PAPER

Recent Advances in Automated Genus-specific Marine Habitat Mapping Enabled by High-resolution Multibeam Bathymetry

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ABSTRACT

There is a great need for accurate, comprehensive maps of seafloor habitat for use in fish stock assessments, marine protected area design, and other resource management pursuits. Recent advances in acoustic remote sensing technology have made it possible to obtain high-resolution (meter to sub-meter) digital elevation models (DEMs) of seafloor bathymetry that can rival or surpass those available for the terrestrial environment. The acquisition and processing of these data are expensive, however, requiring specialized equipment, expertise, and large amounts of both field and laboratory effort per unit area mapped. Further, the interpretation and classification of these data into maps of habitat type is typically (and appropriately) performed only by trained experts that are familiar with both seafloor geomorphology and the nature and limitations of the data sources. Because it is done visually, this interpretation can be very time-consuming and may yield subjective results that are not comparable from site-to-site or between individual interpreters.

We applied an algorithmic terrain analysis approach to efficiently and objectively classify seafloor habitats using the quantifiable landscape metric Topographic Position Index (TPI). We used high-resolution multibeam bathymetry, together with precisely geolocated (± 5 m) ROV observations of fish distribution, to produce a preliminary genus-specific habitat suitability model for eight rockfish (*Sebastes*) species in the Del Monte shale beds of Monterey Bay, California. A high-resolution (2 m) multibeam bathymetry Digital Elevation Model (DEM) was generated and used to produce a derived TPI surface model using repeatable, algorithmic methods. This data layer, together with the positions and counts by species from 229 rockfish observations (2892 total fish) was then used to create preliminary predictive models of habitat suitability and fish distribution, as well as stock estimates for the study area. A second, independent fish observation data set was used to validate the models.

INTRODUCTION

There is a great need for accurate and efficient species-based identification and classification of marine habitats. Marine ecosystem health depends on the abundance and diversity of life within the ecosystem, as well as the quality of habitat associated with the area (Adams et al., 1995). Understanding the link between marine species and their habitats can help reveal ecosystem dynamics affecting both large- and small-scale patterns of species distribution and abundance.

Over the past several decades, marine resources have been declining, and many species have reached critically low levels (Starr, 1998, 2002; Mason, 1999). The National Marine Fisheries Service (NMFS) manages 61 of the 96 species of rockfish (genus *Sebastes*) found along the Pacific Coast from Washington to California. Of these species, 9 are currently listed as "over fished." Other species often caught as "bycatch" during the harvest of economically important species have also declined in both number and overall length of individuals (PFMC, 2004). Rockfish are particularly vulnerable to over fishing. Many species are long-lived, have low fecundity, and slow growth and maturation rates (Yoklavich et al., 2000, 2002). Unlike most fish, rockfish tend to reproduce at greater rates with increased age (Love et al., 2002). For these reasons, increased fishing pressure has resulted in tremendous declines of many rockfish species, and has put the entire rockfish fishery in peril of permanent collapse. With fewer fish of reproductive age living within the population, fish are unable to produce enough offspring to maintain sustainable levels, where sustainable levels are defined as being greater than 25% of the stock which would have existed without fishing pressure (PFMC, 2004). Creating effective management strategies to rebuild declining rockfish populations and maintain sustainable fisheries requires accurate estimates of current stock levels.

In order to determine the effects of fishing pressure on fish growth and reproduction, the Magnuson-Stevens "Sustainable Fisheries" Act of 1996 mandated both state and federal management agencies to designate "Essential Fish Habitat," areas where fish spawn, breed, mature and feed. In 1998, the Pacific Fisheries Management Council (PFMC) under direction from NMFS, identified the entire United States Exclusive Economic Zone (EEZ) of the west coast, which extends 200 miles out from the coastline, as Essential Fish Habitat. In an effort to produce more accurate, species-specific estimates of EFH, PFMC and NMFS prepared an environmental impact statement for Pacific Coast rockfish, which identified Habitat Areas of Particular Concern (HAPC) within areas designated as EFH (PFMC, 2004). In addition, a coast-wide GIS integrating data from various sources has helped to determine the location and extent of both HAPC and EFH along the Pacific Coast of the continental US. Delineating areas where fish live and reproduce is a fundamental step in evaluating stock size and health.

Estimating species abundance and distribution is difficult in the marine environment (Adams et al., 1995; Starr et al., 1996; Cailliet et al., 1999; Yoklavich et al., 2000; Brown et al., 2002). Landscape ecologists rely on habitat-species interactions in both marine and terrestrial environments to quantify and describe numbers and assemblages of species within a region (Austin et al., 1996; Riley et al., 1999; Freeman and Rogers, 2003). Thus, the association between species and habitat is a key factor used in habitat mapping (Ornellas et al., 1998; Greene et al., 1999; García-Charton and Pérez-Ruzafa, 2001; Nasby-Lucas et al., 2002; Urbanski and Szymelfenig, 2003). Many studies rely on remotely sensed data at very coarse resolutions (tens to hundreds of meters), which may tend to blur or obscure particular species' habitat-use patterns. Fine-scale studies of species-habitat associations are very rare, and may provide invaluable insight into ecological processes of distribution and abundance. Rockfish, like many marine organisms, have particularly strong species-habitat associations. Rockfish are typically associated with complex, high-relief rocky substrates, and are often found near rocky outcrops, pinnacles, boulders and artificial structures with high vertical profiles, such as offshore oil rigs (Haldorson and Love, 1991; Love et al.,1991, 1996, 2002; Casselle et al., 2002; Helvey, 2002).

