specific Relative Abundance

a. Benthic habitat data

In order to develop an approach for designating EFH for coral reef species, a benthic habitat data set with the following attributes was sought: 1) data are georeferenced and available across the MHI; 2) habitat classifications are standardized; 3) data include both biological and geomorphological information that might be used to narrowly define EFH. After reviewing available data sets, the benthic habitat maps produced by NOAA's Center for Coastal Monitoring and Assessment (CCMA) best satisfied these criteria. CCMA maps were recently used by Friedlander et al. (2006) to compare spatial trends in reef fish between fished and non-fished areas throughout the MHI.

CCMA benthic habitat shapefiles were downloaded for each of the MHI from http://ccma.nos.noaa.gov/products/biogeography/hawaii_cd_07/data/. All shape files used NAD-83 and were either UTM Zone 5 (Hawai'i Island) or Zone 4 (all other MHI). Each shape file contained habitat polygons down to 30 m. Polygons were originally digitized from orthorectified Multispectral IKONOS™ and Quickbird™ satellite images following the procedure described in Battista et al. (2007) or on the CCMA website. Each polygon was attributed by area in meters and acres, reef zone (e.g. reef flat, reef crest, etc.), geomorphological structure, major biological cover, and percent cover (Table 1).

b. Fish abundance data

Because this approach for designating EFH uses a GIS, fish abundance data that were georeferenced throughout MHI was used from NOAA's Coral Reef Ecosystem Division's (CRED) Reef Assessment and Monitoring Program (RAMP). In addition to the fact that they span the MHI, these data were chosen because they extend deeper (down to 30 m) than other available fish survey data and use a depth-stratified approach that makes it possible to relate fish density to depth. RAMP employs two distinct fish survey types: Belt transects (BLT) and stationary point counts (SPC). Details on survey protocols can be found at www.pifsc.noo.gov/cred/fish.php. For this analysis, only SPC data because was used: 1) SPC surveys are associated with a single GPS data point and do not require information about the directionality of the survey, so there is higher precision when comparing abundance data to remotely sensed habitat data; 2) RAMP now conducts only SPC surveys (I. Williams, pers. comm.), so using these data will make this exercise more compatible with data to be collected in the future. SPC fish abundance data was used from surveys conducted between Oct.-Dec. 2010 from all MHI except Kahoolawe (which was not surveyed by RAMP).

c. Intersecting fish abundance and habitat data

In order to combine benthic habitat and fish abundance data, both data sets were imported into ArcGIS as separate layers and then intersected. Once intersected, the combined attribute table was exported to Excel for analysis.

II. Analysis of Habitat Specific Data

a. Total Fish Abundance by Habitat

To assess the general utility of RAMP's SPC data, significant differences in total fish abundance (density per unit area) between benthic habitats were analyzed. Total fish abundance at a given SPC site was obtained by summing the densities of all species. This approach is valid because SPC surveys use a standardized area (314 m^2). After calculating total density for each site, three separate one-way ANOVAs were run for each of the habitat parameters of interest, namely geomorphological structure, biological cover, and depth. In the ANOVA for geomorphological structure, sites where structure was 'unknown' were excluded; in the ANOVA for biological cover, 'unknown' and 'macroalgae 50-90%' sites were excluded (in the latter case because only one site fit this criterion, so there was no variance to analyze). For the depth ANOVA, SPC surveys were divided into three depth-strata based on breaks in the depth frequency distribution. These breaks were 0-10 m, > 10 m – 20 m, and > 20 m – 30 m. All depth strata had at least 52 SPC surveys.

b. Identification of commercially important species for habitat analyses

To identify which species to evaluate habitat-specific relative abundance, several WPRFMC analyses of commercial and non-commercial reef catch were tabulated: the top ten commercial species in the commercial fish catch between 2005-2009 (Luck and Dalzell 2010); the top 90% of the commercial reef catch for all years of WPRFMC's species-level catch report time series (M. Sabater, Pers. Comm.); and the top ten species in combined commercial and recreational landings (Walker et al., 2012). In all cases, any taxon not identified to the species level was excluded. Also excluded were all carangid species, due to their semi-pelagic nature (Randall 2007). This exercise produced a list of 12 commercially important coral reef species, but because the goal of the exercise was to relate species abundance to habitat data, only those species that were frequently seen in SPC surveys were kept. Most of the preliminary twelve species were seen in a small fraction (< 10%) of surveys (Table 2), so the habitat data only for species seen in $\geq$ 20 % (n=59) SPC surveys were analyzed. There were a total of four species that met these criteria: *Acanthurus dussumieri* (palani), *A. triostegus sandvicensis* (manini), *Naso brevirostris (*Kala lōlō) and *N. unicornis* (kala). These four species are collectively called focal species in the remainder of the document.

c. Habitat-specific relative abundance for focal species

In order to determine the utility of RAMP for species-specific relative density by habitat, the three ANOVAs described in section IIa were repeated, except that we compared the fraction of each species to the total abundance (i.e. species density/total density).

