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Dawn J. Wright

In the face of recent declines in groundfish populations and lack of sufficient stock assessment information, a need has arisen for new methods of assessing groundfish populations. This project evaluates the integration of seafloor transect data gathered by manned submersible with high-resolution sonar imagery to produce a habitat-based stock assessment system for groundfish. The initial data sets are derived from 42 submersible dives made in 1988-1990 and an EM300 bathymetry/backscatter survey of Heceta Bank, Oregon in 1998. The submersible habitat survey investigated seafloor morphology and groundfish abundance along 30 minute transects over six predetermined stations and found a statistical relationship between habitat variability and groundfish distribution and abundance. These transects have been analyzed in a geographic information system (GIS) using dynamic segmentation to display changes in habitat along the transects. The initial phase of the project uses the submersible data in an attempt to extrapolate fish abundance within uniform habitat patches over broader areas of the bank using a classification based on the imagery. Ultimately, such approaches will allow researchers to characterize marine communities over large areas of the seafloor - a major methodological breakthrough for fisheries management and conservation.

Integration of Submersible Transect Data and High-Resolution Sonar Imagery for a Habitat-Based Groundfish Assessment of Heceta Bank, Oregon

by

Nicole M. Nasby

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Committee in Charge:
Dawn J. Wright, Chair
A. Jon Kimerling, Member
Robert W. Embley, Member
Mark A. Hixon, Member

Master of Science research report of Nicole M. Nasby presented on May 18, 2000

APPROVED:

____

Major Professor, representing Marine Resource Management

____

Minor Professor, representing Earth Information Science and Technology

____

Chair of the College of Oceanic and Atmospheric Sciences

____

Dean of Graduate School

I understand that my research report will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Nicole M. Nasby, Author

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INTRODUCTION

Dramatic declines in several groundfish populations have occurred along the U.S. West Coast during the last decade (PFMC 1999, Sampson 1997, Ralston 1998, Bloeser 1999). One problem exacerbating these declines is insufficient stock assessments, especially for species of west coast rockfish (Family Scorpaenidae, Genus *Sebastes)* which comprise the core of the Pacific Coast groundfish fishery. Although evidence has accumulated for substantial declines in the abundance of several species of rockfish, the overall picture is unclear since 78% of rockfish species have never been assessed (Ralston 1998, Bloeser 1999, NMFS 1999). In the 1999 report to Congress by the National Marine Fisheries Service on the status of overfished stocks in the United States, only 12 of the 54 rockfish species managed by the Pacific Fisheries Management Council (PFMC), had been assessed (Table 1). Of those 12 species, five were listed as "overfished" and one species was listed as "approaching overfished condition". For the remaining 42 species of rockfish the status was listed as unknown. The primary reason for this uncertainty in status is the lack of demographic information for these species, which is necessary for stock assessment modeling equations (NRC 1998).

A possible alternative to single species stock assessments of benthic rockfish is a habitat-based community assessment, which serves to assess groundfish populations by recognizing that distinct species are distributed among varying habitats. Previous studies have shown the importance of diversity, quality, and extent of bottom habitats in determining distribution, abundance, and diversity of rockfishes (Carlson and Straty 1981, Pearcy et al. 1989, Carr 1991, Stein et al. 1992). It has been previously demonstrated, within small study areas, that distribution and abundance of rockfish and other groundfish correlate to seafloor texture (Hallacher and Roberts 1985, Richards 1986, Hixon et al. 1991, Love et al. 1991, Hixon and Tissot 1992, Stein et al. 1992, Krieger 1993). However, correlations over larger areas have been difficult due to limitations in the resolution of bathymetric survey maps. This is no longer the case due to the advent of differential GPS and high-resolution sonar systems (Hughes Clarke et al. 1996). These new systems provide bathymetric and backscatter data with sufficient resolution to formulate habitat classifications over broad areas of the continental shelf and slope. Sonar data can be applied in an assessment of seafloor habitat and fish density over large areas by extrapolating from direct samples of fish-habitat associations.

This habitat-based assessment strategy was utilized on Heceta Bank, Oregon, by combining a comprehensive historical submersible survey and new high-resolution sonar images. The biological and geological morphology observations made in the submersible survey served as groundtruthing for the backscatter and bathymetry data from the sonar images. The merging of these two data sets allowed for extrapolations of habitat and fish abundance for larger portions of the bank.