Given the difficulties of estimating species abundance and distribution, and given the close association marine species have with their habitat (O'Connell et al., 1998; Urbanski and Szymelfenig, 2003), surveys of benthic geomorphology are a cost-effective and efficient method of generating habitat maps (Whitmire, 2003). Multibeam bathymetric surveys can provide 100% areal coverage at sub-meter resolution, and depending on the particular system used, are capable of high resolution mapping of both shallow (1m) and deep (1000m+) environments (Mayer et al., 1997). Multibeam data can be used to create digital elevation models (DEMs), or 3D surface models of the seafloor, which can be analyzed with a variety of geospatial analysis methods.

Traditionally, trained experts that are familiar with both seafloor geomorphology and the nature and limitations of the data sources have generally performed the interpretation and classification of these data into maps of habitat type. Because it is typically done by visual means, this interpretation can be very time-consuming and may yield subjective results that are not comparable from site to site or between individual interpreters. Recent advances in geographic information system (GIS)-based algorithmic analysis of DEM and derived data products show great promise for use in classifying marine habitats. The purpose of this study is to use an algorithmic terrain analysis approach to efficiently, non-subjectively classify seafloor habitat suitability according to Topographic Position Index (TPI). Our aim was to test GIS modeling tools that can be applied to multibeam bathymetry data to predict the distribution of particular species, given species-specific habitat association parameters.

Methods

General Approach

We used high-resolution multibeam bathymetry, together with precisely geolocated (± 5 m) ROV observations of fish distribution, to produce a genus-specific habitat suitability model for eight rockfish (*Sebastes*) species in the Del Monte shale beds of Monterey Bay, California, USA. A high-resolution (2 m) multibeam bathymetry digital elevation model was generated and used to derive a TPI surface model. Relying on correlation between rockfish distribution and complex, high-relief substrates, we used TPI to locate areas with these characteristics. Video data collected from a remotely operated vehicle (ROV) were used to determine actual rockfish abundance and distribution along linear strip transects within the multibeam survey area. The TPI surface model, together with the positions and counts by species from 229 rockfish observations (2892 total fish) were then used to assess habitat association(s) of rockfish relative to TPI landscape feature classes. This information was used to create a predictive model of habitat suitability and fish distribution, as well as stock estimates for the study area. A second, independent fish observation data set was used to validate the model.

The video data were also used to produce stock estimates by extrapolating the number of fish found along the transects over the entire survey area, stratified by habitat suitability.

Site Description

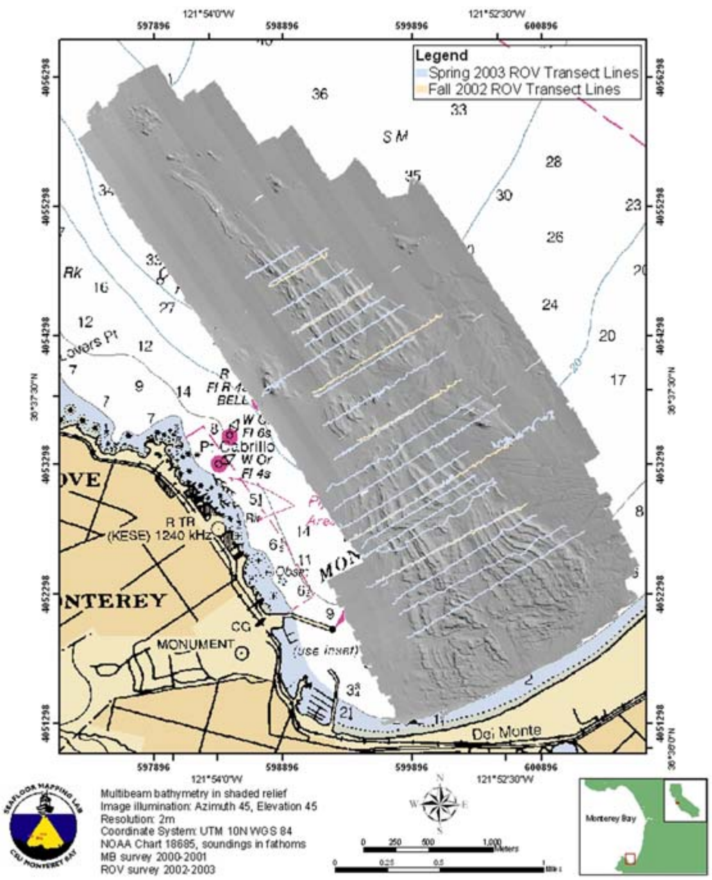
The Del Monte shale beds cover an area of approximately 9.5 km^2, located approximately a kilometer offshore from Monterey Harbor, Cannery Row and Del Monte beach in central California (Figure 1). The shale beds are a relatively low-relief environment, composed of Miocene Monterey Formation, distinguished by laminated semi-siliceous mudstone and sandy siltstone (Eittreim et al., 2002). The outcrop is characterized by long, linear ledges dipping down to the northeast, surrounded by unconsolidated sediment, ranging from 10 to 70 m in depth (Greene, 1990; Storlazzi and Field, 2000). The benthic invertebrate community is distinguished by the plumose anemone *Metridium senili*, and numerous species of sponges, cup corals, anemones, and sea stars. The site is home to over 20 species of rockfish (*Sebastes* spp.), several of which have been identified by the National Marine Fisheries Service (NMFS) as over-fished (PFMC, 2004). The area is open to recreational fishing, and for near shore areas such the shale beds, the recreational fishing harvest generally exceeds commercial harvest (Starr et al., 2002). Overall, the shale beds provide a wonderful opportunity to study the link between species and habitat; they are located near to shore and have a diversity of habitats.