III. GIS-Approach for delineating EFH using a pilot species

a. Selection of Pilot Species

In order to show how habitat specific density data might be used to actually designate EFH, these data were combined with bathymetry data for a pilot species, *Acanthurus triostegus sanvicensis* (hereafter referred to as 'manini'). Manini was chosen because in the one-way ANOVAs it showed significant differences in relative abundance by depth, it showed near significant differences in relative abundance by geomorphological structure, and of all four species it had the narrowest bathymetric range (down to 46 m) in Hawai'i (Luck and Pylman, 2012). This latter factor was important because benthic habitat maps extend to ~30 m only.

b. *Creation of essential fish habitat for manini*

In order to approximate the area of EFH for manini, polygons were created that incorporated both habitat and bathymetry (to account for habitat depth) for O'ahu. The habitat data came from the benthic habitat maps as described above; bathymetry data were acquired from the State of Hawai'i in 5-m resolution. Bathymetry data had been previously stitched together using LiDAR and range from the shoreline to about 500 m (C. Kelley, pers. comm.). The coordinate system and datum used for the bathymetry data were WGS-1984 and GCS, respectively, so it was necessary to re-project and transform the data to make it uniform with our benthic habitat maps.

In ArcGIS, at least two tools can be used to delimit a bathymetric range, namely the 'contour' and 'reclassify' tools. To test the effectiveness of each tool, each tool was separately used to eliminate habitats deeper than 46 m, the known bathymetric range of manini in the Hawaiian Archipelago. For each island, portions of the bathymetry raster shallower than 46 m were exported as a new layer and then converted to polygons so that habitat area could be calculated. These new polygons represented the potential depths of manini habitat. Next, high abundance depths were mapped as all depths shallower than 20 m because manini was significantly more abundant in < 20 m in one-way ANOVAs. To identify high abundance benthic habitats, the select by attribute feature was used to pick habitats that had both the cover and structure types that independently supported the highest manini densities in their respective ANOVAs. Finally, to identify EFH, the intersect tool was used to find the union between high abundance depths and high abundance benthic habitats.

Results

I. Habitat Specific Data

a. *Total fish abundance by habitat*

Total fish density was significantly different by both biological cover and geomorphological structure, but was not significant by depth (Table 3). Of all structures, Rock/Boulder had the highest fish density (0.581 fish m^2) but also had the largest standard deviation between sites (Fig. 1A). Aggregate coral (0.490 fish m^2) and sand (0.457 fish m^2) had the second and third highest densities respectively, and both had moderate to low standard deviations. Pavement with sand channels consistently had the lowest density at 0.307 fish m^2 (σ. = 0.104). With respect to biological cover, the three habitat classifications with coral as the dominant cover had the three highest total fish densities. This pattern was true even for coral habitats with relatively low coral cover (i.e. 10 - <50% coral cover vs. 50 - <90% and > 90% coral cover). The lowest total fish densities occurred in sites with turf at 10 -50% as the dominant cover; mean fish density at those site was 0.196 fish m^2 with a standard deviation of 0.020 fish m^2. Although differences between total fish density between depth strata were not significant, the highest mean density was found between in > 10 – 20 m at 0.51 fish m^2.

b. *Relative abundance of focal species by habitat*

Of our four focal species, the two *Acanthurus* spp. (manini and palani) differed significantly in their relative abundance by depth strata but not between habitats with different biological cover or geomorphological structure (Table 3). Manini was most abundant between 0-10 m (0.008 fish m^2) and least abundant below 20 m (0.003 fish m^2). Palani showed the opposite trend, and was significantly more abundant below 20 m. Of the two *Naso* spp., Kala lōlō differed significantly between habitats with different structures, but showed no difference by depth or biological cover; its average density was highest at spur and groove (0.019 fish m^2) sites, moderate at aggregate reef (0.11 fish m^2) and sand (0.010 fish m^2) sites, and at low densities in all other habitats. Kala showed near significant differences between depths but had very high p-values for both structure and depth.

Even though manini density did not significantly differ by cover or structure types, some benthic habitats had notably higher abundance of manini. With respect to cover, manini had its highest densities over turf (Fig. 3A); for structure, manini was most abundant at pavement with sand channels and spur and groove sites (Fig. 3B). No other classification of either cover or habitat had an average density above 0.2 m^2, so I decided to use these cover and structure types to derive high abundance habitats.

II. GIS-based designation of manini EFH

Using the lower distribution of manini (46 m), O‘ahu has at least 392.73 km^2 of habitat that fall within the potential depths used by the species (Table 4). High abundance depths ($\leq$ 20 m) totaled 279.98 km^2. The high abundance habitats (spur and groove with turf; pavement with sand channels and turf) totaled 98.59 km^2; however, not all high abundance habitats were $\leq$ 20 m depth. When I intersected high abundance habitats with high abundance depths, the remaining fish habitat, which I call EFH, was just 78.54 km2 or ~20% of habitat area within the 46 m contour. This paring down of habitat from potential depth range to EFH can be seen visually in Figs. 3-6.

Discussion

Our approach to designating EFH illustrates some of the strengths and deficiencies of currently available habitat and abundance data for EFH designation. Provided that a species has a relatively shallow depth distribution (ideally < 30 m) and some measure of fish abundance by habitat, we have shown that a GIS can be used to map EFH using remotely sensed benthic habitat maps and multibeam bathymetry data. However, given the state of many of the input data sets, estimates of EFH produced in this manner must be regarded as first-order approximations.

In our estimation, the main challenge for designating EFH is the limited availability of relative abundance data throughout the range of habitats a given species may use. While RAMP data is probably the most comprehensive data set for these purposes, it has several key limitations (Williams 2010). Firstly, it extends only to 30 m depth, approximately the limits of traditional scuba technology. Many reef species, however, range well below 30 m (Pylman and Luck, 2012); abundance data from these depths are very limited. Secondly, like most visual fish surveys, RAMP surveys are biased with respect to time of day and fish taxon of interest. The abundance of species that are diurnally-cryptic and/or nocturnal cannot be accurately estimated using day-time censuses only. The randomized sampling design of RAMP surveys is not well-suited for reef species that are highly clumped in their distributions (e.g. Kyphosidae). Finally, RAMP surveys are only conducted on hard-bottom habitats, so taxa found predominantly on soft substrate (e.g. Mugilidae) are likely to be undercounted (Williams 2010).