This new technique recognizes the importance of habitat classifications in management strategies as evidenced by the inclusion of Essential Fish Habitat and Habitat Areas of Particular Concern mandates in the revised Magnuson-Stevens Fishery Conservation Act (Langton 1996, NMFS 1996). Ultimately, this approach could be beneficial not only for fisheries assessment and management, but also could be utilized as a tool for the establishment and management of marine reserves and protected areas.

BACKGROUND

Heceta Bank, a 50 km long shoal on the outer shelf of central Oregon (Figure 1), is the largest rocky reef of the Pacific Northwest. The seafloor morphology of this area is characterized by a high frequency of variation in bottom types and textures and provides a specialized habitat for many species of groundfish and invertebrates. This characteristic has helped to make Heceta Bank one of the largest and most important of the heavily fished rocky banks on the outer continental shelf of Oregon.

Prior to 1987 very little was known about the distribution and abundance of fishes along Heceta Bank. The only data available were from surfaced based-sampling gear utilizing bottom trawls equipped with roller gear in low relief areas (Gunderson and Sample 1980; Barss et al. 1982; Dark et al. 1983; Broeder and Pearcy 1984; Weinberg et al. 1984). Barss et al. (1982) attempted to analyze and associate trawl catches with the seafloor morphology through the classification of “rough” or “smooth” terrain. The “rough” terrain in this study, however, was still trawlable and relatively low relief. This method did not provide data from the high variety of bottom types present on the bank, and thus presented a relatively limited view of the correlation between fish abundance and bottom type for Heceta Bank.

It wasn’t until 1987 that the first non-surface based study was performed using 16 submersible dives to characterize fish populations and habitats on

Heceta Bank (Pearcy et al. 1989). Following this initial exploration, a more extensive study was performed using the manned research submersible *Delta* for surveys in 1988, 1989 and 1990 (Hixon et al. 1991, Stein et al. 1992). The objective of these surveys was to investigate relationships between the abundance of groundfish and macroinvertebrates and the morphology and texture of the seafloor, as well as to test for interannual variation in these relationships. The fish observed during this study fell into a total of 69 taxa, representing 24 families, dominated by 24 species of rockfish. Multivariate analysis detected statistical relationships between habitat characteristics and fish distribution and abundance by species. This extensive study provided unparalleled data on fish-habitat associations in this region and became a baseline for future analysis.

Although invaluable, data from this set of submersible dives provides only small, detailed, “snapshots” of limited areas of the bank. A 1998 survey using a hull mounted, EM300 digital multibeam sonar, provides high resolution bathymetry and backscatter imagery over Heceta Bank. Over the past several decades, both sidescan and multibeam sonar have proven to be a useful method for examining variations in seafloor habitat (Able et al. 1987, Greene et al 1995, Yoklavich et al. 1995). Multibeam sonar is a technology used to visualize seafloor bathymetry by utilizing echo-sounding principles to listen for the reflection of the surface of the seafloor. It remotely “sees” the variations in the seafloor by generating a short pulse of sound and then listening for the echo of the pulse from the bottom. Upon striking a portion of the ocean floor, the sound wave illuminates or ensonifies that segment of the bottom. Sonar images produce invaluable data by using acoustic signals to differentiate areas of hard substrata from surrounding soft sediments based on differences in the intensity of reflected sound. This technology allows the distinct advantage of examining seafloor sediment and geological morphology features without resorting to expensive bottom sampling and direct observation techniques.

MATERIALS AND METHODS

Submersible Dives

The comprehensive submersible observation data were collected using the manned submersible *Delta* on six predetermined stations along Heceta Bank (Hixon et al. 1991, Stein et al. 1992). Dives were performed in 1988, 1989 and 1990 during the month of September. There were 18 dives in 1988, 12 in 1989, and 12 in 1990, for a total of 42 dives and 84 transects (Figure 2). Each dive consisted of two 30 minute timed transects with a 10 minute rest period between transects. The average approximate length of each 30 minute transect was 1015 m. Data were collected via direct observations through a view port from approximately 2 m above the bottom, with a transect width of about 2.3 m. During the transects, observations were verbally tape-recorded and visually recorded by standard VHS videotape with timed data logger and audio track.