Multibeam Bathymetry

Multibeam bathymetric data were collected by the Seafloor Mapping Lab at CSUMB (SFML), with a Reson 8101 Seabat multibeam sonar, which can map depths of 1 to nearly 300 meters. The 8101 operates at 240 kHz, capable of taking up to 3,000 soundings per second with a swath coverage of up to 7.4 times the water depth, and a swath angle of 150°. A Triton Elics, International Isis Sonar data acquisition system onboard the R/V *MacGinitie* simultaneously logged the multibeam data along with the position and attitude data generated by an

Figure 1

Del Monte shale bed multibeam bathymetry in shaded relief with ROV tracklines for Fall 2002 and Spring 2003 surveys. Tracklines have been buffered by 2.5 m on either side to create a 5 m corridor representing the visual area covered by the ROV during the surveys. Buffered transect areas were used in the evaluation of all habitat suitability models.



Applanix Position and Orientation System, Marine Vessel (POS-MV) for heave, pitch, roll and yaw corrections (with +/-0.02° accuracy); and Trimble 4700 GPS with differential corrections from the Trimble ProBeacon receiver (with +/- 1-2 m accuracy). An Applied Microsystems Limited (AML) SV+ sound velocity profiler recorded the speed of sound through the water column for use in correcting refraction errors. Multibeam survey data were then post-processed at SFML using Caris Hydrographic Information Processing System (HIPS) 5.2 software. Tide and SVP (sound velocity profile) corrections were applied, and the data were cleaned to remove erroneous soundings.

Multibeam bathymetric data for the shale beds were collected during three survey days in 2000 and 2001. After initial post-processing, the data from 2001 were reprocessed to correct a latency error produced from the shipboard Isis data acquisition computer at the time of the survey. The majority of artifacts were removed during rigorous QA/QC in order to ensure the most accurate landscape analysis results possible. A shoal-biased x,y,z (Easting, Northing, depth) file in UTM projection (Zone 10, WGS-1984) with 2 m resolution was exported from Caris HIPS, gridded (with no interpolation) and reviewed in Fledermaus 6.1, and exported as a 2 m digital elevation model (DEM) representing a three-dimensional surface model of the seafloor. This DEM, which was produced from cleaned, high-density, high-confidence bathymetric soundings using no interpolation, was imported into ArcGIS, and provided the data for all subsequent landscape analysis. Grayscale shaded-relief geotiffs with 2 m resolution were also exported from Caris HIPS and imported into GIS for visual interpretation of geomorphic features (Figure 1).

ROV Video Analysis

Geomorphology groundtruth and fish census data were collected using a Hyball remotely operated vehicle (ROV) deployed from the R/V *MacGinitie* during two surveys in fall 2002 and spring 2003. Transects were run perpendicular to the strike of the rocky outcrops, running NNE by SSW in order to best view the differentially eroded, under-cut shale ledges. Tracklines were spaced approximately 500 m apart and averaged 1 km in length (Figure 1). The ROV was flown at an average speed of 0.25 m/s, approximately 1-2 m from the bottom, with a forward and downward viewing angle of approximately 45°. Two parallel laser beams were mounted on the frame of the ROV spaced 20 cm apart to determine relative size of individual fish, relative distance from the bottom and visibility. The ROV paused for large fish aggregations to more accurately count and identify individuals, and at the base of large ledge features to pan from left to right to record any species-ledge interactions before continuing up and over these features. Video data from transect lines, or parts of transect lines, that did not run perpendicular to the strike of the ledges, were flown consistently above 2 m from the bottom, or where the ROV was dragged by the *MacGinitie*, were excluded from the project. Video from the ROV was captured with a JVC 470 line resolution, 0.95 lux color CCD video camera with an F 0.8 Pentax lens, and the data were recorded onto mini-DV tapes.

Positional data from the ROV were determined with a Trackpoint II+ ultra-short baseline acoustic tracking system (ORE International), with +/- 2 m accuracy (as determined by dockside testing at a variety of ranges and depths). ROV depth was recorded with a pressure sensor mounted on the vehicle. ROV position and depth information were recorded onto the videotape using a Horita GPS-3 encoder. ROV data were collected over 3 survey days in October and November 2002, and over 6 days in April and May 2003, and resulted in approximately 9.5 hours of useable ROV footage for the fall survey, and 32.2 hours for the spring survey.

The ROV transect navigation data were recorded and corrected using Hypack Max v. 2.12 software. The Trackpoint II system aboard the *MacGinitie* received response pings from the mobile beacon mounted on the ROV and generated distance and bearing offsets, which were supplied to the Hypack computer for use in generating real-world x,y,z coordinates for the ROV based on the GPS position of the *MacGinitie* (resulting in a combined ROV positional accuracy of ± 5 m). Occasionally, the acoustic tracking system would produce erroneous ROV positions, or fail to update ROV position when it had in fact moved. These positioning errors were corrected by post-processing the trackline data in the lab. Obvious incorrect positions (based on calculated velocity) were rejected and missing positions were interpolated where necessary. A 2.5 m buffer on either side of the corrected tracklines was applied to encompass the viewable area surveyed by the ROV. Area and distance were calculated for the tracklines to determine the amount of area surveyed. Buffered tracklines were used in subsequent landscape analysis of the bathymetric data, and for evaluation of model efficiency.

Video analysis was completed in the lab using a JVC BR-DV600 mini-DV digital VCR with monitor display. Tapes were reviewed and positional data retrieved using the Horita GPS-3 decoder. The latitude and longitude and UTM coordinates of individual fish observations were recorded in a text file, and species identification, abundance, depth, substrate classification and important features were recorded on log sheets. Individual fish that the observer was unable to identify to species, and all juvenile rockfish, were excluded from the study (but will be considered in subsequent work). Substrate classification was visually assessed from the video footage based on percent cover of primary and secondary substrates, with the primary substrate covering over 50% of the viewable area. Substrate classes were divided into 6 categories: sand, cobbles (rock fragments < 0.25 m), rubble (rock fragments greater than 0.25 m, and less than 0.5 m in size), boulder (individual rocks greater than 0.5 m in size), small ledges (height < 0. 5 m) and ledges (height > 0.5 m). This visual substrate classification was accomplished using the paired lasers as well as the depth and other telemetry information from the ROV, and was used for verification and groundtruthing of the multibeam DEM and its derived products, but was not directly employed in developing the habitat suitability models.