Despite these limitations, our analysis of habitat-specific abundance suggests that RAMP data will be useful in delimiting EFH for some species. Three of our four focal species had significant differences ($\alpha = 0.05$) in density by at least one habitat factor. Per NMFS ranking system of EFH quality, all three of these species may qualify for elevation to data quality level 2 (50 CFR Pt. 600.815). Species-specific patterns were strongest with respect to depth (Table 3); however, because they do not extend below 30 m, RAMP depth data are best-suited for species whose distributions are primarily within 30 m. Of the two benthic habitat factors, geomorphological structure appears more useful (as indicated by lower average p-values) than major biological cover. This may reflect the need of reef species for shelter; alternatively, it could be that the breaks in biological cover used in benthic habitat classifications (e.g. < 10% coral vs. 50-90% coral) do not reflect ecological breaks. We recognize, however, that the patterns in relative abundance by habitat factor that we observed may reflect our relatively simple statistical approach. We recommend further investigation of habitat-specific data using a multivariate approach that more explicitly accounts for interaction between habitat factors. Moreover, we used RAMP data from a single year with no repetition of individual sites. It is possible that with additional data from each site, patterns in relative abundance by habitat could change significantly.

For species not well covered by RAMP's sampling design, descriptive accounts of habitat preference, which are available throughout the literature, may be necessary to use (see Pylman and Luck 2012), to designate EFH. If it is known, for example, that a fish spawns in a specific habitat, it is a relatively straightforward procedure to map those habitats using a GIS. As our literature review (Pylman and Luck 2012) and metatable (Pylman and Luck 2012) reveal, however, such specific requirements are known for only a handful of reef species.

Our pilot GIS analysis using manini habitats around O'ahu also demonstrates the limitations of available benthic habitat data. Like RAMP survey data, CCMA's benthic habitat maps extend to 30 m only. For species with deeper distributions, it may be necessary to use backscatter data to delineate between hard and soft substrates below 30 m. Such an approach was used by Kahng and Kelley (2007) when studying mesophotic habitats in the Au'Au channel. In their study, they defined a backscatter values > 186 as hard substrate, and those below as soft substrate. Their threshold was based on correlations of backscatter data with video footage of the substratum collected by a submersible. Because collecting such video footage is expensive, it may be more practical for WPRFMC to identify and adopt a threshold backscatter value from the literature. Kahng and Kelley (2007) mention that the backscatter threshold of 186 has also been used by to define hard substrates off California, so 186 may be a good working threshold. However, even with a suitable threshold, the availability of backscatter data for the MHI may limit its utility in defining EFH. Currently the Pacific Islands Benthic Habitat Mapping Center has publicly available backscatter data only for Niʻihau and Penguin Banks (PIBHMC website).

When defining EFH for manini, we encountered several long stretches off O‘ahu that lacked bathymetry data. The relative importance of these bathymetric data gaps for defining EFH will depend on their extent (which varies by island) and their depth range relative to the depths the species of interest inhabits. For example, the potential depth distribution of manini in the MHI extends to 46 m, but for O’ahu there are two long tracts (~10 and 30 km, respectively) off the North and Windward shores that lack bathymetric data within this range. However, these data gaps did not affect our EFH designation because although they occurred within the potential depth of range of manini, they were below the depths at which manini is most abundant (< 20 m). For species with high abundance at depths with limited bathymetric data, it may be necessary to gaps by either reclassifying them or by drawing manual contours in ArcGIS. Reclassification is quicker but coarser. One would simply direct ArcGIS to reclassify raster areas without data (but within the surveyed range) as falling within or outside of the potential depth range of the species Although manual contouring introduces uncertainty, it could be more accurate if there holes in bathymetric data are small and isolated. Of the two techniques, manual contouring is also more labor intensive.

Summary and Recommendations

Because our procedure projects EFH from empirical trends in relative abundance, it might be instructive to ground-truth some of the locations projected as manini EFH by habitat characteristics but actually surveyed by RAMP. This could be done cost-effectively with shallow-water visual fish surveys. High relative abundance of manini at predicted EFH sites would support the validity of our approach.