Direct and video-taped observations along the transects included fish, macroinvertebrate, and bottom type characterizations. All fishes along the transects were identified, counted and lengths were estimated to the nearest decimeter using a four-decimeter fiberglass rod suspended within the observer's view. Bottom type was categorized from videotapes using a two-code combination, the first letter indicating the primary substratum and the second letter indicating the secondary substratum. The seven possible categories in order of increasing particle size or relief were mud (M), sand (S), pebble (P, diameter <6.5cm), cobble (C, >6.5 and

<25.5 cm), boulder (B, >25.5 cm), continuous flat rock (F, low vertical relief), and diagonal rock ridge (R, high vertical relief) (Figure 3). Substrate was noted as “primary” if it covered at least 50% of the area view and “secondary” if it covered more than 20% of the area viewed. If the field of view was purely a single substratum, or the second most abundant substratum covered less than 20% of the field, the same letter was employed twice (e.g. MM).

The latitude and longitude positions of each transect were made with Loran-C using a Trackpoint II system and positioning the vessel directly above the submersible every 10 to 15 minutes. At least three position points were made per transect and the locations of bottom type and biological data were interpolated between these points. Under normal conditions, the absolute accuracy of positions using Loran-C were within about 150 to 500 m (Melton 1986). Sea-going navigation today is more precise due to the use of differential global positioning system (DGPS) which has a positioning accuracy of 1 - 2 m (Hughes Clarke et al. 1996).

Multibeam Sonar

A survey of Heceta Bank was conducted in May of 1998 using an EM300 (30kHz) multibeam/backscatter sonar system (Merle et al. 1998). This survey provides a highly detailed, precisely navigated seafloor map of bathymetry and seafloor texture (Figures 2 and 4). The survey consisted of 47 overlapping north-south swaths up to 45 km long which imaged approximately

725 km^2 of seafloor and obtained nearly 100% coverage of high-resolution bathymetry and backscatter amplitude. These data can be usefully gridded to less than 5 meters on the shallowest portions of the bank from depths of 70 to 150 meters, and to about 5 to 10 meters at depths down to about 500 meters, and provide highly detailed geologic information. In the bathymetric image structures such as “megajoints” and small faults are distinguished in many places (Figure 4b) and the backscatter data clearly show variations in sediment cover superimposed on the underling structures (Figure 4c).

The data were processed using John Hughes Clark’s SWATHED program (Ocean Mapping Group, Univ. New Brunswick). SWATHED is a graphical tool for editing swaths of multibeam data. Data processing steps included: navigation cleaning, swathed (sounding cleaning and tide correction), fix roll bias and refraction problems, set up map sheets, grid the bathymetry, and mosaic the multibeam data.

Data Integration and Habitat Assessment

Dynamic Segmentation

The sonar and submersible transect data were combined using ArcView and Arc/Info geographic information system (GIS) software (Environmental Systems Research Institute, Inc, Redlands, CA). In order to represent the dive transects in GIS as linear features displaying changes in habitat and fish density, the dynamic segmentation data structure was required (ESRI 1994). The problem of representing complex linear geographic features (particularly single arcs with a multitude of attributes) for marine uses such as coastlines, navigation and transects is best resolved through the use of dynamic segmentation. This concept was originally developed for the transportation industry and has only recently been applied in other disciplines, including marine applications. Cowie (1997), Vanzwol (1995) and the California Department of Fish and Game (1996) have made extensive use of the technique for data related to streams and rivers, and Wong et al. (1995) describe the use of dynamic segmentation for the management and analysis of marine geoscience data. The challenge in representing linear transects stems from the fact that navigation tracklines are best represented as a linear feature rather than as individual points, but the start-to-end continuity of a navigation trackline attributes are lost if the navigation is assembled as a simple line coverage.

Dynamic segmentation is a data structure used for modeling and analyzing linear features. It allows for the association of multiple sets of attributes along any portion of a linear feature. There are three specific cases where dynamic segmentation is most useful. The first is linear features containing one-too-many relationships, such as three bus routes along the same street. The second is when using a linear system of measure to denote precise locations, such as knowing how many miles it is to each turn off or road sign on a state highway. The third is when features contain segmented data. This is the case that applies to the use of transects in the Heceta Bank habitat assessment.