Discrete fish observations were made at a minimum distance of 5 m apart. That is, a single fish or group of fish was considered a discrete and separate observation if it was separated by other fish by at least 5 m. Fish encountered closer together than 5 m were considered a single group of fish. This 5 m distance cutoff was used due to limitations of visibility, positioning accuracy/precision, and our inability to separately mark the position of every single fish. The precise location of single fish observations was determined by recording the position of the ROV as it occupied the spot where the fish was initially observed. Observations of groups of individuals and large schools were determined by recording the position of the ROV at the center of the group or school. Individuals were identified to species when in visual range (≤5 m).

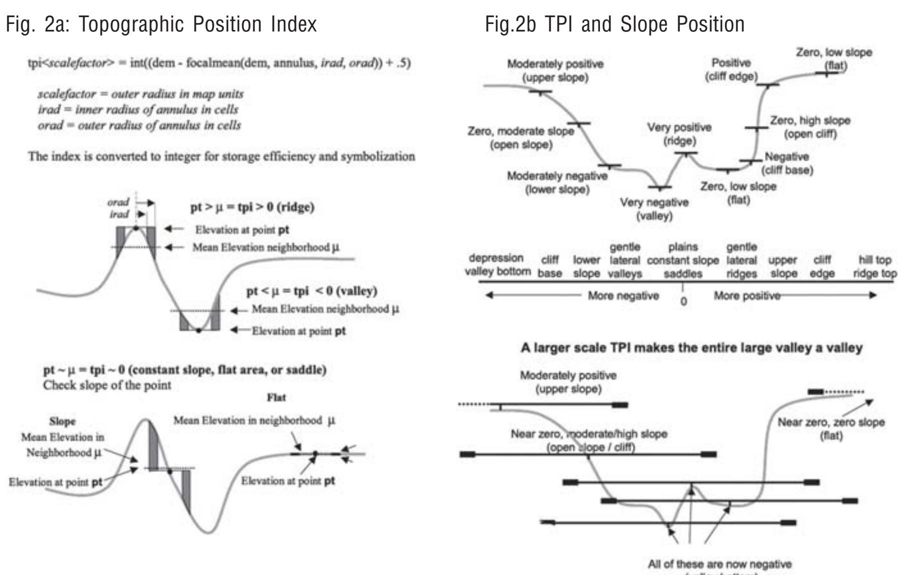
Information from the log sheets and text files were integrated into a database, then imported into GIS as a point data layer, with an attribute table which included the parameters logged during video analysis. Spatial analysis of the video data was done in ArcGIS 8.3.

GIS Analysis

Analysis of the multibeam data was done using ESRI ArcGIS 8.3 and ArcView 3.2. The use of GIS allows large geospatial datasets to be manipulated and analyzed together, and combines the use of various spatial analysis tools for a detailed study of landscape features. Given potential rockfish association with complex and/or high-relief substrate, a relative topographic position surface model was generated from the DEM in order to visualize and quantify areas of relative high complexity and relief. Although the multibeam bathymetry DEM extended both shallower and deeper, the GIS analysis and creation of suitability models was constrained to the depth range of the useable ROV transect data (15 – 65 m).

Figure 2

Schematic depiction of TPI calculation. Brown/Gray line represents a hypothetical cross-section view of a DEM, with cases illustrated showing TPI calculation of various feature types (peak, valley, etc.).
(a) Positive TPI values represent locations that are higher (ridges) than the average of their surroundings, as defined by their neighborhood. Negative TPI values represent locations that are lower than their surroundings (valleys). TPI values near zero are either flat areas (where the slope is near zero) or areas of constant slope (where the slope of the point is significantly greater than zero). (b) Landscape features of a variety of sizes and scales can be classified by adjusting the neighborhood size (TPI scale) of the analysis (Weiss, 2001)



Topographic Position Index

Topographic Position Index (TPI) is a measure of where a location is in the overall landscape (TPI in the marine context is also sometimes called BPI, or Bathymetric Position Index; but as it involves a general algorithm with applications for both terrestrial and marine landscape analysis, the less-specific term TPI will be used in this document). That is, in relative terms, the topographic position of a place may be a hilltop, or a valley bottom, or a slope, or an exposed ridge, or a flat plain, or another feature. TPI can be calculated for each cell in a DEM grid by comparing the elevation of the cell to the mean elevation of the surrounding cells in an annulus, or ring, around the cell (Figure 2). Locations that are higher than their surroundings (at the scale specified) will have positive TPI values, while those that are lower will have negative values. Flat areas, as well as areas of constant slope, result in zero or near-zero TPI values. These two cases can then be distinguished based on slope.

TPI is entirely scale-dependent; by adjusting the inner and outer radius of the annulus of cells, features of different scales can be delineated. Thus, TPI can be used to find fine-scale features in a DEM such as crevices and pinnacle tops, or on a broader scale to find slope breaks, canyon axes and walls, abyssal plains, and the like.

The TPI algorithm used in this study is adapted from Weiss, 2001 (poster presented at ESRI User Conference, from which Figure 2 is borrowed).