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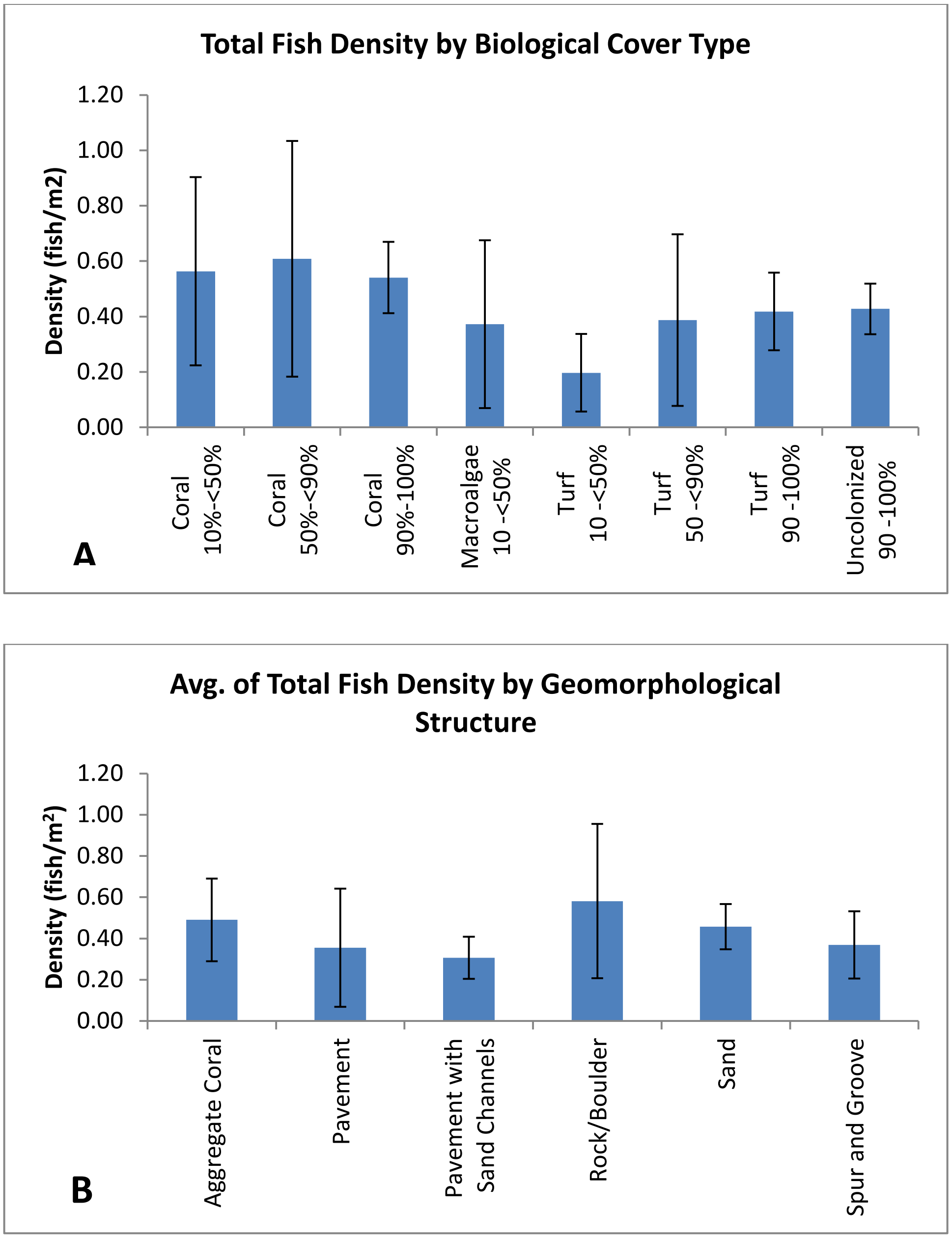

Figure 1. Total fish density in stationary point count (SPC) surveys as a function of (A) benthic habitat type or (B) geomorphological structure. One-way ANOVAS showed significant differences ($\alpha = 0.05$) between sites using either factor. Error bars are standard deviations.