The submersible transects are linear features containing segmented data with bottom type and fish density attributes that change frequently.

The dynamic segmentation data structure is based on route systems and uses data files called event tables to store segmented data for linear features. Event tables contain records called events which identify and describe a particular location along a linear feature. Event records, comprised of a route identifier, measure values from the starting point of the line, and containing one or more attributes describing the location. For example, an event table describing habitat may contain a route identifier of 2090, a "to" measure of 30, and an attribute of '"rock ridge". This means that the bottom type on submersible dive #2090 is rock ridge between the measures of 0 m and 30 m along the transect (Figure 5).

Because events reference routes and measure locations along the routes, they can be edited and maintained independently of coverage topology. Data for linear features can be stored in many different event tables. For example, there may be event tables for bottom type, fish species, and invertebrate species, where each reference the same dive transect.

GIS Procedures

Positional data for the *Delta* submersible dive transects were entered from the original log book, noting latitude, longitude, time, depth and dive number. Transect positions for dives from all three years were added to ArcView in the form of tab-delimited text tables and converted to shapefile points. They were

made into shapefile lines using the Environmental Systems Research Institute (ESRI) script GPS2Shape. These shapefiles were then converted to coverages in Arc/Info using the command SHAPEARC, and projected to a geographic projection using the command PROJECTDEFINE. The coverages from each year were then combined in Arc/Info using the command APPEND. This was performed for both the point and line data. The line coverages were then overlain onto the sonar bathymetry data in ERDAS Imagine (Figure 2).

For the dynamic segmentation process, the appended line coverages were projected to UTM coordinates using the Arc/Info command PROJECT. This was done in order to change the units to meters, and was necessary in order to link the habitat classifications with the “to and from” measure system of the event table. The next step was to make the line coverage into a route-system in ArcEdit. First the edit feature was set to the line coverage. The command SELECT PATH was used to designate directionality by indicating the start and end point of the route. The command MAKEROUTE was then used to designate the route-system. This created a route attribute table (RAT) and section attribute table (SEC). Route systems were designated delta88, delta89, and delta90 according to the survey year. The SELECT PATH and MAKEROUTE steps were performed for each transect.

Fish density was calculated along each segment of habitat type using the observation data for species observed in the highest density, accounting for 90% of the total, plus a few rare species of commercial importance (i.e., lingcod, sablefish, dover sole and rex sole) (Figure 6). Those species assessed were:

juvenile *Sebastes* sp. (unknown juvenile rockfish), *Sebastes elongatus* (greenstriped rockfish), *Sebastes wilsoni* (pygmy rockfish), *Sebastes helvomaculatus* (rosethorn rockfish), *Sebastes zacentrus* (sharpchin rockfish), *Sebastes flavidus* (yellowtail rockfish), *Ophiodon elongatus* (lingcod), *Sebastolobus alascanus* (shortspine thornyhead), *Anoplopoma fimbria* (sablefish), *Microstomus pacificus* (dover sole) and *Glyptocephalus zachirus* (rex sole). The density in fish per meter squared was calculated by taking the number of fish sighted in that habitat segment, dividing by the length of the habitat segment and then dividing by 2.3 for the width of the transect.

The event table was created as a dBASE IV file with the following features: ID, to, habitat, route-id#, transect number, and fish per meter squared for each species. The route-id# is an internal number assigned within the RAT for each transect when the route was created. The dBASE table was converted to an INFO file using the Arc command DBASEINFO. The event table was then prepared using the commands EVENTSOURCE (syntax: EVENTSOURCE ADD CONTINUOUS <source_name> <table_name> {database} {relate_type} {route_key_item} {event_key_item} {measure_item}), followed by the command EVENTSAVE. A coverage was then created combining the route-system and event table using the command EVENTARC (syntax: EVENTARC <in_cover> <in_route_system> <event_source> <out_cover>) followed with the BUILD command to rebuild the coverage topology. The segmented line could then be viewed in ArcView displaying either the habitat or the fish density as the unique classification value.