TPI calculation is done using the formula:

tpi<*scalefacto*r> = int((dem - focalmean(dem, annulus, *ira*d, *ora*d)) + 0.5)

where

scalefactor = outer radius in map units
irad = inner radius of annulus in cells
orad = outer radius of annulus in cells

The initial result of this raster algebra equation is a new raster layer with the same resolution as the original DEM, in which each cell holds a value of *relative* rather than *absolute* elevation; that is, the "raw" TPI cell values in the resulting raster are the differences (positive or negative) between the original DEM elevations and the mean elevation of the surrounding cells at the scale factor specified (expressed as an integer to reduce computation and storage costs). The overall range of the raw TPI values is somewhat dependent upon the original DEM dataset and scale factor, but will generally be somewhat normally distributed and include both negative and positive numbers. It is generally most useful to reclassify the raw TPI values in order to standardize the results and distinguish truly flat areas from those with uniform slopes (both of which have raw TPI values near zero). A standard deviation classification scheme is commonly used, with ½ standard deviation (SD) class breaks above and below the mean:

Class Description	Breakpoints
6 ridge	> +1 SD
5 upper slope	> +0.5 SD, =< +1 SD
4 middle slope	> -0.5 SD, =< +0.5 SD, slope > 5 deg
3 flat	> -0.5 SD, =< +0.5 SD, slope <= 5 deg
2 lower slope	> -1.0 SD, =< -0.5 SD
1 valley	=< -1.0 SD

Those cells with raw TPI values between ± ½ standard deviation of the mean are either assigned to class 3 ("flat") if the slope (calculated from the original DEM) at the corresponding location is less than or equal to five degrees, or class 4 ("middle slope") if the slope is greater than five degrees. Thus, six classes are created, delineating features ranging from valleys/depressions, through slopes and flats, to peaks/ridges. Because the algorithm can be performed using any desired scale factor, features of various sizes can be classified, from small boulder/reefs/crevices, up to continental shelf breaks and canyons, with the only limiting factor being the original DEM resolution. Features classified at various scales can then be nested (i.e. "peaks in flats" may represent reefs delineated using a TPI_{50} that are found within sand flats derived using a broader scale such as TPI_{250}) in an attempt to represent the fractal nature of geomorphology and a range of habitat scales. For this study, TPI surfaces with neighborhood sizes of 10, 20, 30, 40, 50, 60, 80, 100, 120 and 150 m were generated using the 2m DEM. Each TPI scale factor result was visually compared to the grayscale geotiff in GIS to assess accuracy of geomorphic feature definition. Substrate data collected during ROV video analysis was also compared to each TPI surface for further accuracy assessment.

Habitat Utilization Analysis

The degree to which a resource is used by a species relative to the abundance of that resource in the environment can be used as a measure of "association", or whether the species is a generalist or specialist regarding the resources in question. If a species tends to utilize a resource type a high percentage of the time, despite that resource type being rare in the environment, it can be said to be associated with that resource type (Krebs, 1989). On the other hand, if a species uses the different resource types available in proportion to their availability, then there is no association with any particular resource type. We used Manly's alpha (Manly et al., 1972) to assess whether the 8 *Sebastes* species in our study associated with (or avoided) landscape features delineated by the TPI surface derived from the multibeam DEM. The percent occurrence of each species within each TPI class was used, together with the abundance of those classes within the transect areas, to calculate alpha for each species/TPI class combination.

Habitat Suitability Model

A preliminary habitat suitability model was designed to predict areas of high rockfish density. This simple model incorporated only TPI as a single-factor. Spring ROV video data were used to create and refine the habitat suitability model, and Fall ROV video data were used to evaluate the predictive ability of the model.

Stock Estimates

Stock estimates were created using the video analysis data, transformed into density calculations of fish per unit area projected over the multibeam survey area. Density calculations were stratified by suitability category for the model, taking number of fish per transect area found in each category. This number was multiplied by the total amount of area within the multibeam survey area with the same suitability category. The formula for the stock estimates *for each suitability category* was: (number of fish (by species)/transect area) x total survey area.

Results

ROV Video Analysis

The ROV Video data were collected in fall 2002 and spring 2003. ROV survey trackline distance totaled 10,494 m over 6 transects during the fall survey, and 48,662 m over 21 transects during the spring survey (Figure 1). The database generated from the fall survey included a total of 730 individual rockfish identified to species; the spring survey included 2892 individuals. Eight species were included in the study: *Sebastes mystinus* (blue rockfish), *S. serranoides/S. flavidus* (olive/yellowtail rockfish), *S. miniatus* (vermilion rockfish), *S. auriculatus* (brown rockfish), *S. carnatus* (gopher rockfish), *S. pinniger* (canary rockfish), *S. rosaceus* (rosy rockfish), and *S. rubrivinctus* (flag rockfish). There were 4 other rockfish species identified during the analysis, but they each accounted for less than 0.5% of the total number of fish, so these species were excluded from the study.

GIS Analysis

Visual analysis of the ROV data in relation to the geomorphology of the reef suggested there was a strong relationship between fish distribution and abundance, and local-relief and complexity along the shale beds (Figure 3). Indeed, as suggested by the rockfish natural history literature and true to their common name, most *Sebastes* species tend to inhabit rocky outcrops and reefs, and are associated with high relief habitat (Haldorson and Love, 1991; Love et al., 1991, 1996, 2002; Casselle et al., 2002; Helvey, 2002).

However, the shale beds comprise a relatively low-relief environment, containing features generally less than 2 m in vertical relief. Even though the 2 m resolution of the DEM, and thus the derived TPI surface, would normally be considered very high-resolution bathymetric data, this proved to be a confounding factor in the landscape analysis of this area. With a resolution of the same magnitude as the maximum vertical relief, some features were not delineated as clearly as might have been expected from visual analysis of the video imagery.

Topographic Position Index (TPI)

Multiple TPI grids with neighborhoods ranging from 10 to 150 m were generated and compared to the shaded relief geotiff image, substrate and fish data collected during the ROV surveys. After analysis, TPI_{50} was determined to be the optimal neighborhood size, best matching both the observational data and geomorphic features (Figure 4).