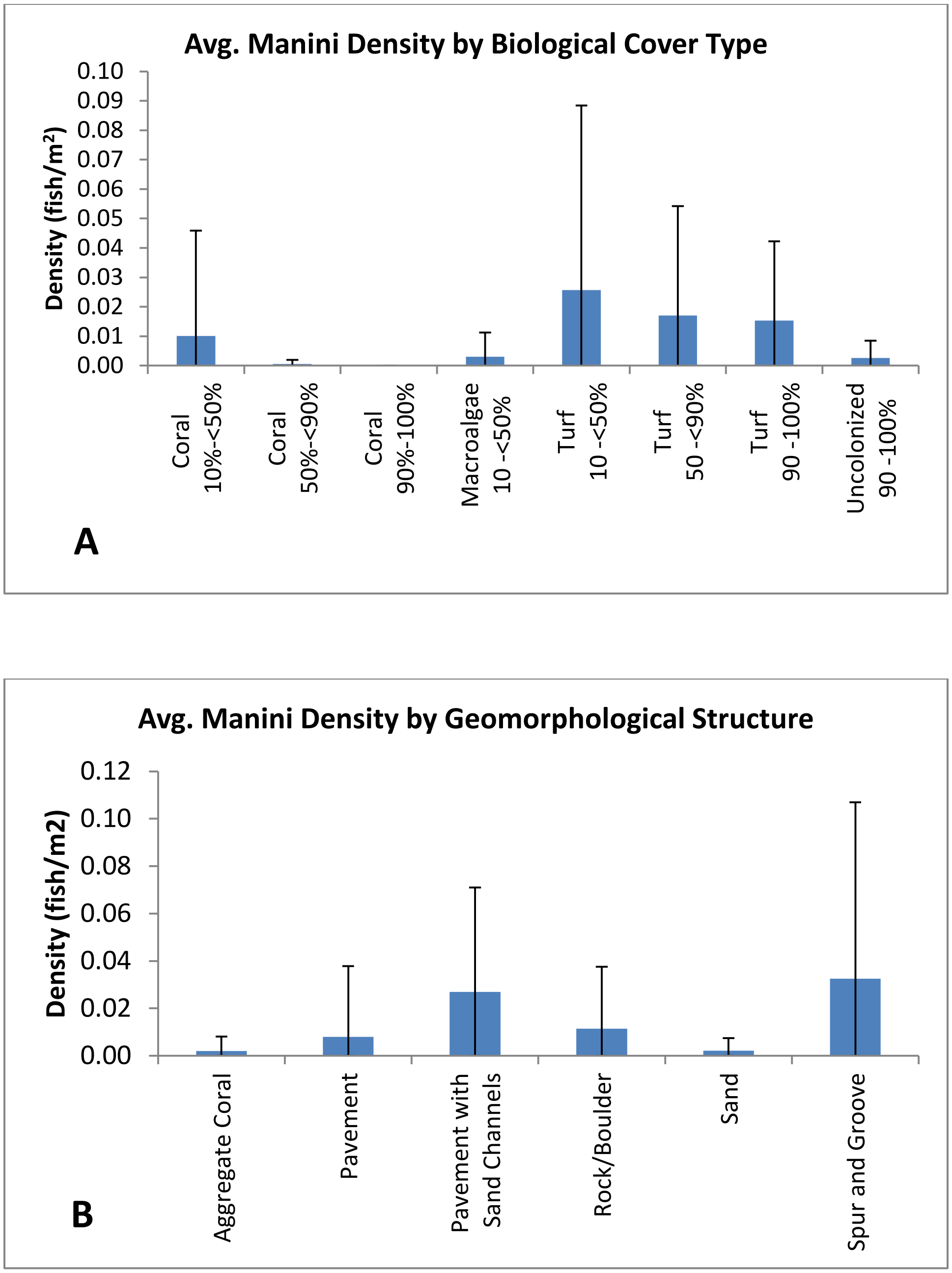

Figure 2. Average density of manini in stationary point count (SPC) surveys as a function of (A) benthic habitat type or (B) geomorphological structure. Of all biological covers, only turf sites (all three categories) had densities higher than 0.02 fish m2. Of all structure types, only spur and groove and pavement with sand channel sites had fish densities of 0.02 fish m^2. Error bars are standard deviations.