The segmented transects were integrated with the sonar data in ArcView. The sonar image was imported as an ERDAS .img file into ArcInfo using the command IMAGEGRID, and then added to ArcView as a grid data source. In combining the sonar and submersible data sets, all segmented dive transect data were reprojected with a 500-meter offset to the east. This was performed in Arc/Info by using the commands PROJECT and XSHIFT. This was determined to be the best correction for discrepancies between the Loran-C and GPS positions by comparing the two data sets and matching borders of well-defined habitat, specifically along the mud or rock features of the bank. It appeared that using a 500-meter shift to the east for the submersible transects gave a very close match of the two data sets, but it was unclear whether there was a north-south shift present as well. ArcView layouts were created to show changes in bottom type on backscatter (Figure 7) and bathymetry data (Figure 8) and density of fish along the transects with bathymetry data (Figures 9 – 20).

Habitat Assessment

Extrapolations of bottom type and fish density data were performed by selecting patches of relative habitat homogeneity around each area where transects were performed (Figure 20). These patches were chosen by looking at patterns in the backscatter values and seafloor morphology features using the backscatter and bathymetry data. In areas of mud (low backscatter) off the bank, borders were chosen by maintaining constant depth as well as equal distance from the bank. In selecting patches to represent areas of similar habitat, the

boundaries were relatively well defined in areas of rock and mud, but for mixtures of sand, cobble, pebble and boulder it was more difficult to draw distinct boundaries. Overall, habitat patch borders were drawn conservatively and only areas adjacent to the submersible transects were used for habitat extrapolation.

Habitat patches were created by adding a new theme in ArcView and using the interactive polygon tool to draw a polygon around areas of relative homogeneous bottom type adjacent to the transects. These polygons were made into coverages in Arc using the command SHAPEARC, followed by the command BUILD and then projected into UTM coordinates using the command PROJECTDEFINE. The area of each patch was determined by looking at the polygon attribute table (PAT) in ArcInfo.

Using the observation data from the transects from all three years, each habitat patch was characterized by percent bottom type, density of fish and estimated abundance of fish as determined by the dive transect observation data contained within that patch. The grand mean density and standard error for each species was determined by using a weighted density for each habitat segment based on a proportion of the length of that segment to the overall transect distance within that habitat patch. This utilized the associations of the fish species with substrate type and weighted its contribution to the overall density by the comparative length of that segment. The grand mean density was calculated as:

$$\overline{x} = \sum_{i=1}^{n} d_i \, p_i$$

where:

d = density of fish within a segment of continuous bottom type
p = bottom type segment length / total transect length within the patch

Fish abundance for each habitat patch was determined by multiplying the area of the patch and the grand mean density and standard error of each species.

RESULTS

In this study it was determined that bottom type features were distinguishable within the sonar imagery and that there was a high correlation between the submersible observations and the sonar data. Side-lit bathymetry data gave an indication of habitat features by highlighting large areas of rock and high relief. The backscatter data gave a strong indication of changes in habitat substrate type and larger scale changes in backscatter matched changes observed in bottom type from the submersible data. The relationship between sea floor relief and backscatter, observed from the sonar imagery, was not necessarily defined by higher backscatter reflectivity with increasing relief. Rock ridge sections of the bank were detected as mid-backscatter values and the mixture of boulder-cobble-pebble substrate was found in the high-backscatter range. Mud bottoms were generally characterized by low reflectivity, except in areas such as the south edge of the bank, where higher backscatter values were most likely due to the presence of carbonate, which is known to have a higher reflectivity (Carson et al. 1994).

Combining the sonar derived habitat patches and submersible observations showed that, of the eight habitat patches that were defined and analyzed, three habitat patches were predominantly rock ridge, two were predominantly mud, and three were a boulder/cobble/pebble mixture (Figure 21).

Fishes with the highest association with rock ridge habitat patches were yellowtail

rockfish, juvenile rockfish, and lingcod, those primarily associated with mud habitats were dover sole, rex sole and shortspine thornyheads, and those found associated with mixed substrate patches were sharpchin rockfish, rosethorn rockfish, greenstriped rockfish and pygmy rockfish (Figure 22).