Although the TPI algorithm was very effective at classifying relative topographic position, it was susceptible to edge effects and artifacts in the DEM. For example, the nearshore edge of the DEM tended to be classified as a "peak," or a high area relative to its neighbors. The lack of neighbors to the shoreward side caused this misclassification. As this area was not actually a relative high, but was found on the upslope edge of the dataset, a 50 m buffer was created around the edges of the TPI_{50} grid. Data within the 50 m buffer were excluded from all subsequent calculations. Residual artifacts in the DEM from overlap in the multibeam data were also often erroneously classified as "peaks." Multibeam surveys are designed as a series of parallel swaths covering the seafloor, which incorporate some degree of overlap in the data coverage. Sounding data collected on the outer edge of each swath can sometimes appear to be artificially elevated (or depressed) due to inadequate sound velocity correction or motion latency artifacts. Thus, swath overlap can sometimes produce artifacts, which appear to be higher (or lower) in elevation than the surrounding areas. Although the great majority of these artifacts were removed during multibeam data processing, a few residuals remained and proved to be a confounding factor in the calculation of the habitat suitability model.

Figure 3

Rockfish distribution and abundance calculated from analysis of ROV video data. Visual analysis of these data revealed a strong association between rockfish and high relief habitat.

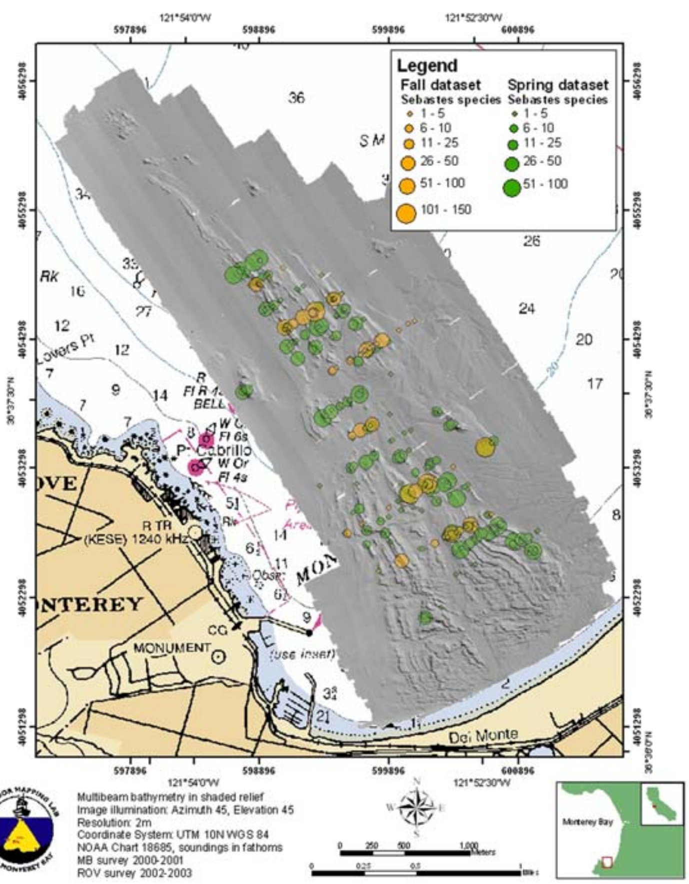
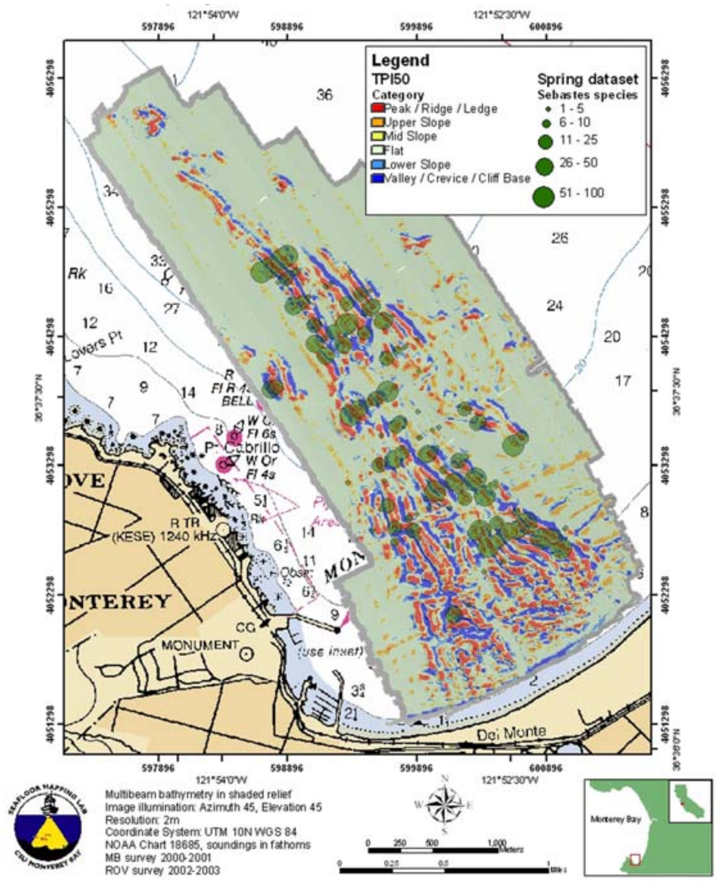


Figure 4

TPI_{50} analysis of multibeam survey area with distribution and abundance of rockfish observed during Spring 2003 ROV survey. TPI_{50} classes derived from bathymetry DEM. Symbol size for fish data is proportional to number of rockfish observed, and grid color indicates TPI_{50} class. Note 50 meter buffered area around extent of multibeam survey area has been eliminated from TPI analysis due to edge and artifact noise.