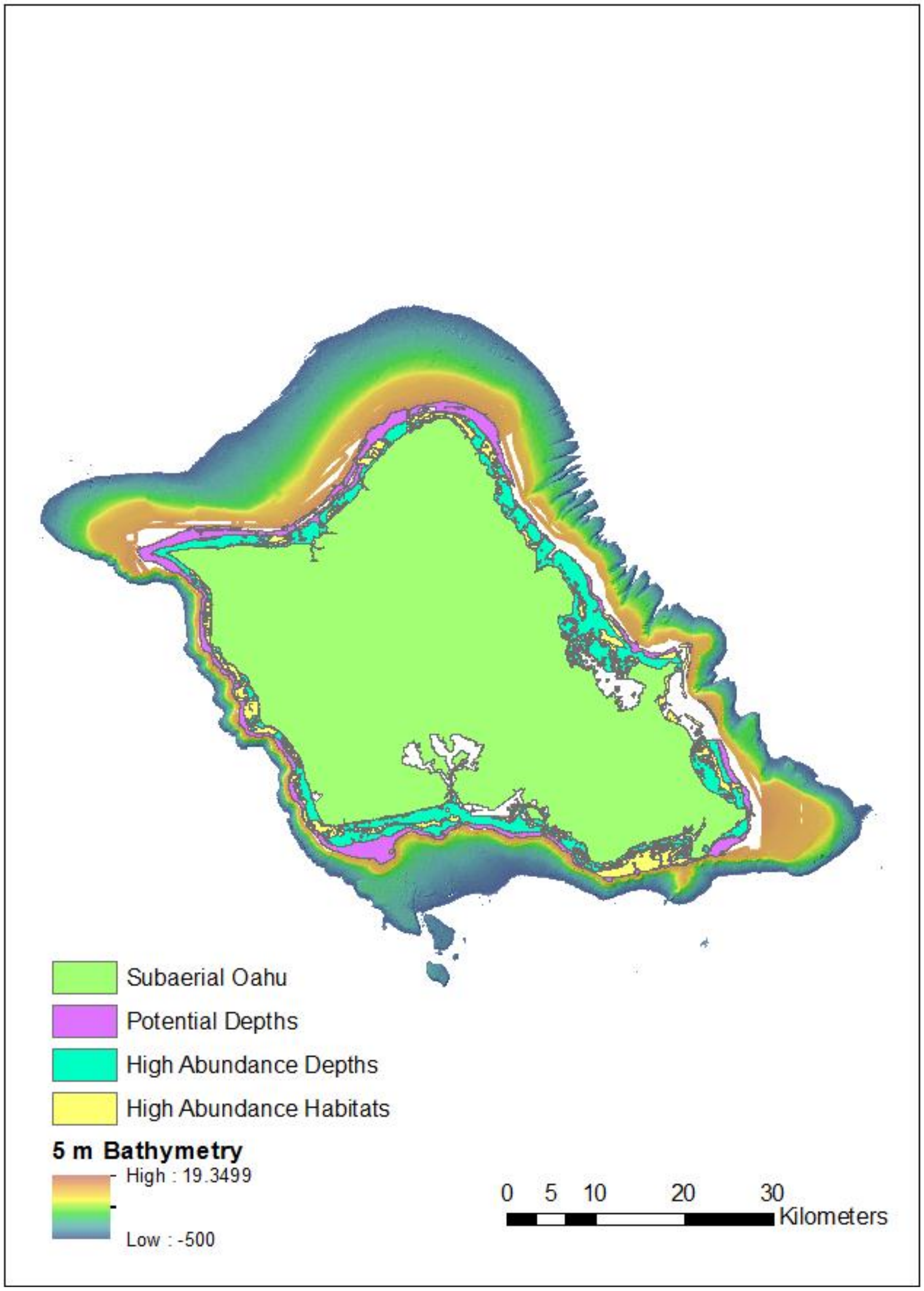

Figure 3. Selected habitats of the manini (*Acanthurus triostegus sandvicensis*) off O‘ahu. Areas in white are those without multibeam bathymetry data. Potential depths are all habitats with bathymetric data down to the deepest known distribution of manini in Hawaii (46 m). High abundance depths are habitats < 20 m because the relative abundance of manini in SPC surveys was significantly higher within that depth range. High abundance habitats are those with both biological cover type and geomorphological structure that supported average manini densities > 0.02 fish per m^2 in SPC surveys.

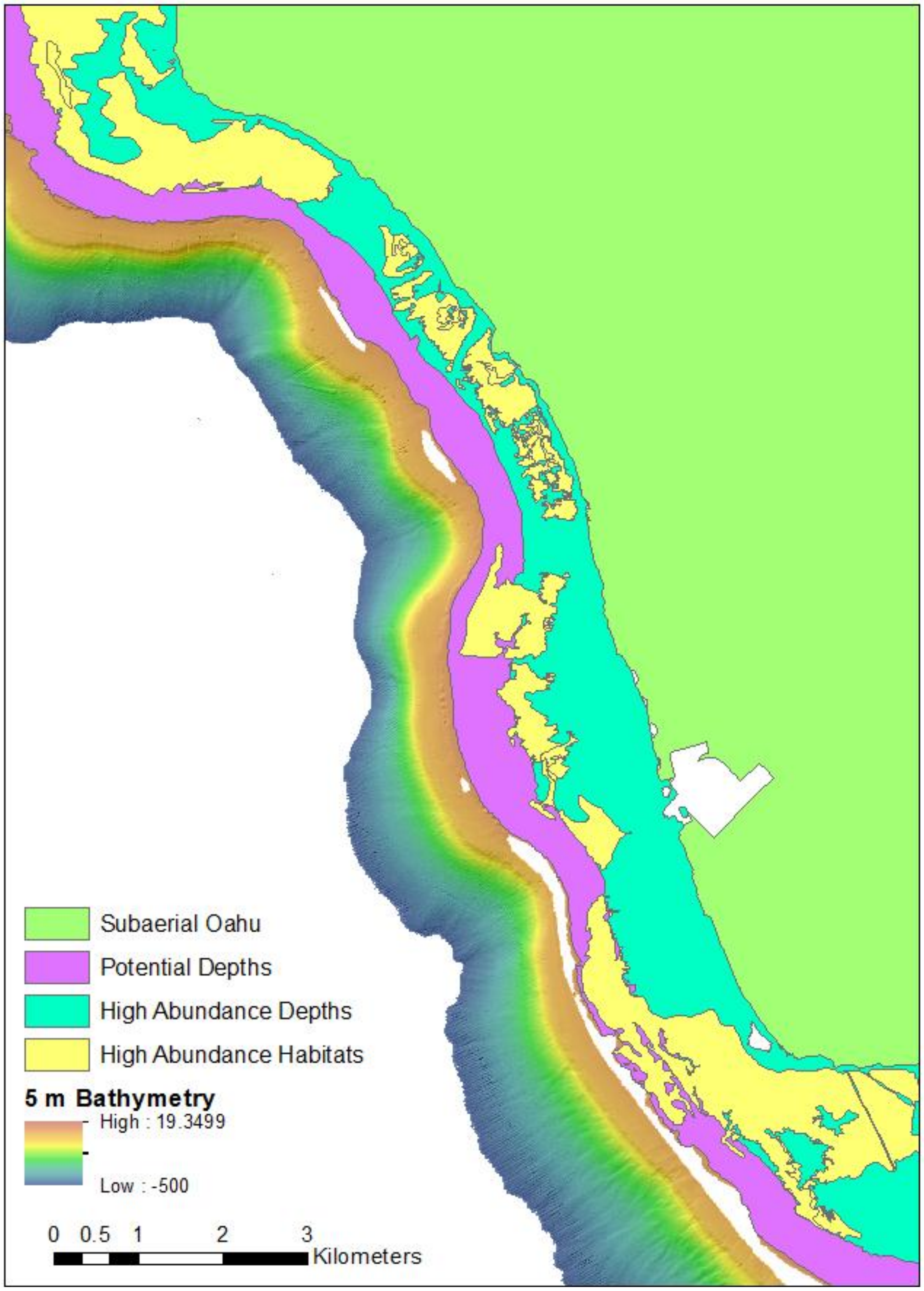

Figure 4. Selected habitats of the manini (*Acanthurus triostegus sandvicensis*) between approximately Barber's Point and Nanakuli, O'ahu. For details on the figure legend, see Fig. 2.