Using the grand mean and standard error of fish density along with the area of each patch, abundance of each species was estimated (Table 2). The fish found in the highest abundance overall were juvenile rockfish and pygmy rockfish, and those in the lowest abundance were lingcod and sablefish. The total area of all habitats assessed was 141 km^2 and the total number of estimated fish and standard error for that area was 156,598,000 ± 16,854,000. This consisted of approximately 2,747,000 ± 290,000 yellowtail rockfish, 143,000 ± 17,000 lingcod, 1,433,000 ± 87,000 shortspine thornyhead, 284,000 ± 34,000 sablefish, 1,445,000 ± 70,000 dover sole, and 440,000 ± 39,000 rex sole.

Of the groundfish species examined in this study using the 1988-1990 submersible observations, the status for these species was reported in the recent 1999 report to Congress for all but pygmy rockfish (NMFS 1999). In this report, only the lingcod was reported as "overfished". Yellowtail rockfish, shortspine thornyhead, sablefish, and dover sole were listed as "not approaching overfished", and for rex sole, greeenstriped rockfish, rosethorn rockfish and sharpchin rockfish the status was reported as "unknown" (NMFS 1999). The methodology outlined here may be an alternative method of assessing these and other groundfish species that are currently unassessed. Of the species that were analyzed in this study, one species that this technique may not be as effective for

Is yellowtail rockfish. Yellowtail rockfish have been shown to be found as high as 25-35 m off the bottom and abundance may not be accurately detectable from submersible surveys (Pearcy 1992).

DISCUSSION

This exploratory project is an example of how sonar and submersible data can be combined to perform habitat-based stock assessments of multiple species of groundfish. Ideally the best scenario would have been to gather the sonar data first, and use that detailed information to define patches of uniform bottom type for planning subsequent stratified random sampling and groundtruthing using submersible transects. However, despite this limitation, Hixon et al.'s (1991) study is one of only a few comprehensive habitat/groundfish studies and has provided an excellent data base for testing the effectiveness of a combined sonar and seafloor transect set in determining groundfish habitat.

There were several disadvantages to using historical data for this analysis. One problem was that of inconsistency in positional data due to the use of Loran-C in the submersible study. Another problem was limited spatial sampling provided by the survey. The stations for this study were chosen as representative habitats for Heceta Bank from a number of exploratory submersible dives conducted by Pearcy et al. (1989) in 1987. However, not all of the representative habitat areas were sampled since high-resolution bathymetric maps were not available at that time. Lack of complete habitat data made it difficult to extrapolate bottom type and fish density data to the entire bank.

This study provided an expanded view of the areas around the historical *Delta* transects, but in order to perform a full assessment it would be important to have habitat information on the entire extent of the bank. The sonar data have indicated areas on the bank that contain unique habitat that have not been surveyed. The next phase of this project will include submersible transects on unsurveyed areas as well as repeating the historical transect locations. Not only will this optimize the techniques developed in this project, but it may also give an indication of changes in fish density over the past decade.

Some of the limitations of this habitat-based approach to stock assessments are due to the geological assumptions of the sonar data. Habitat type can not be determined by bathymetry or backscatter data alone, but the information provided by both of these data sets, in addition to groundtruthing by direct sampling, can give a clearer picture of the overall habitat environment. Backscatter intensity can give an indication of bottom substrate, but values may vary due to underlying geological features, such as with the possible underlying carbonate off the south edge of the bank. Structural relief that can provide complex habitat for fish to hde may be detected through the bathymetry data. Statistical indices of local relief that can be derived directly from the bathymetric data have been proposed as a simple way to tie groundfish stocks to seafloor habitat (Fox et al. 1999). The addition of the backscatter data has the advantage of giving an indication of substrate type, which is an important microhabitat classification for fish association patterns. The combined sonar bathymetry/backscatter and submersible approach will be useful as a stock assessment tool for all of Heceta Bank once there is a better understanding of the habitats throughout the bank.

CONCLUSIONS

This preliminary work is a step toward creating a model approach for characterizing and quantifying groundfish and their habitat associations on a scale meaningful to the stock assessment of commercial species and conservation of benthic communities. It is undisputed that traditional stock assessment methods for groundfish have been inadequate. This study looks at methods for assessing stocks when there is a lack of adequate demographic information about specific groundfish species, which are important for many stock assessment models. Overall this habitat-based approach to stock assessment has particular usefulness for defining and mapping essential fish habitat, as well as for designing and managing marine reserves and protected areas.

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