Habitat Utilization Analysis

The visual examination of fish distribution relative to the TPI surface, as well as the Manly's alpha results agreed strongly with the expected high affinity of rockfish for complex, high-relief habitats. Because it takes resource availability into account, Manly's alpha revealed an even stronger association with certain TPI classes by rockfish than was originally expected, with most fish strongly associated with middle and upper slopes as well as peaks and ridges, while one species (*S. carnatus*) surprisingly seemed to occupy "valleys" (low areas *between* outcrop ledges) more often than others (Figure 5).

Habitat Suitability Model

Analysis of the spring ROV observation data, summary statistics of fish abundance by species and TPI class, and the Manly's alpha results, suggested that TPI_{50} peaks seemed to be the most attractive feature to rockfish. However, while they might be attractive features near which fish are nearly always found, rockfish were not always observed clustered directly on top of peaks. For this reason, the TPI_{50} grid was reclassified in 10 m increments into a "distance to TPI_{50} peaks" surface, and this was ranked according to suitability (highest = 1 for 0-10 m from a "peak", to lowest = 10 for > 90 m from a "peak") This method of assigning highest suitability to the area immediately around peak features proved to be more effective than using only the peaks themselves in accounting for fish that were found near but not directly on top of peak features and can be justified by literature accounts of rockfish behavior and natural history (PFMC, 2004).

Model Evaluation

Summary statistics were generated for the TPI-based habitat suitability model with respect to number and percent of rockfish by species found in each category for both the fall and spring surveys (Table 1). The fall dataset was not included in the generation of the model, and therefore can be considered an independent dataset for use in validation of the model. Model performance was evaluated by comparing the results of the "most suitable" category 1 for both the fall and spring surveys. Density estimates (# fish / 100 m^2) were also generated for each of the models (Table 2). The suitability model appears to predict an average of 80% of rockfish within the "most suitable" category 1 (Table 1).

Table 1

Topographic Position Index-based habitat suitability model evaluation. Model success was evaluated by the percentage of fish occurring in the "most suitable" class (Category 1).

Percentage of fish found in each distance to TPI50 category

	SPRING							FALL						
	category							category						
	1	2	3	4	5	6	7-10	1	2	3	4	5	6	7-10
S. mystinus	88.3	9.9	1.5	0.3	0.0	0.0	0.0	89.1	6.6	4.3	0.0	0.0	0.0	0.0
S. serranoides/ S. flavidus	89.1	5.3	4.4	1.3	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
S. miniatus	82.2	11.8	3.3	0.7	0.7	1.3	0.0	39.5	39.5	13.2	2.6	0.0	0.0	5.3
S. auriculatus	79.4	14.7	0.0	0.0	0.0	5.9	0.0	77.8	22.2	0.0	0.0	0.0	0.0	0.0
S. carnatus	62.2	14.7	4.4	0.0	4.4	0.0	2.2	50.0	0.0	50.0	0.0	0.0	0.0	0.0
S. pinniger	83.3	14.7	4.2	0.0	0.0	2.1	0.0	7.7	46.2	0.0	0.0	46.2	0.0	0.0
S. rosaceus	78.1	14.7	0.0	0.0	0.0	0.0	0.0	66.7	16.7	0.0	16.7	0.0	0.0	0.0
S. rubrivinctus	78.9	14.7	5.3	0.0	5.3	0.0	0.0	57.1	42.9	0.0	0.0	0.0	0.0	0.0

Table 2

Density (#/ 100 m²) estimates for Topographic Position Index-based habitat suitability model.

Fish density (#/100m2) in each distance to TPI50 category	SPRING							FALL						
	category							category						
	1	2	3	4	5	6	7-10	1	2	3	4	5	6	7-10
S. mystinus	1.60	0.36	0.08	0.02	0.01	0.01	0.00	1.89	0.25	0.22	0.00	0.00	0.00	0.00
S. serranoides/ S. flavidus	0.23	0.03	0.03	0.02	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00
S. miniatus	0.10	0.03	0.01	0.00	0.01	0.02	0.00	0.05	0.09	0.04	0.01	0.00	0.00	0.00
S. auriculatus	0.02	0.01	0.00	0.00	0.00	0.02	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00
S. carnatus	0.02	0.02	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00
S. pinniger	0.03	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.00	0.14	0.00	0.00
S. rosaceus	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00
S. rubrivinctus	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00

Figure 5

Manly's alpha analysis of habitat utilization by rockfish in Spring. Manly's alpha expresses the level of use of a resource type relative to its availability in the environment. For each Topographic Position Index class the percent likelihood of each species' use of that class is shown, given equal availability of all classes. The horizontal axis represents a lack of association with the resource, and the height of each bar above or below this line expresses the degree of association or avoidance for each resource class (if any).

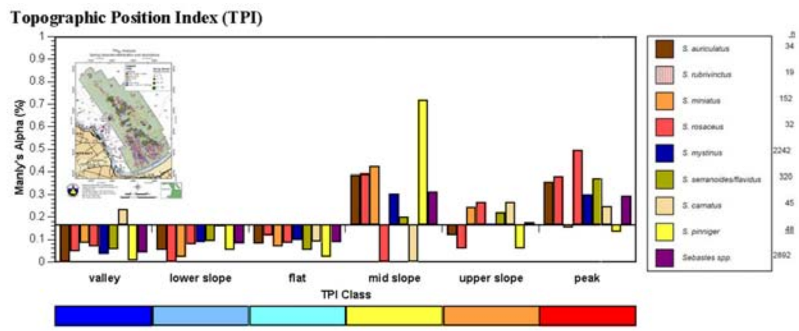


Figure 6

Habitat Suitability Model: Distance to TPI_{50} Peaks. Displays distribution and abundance of rockfish for the spring dataset. Size of symbol is proportional to number of rockfish observed, and grid color indicates Model 1 habitat suitability. Note habitat suitability categories also display density of rockfish for the spring dataset found within each category. Analysis mask indicates area where ROV video data has been collected. Results limited to the analysis mask area in the foreground, and results projected for the entire survey area in the background, or the "grayed-out" area.