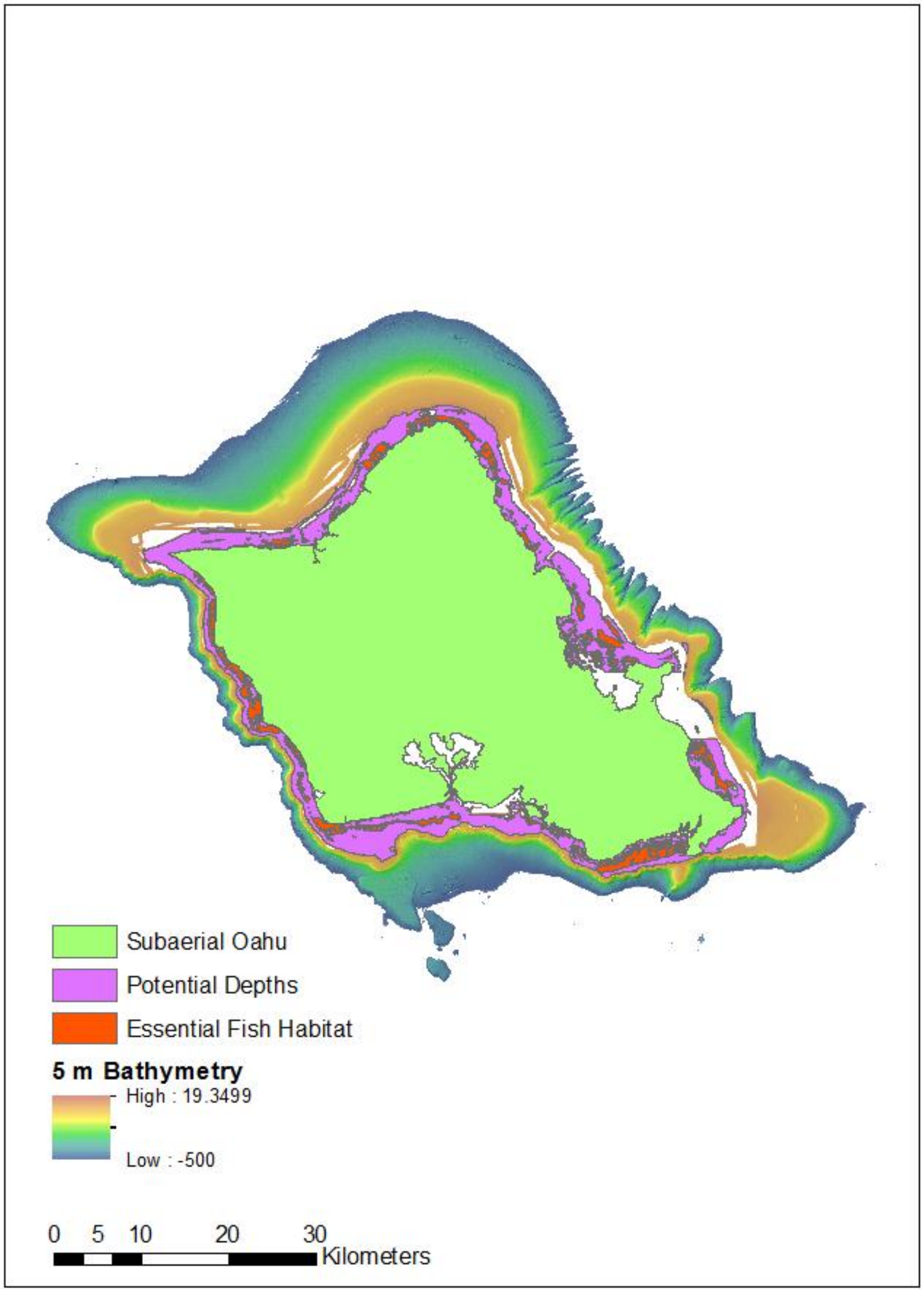

Figure 5. Selected habitats of the manini (*Acanthurus triostegus sandvicensis*) off O'ahu. Areas in white are those without multibeam bathymetry data. Potential depths are all habitats with bathymetric data down to the deepest known distribution of manini in Hawaii (46 m). Essential fish habitats for manini are the intersections of high abundance depths and high abundance habitats (see Fig. 3).

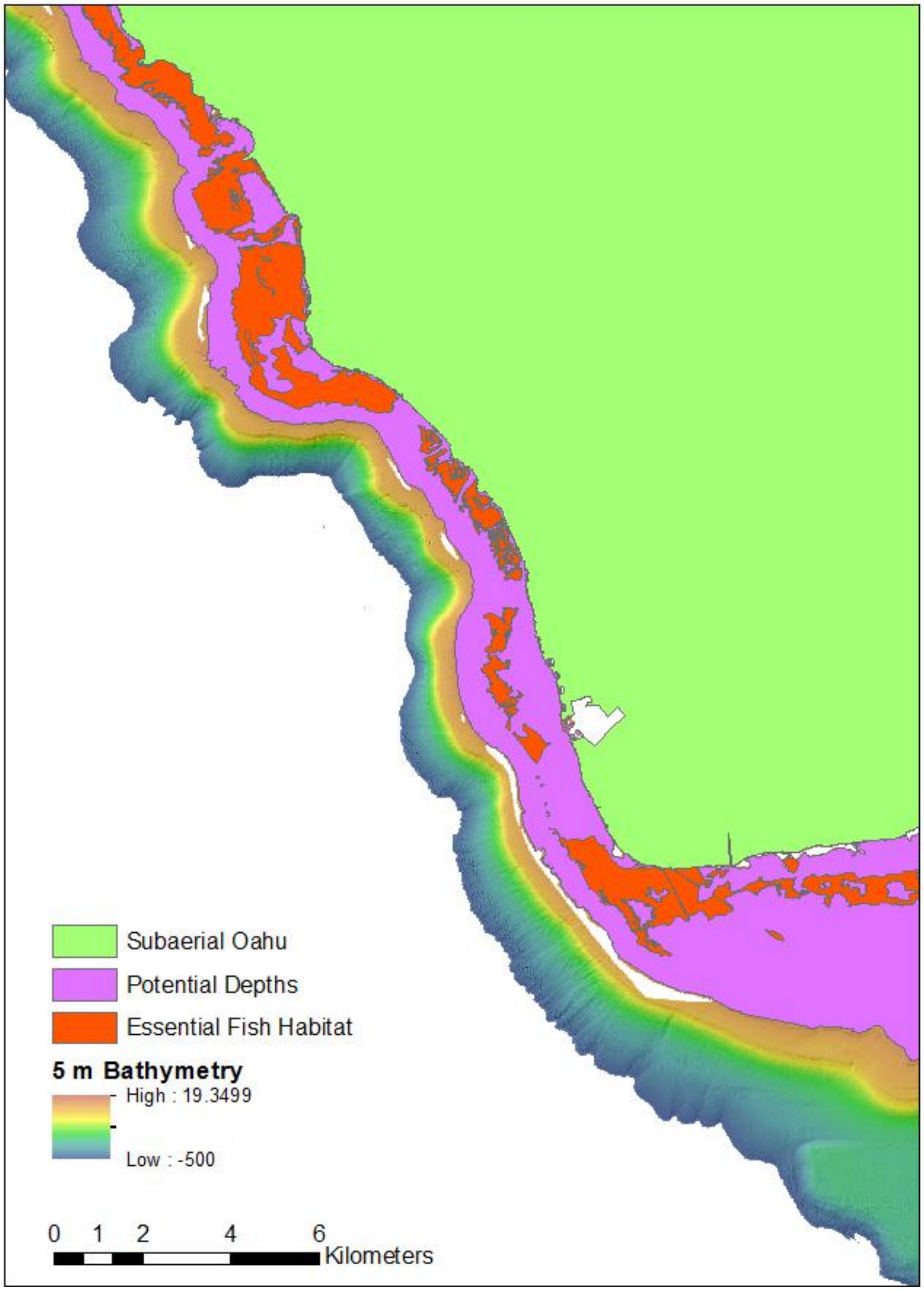

Figure 6. Selected habitats of the manini (*Acanthurus triostegus sandvicensis*) between approximately Barber's Point and Nanakuli, O'ahu. Essential fish habitats for manini are the intersections of high abundance depths and high abundance habitats (see Fig. 3). For details on the figure legend, see Fig. 2.

Table 1. Summary of attributes for benthic habitat polygons from the Main Hawaiian Islands (MHI). Habitat data were acquired from NOAA's Center for Costal Monitoring and Assessment.

Attribute	Values
Area	m^2 and acres
Major Biological Cover	Coral, seagrass, emergent vegetation, encrusting/coralline algae, macroalgae, turf algae, uncolonized, unknown
Percent Cover	% of major biological cover
Structure	Aggregate reef, aggregate patch reef, artificial, individual patch reef, mud, pavement, pavement with sand channels, reef rubble, rock/boulder, sand, scattered coral/rock in unconsolidated sediment, spur and groove
Zone	Back reef, bank/shelf, bank/shelf escarpment, channel, dredged, forereef, lagoon, land, reef crest, reef flat, shoreline intertidal, unknown, vertical wall

Table 2. Percentage of stationary point count (SPC) surveys in which commercially important coral reef species were seen. Species seen in at least 20% of SPC surveys (the first four species in this table) were analyzed for habitat-specific relative abundance.

Species	% of SPC surveys seen
Acanthurus dussumieri	32.07
Acanthurus triostegus	30.97
Naso unicornis	23.91
Naso brevirostris	20.1
Parupeneus cyclostomus	9.78
Mulloidichthys flavolineatus	9.23
Mulloidichthys vanicolensis	4.34
Parupeneus porphyreus	3.8
Naso annulatus	1.63
Kuhlia sandvicensis	0.54
Mulloidichthys pfluegeri	0.54
Chanos Chanos	None

Table 3. P-values for ANOVAs using SPC survey data. P-values highlighted green are significant at α = 0.05; those highlighted orange are significant at α = 0.10. The ANOVAs for total fish abundance compared total fish density between survey sites for each of the three habitat factors. The other ANOVAS compared relative abundance of each species (species density/total fish density). Note that manini = *Acanthurus triostegus sandvicensis*, palani = *A. dussemieri*, Kala lōlō = *Naso brevirostris*, and Kala = *N. unicornis*; cover is short for biological cover and structure is short for geomorphological structure.

Factor	All Fishes	Manini	Palani	Kala lōlō	Kala
Cover	0.021	0.586	0.545	0.129	0.080
Structure	0.002	0.116	0.170	0.036	0.827
Depth	0.225	0.008	0.018	0.281	0.761

Table 4. Total area of manini (*Acanthurus triostegus sandvicensis*) habitat by habitat classification. Potential depths are all habitats with bathymetric data down to the deepest known distribution of manini in Hawaii (46 m). High abundance depths are habitats < 20 m; the relative abundance of manini in SPC surveys was significantly higher within this depth range. High abundance habitats are those with both biological cover type and geomorphological structure that supported average manini densities > 0.02 fish per m^2 in SPC surveys. Essential fish habitats for manini are the intersections of high abundance depths and high abundance habitats.

Habitat Range	Area (km^2)
Potential Depths	392.73
High Abundance Depths	279.98
High Abundance Habitats	98.59
Essential Fish Habitat	78.54