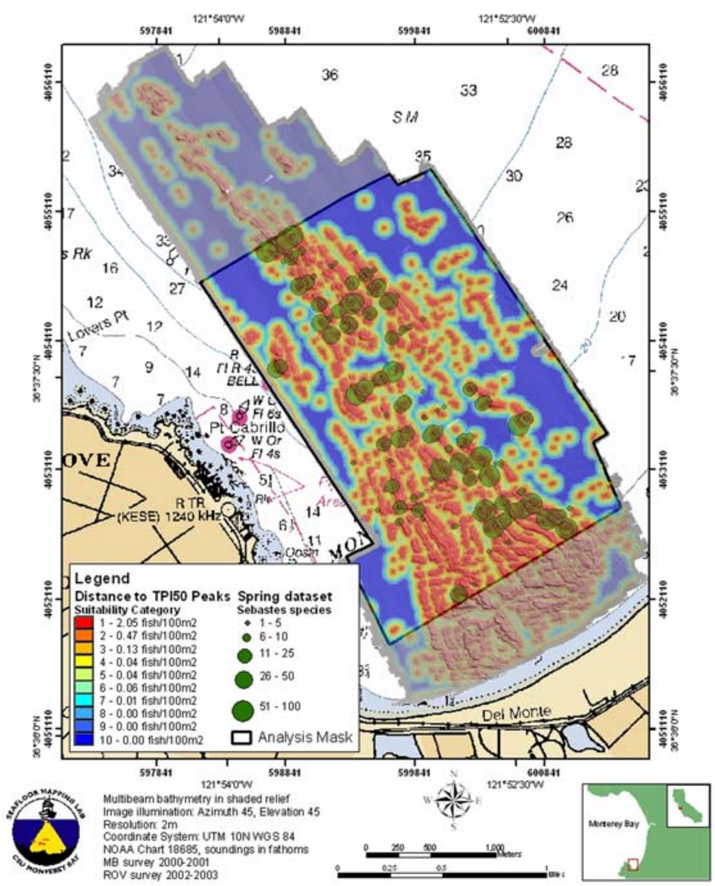


Table 3

Stock estimates for Topographic Position Index-based habitat suitability model. Stock estimates were calculated for each category by taking (# fish by species/transect area)*total survey area. Adjusted stock estimates accounted for the fact that only a portion of the area delineated by each suitability category actually contained fish.

Stock Estimate (# fish/transect area)*total transect area	SPRING - UNADJUSTED							SPRING - ADJUSTED						
	category							category						
	1	2	3	4	5	6	7-10	1	2	3	4	5	6	7-10
S. mystinus	30374	4250	743	178	44	56	0	3622	96	10	1	0	0	0
S. serranoides /S. flavidus	4374	325	315	119	0	0	0	522	7	4	0	0	0	0
S. miniatus	1919	345	113	30	44	111	0	229	8	1	0	0	0	0
S. auriculatus	414	96	0	0	0	111	0	49	2	0	0	0	0	0
S. carnatus	430	230	45	0	87	0	55	51	5	1	0	0	0	0
S. pinniger	614	96	45	0	0	56	0	73	2	1	0	0	0	0
S. rosaceus	384	134	0	0	0	0	0	46	3	0	0	0	0	0
S. rubrivinctus	230	38	23	0	44	0	0	27	1	0	0	0	0	0

Stock Estimates

Stock estimates were calculated by taking the number of fish found in a particular suitability category, and extrapolating the total amount of fish that would be found in the study site given the total area comprised of that category. Adjusted stock estimates were also calculated to take into account the fact that fish were not found everywhere there was available habitat within the study area. Proportion values were computed based on the amount of area in which rockfish were found within the transect, divided by the area found within the transect for each habitat suitability category. These proportions were multiplied with the original stock values to produce adjusted, potentially more accurate estimates (Table 3). On average, the adjusted stock values were 5% of the original estimate.

Discussion

The goal of this project was to test a semi-automated GIS landscape analysis tool (Topographic Position Index, TPI) with high-resolution multibeam bathymetry data to create a preliminary model capable of predicting the distribution and abundance of particular species, based on habitat association. ROV footage provided habitat ground-truth and fish census data, which were used to both assess and inform the model generation process.

While the results are preliminary, it appears that the simple model produced, (which consisted only of distance to TPI_{50} peaks), quite effectively predicts the distribution of the majority of rockfish, with a high percentage of fish falling within the "most suitable" category for both the spring and fall datasets. While some differences were observed in *Sebastes* distribution in the study area between fall and spring, they were deemed to be similar enough to use for cross-validation. In addition, the species concerned are not known to migrate or exhibit large-scale movements on a seasonal basis. When using raw percentage of fish as the basis of comparison, the model predicted an average of 84.5% for 5 of 8 the species observed in spring, and an average of 76.6% for 4 of 8 species observed in fall.

We are currently making efforts to better assess the predictive ability and efficiency of the TPI-based model using other statistical means. An effective predictive model should not only agree with the observed distribution of the organism in question where they do indeed occur, but should also predict their absence where they do not occur. A model that is overly inclusive obviously will be successful in the former case, but not in the latter, and such errors of commission could lead to undesirable and inaccurate results if the model is used to make stock estimates or resource management decisions. Confounding the effort to assess the efficiency of habitat suitability models is the fact that they typically model only *potential* rather than *realized* habitat. This is especially significant in the case of a genus such as *Sebastes*, whose populations have been so decimated by over fishing that they are almost certainly not habitat-limited.

One method of potentially improving the efficiency and specificity of the habitat model created in this study may be to incorporate other factors that can be derived from the bathymetric DEM such as depth, slope, and rugosity. While they may be cross-correlated in some instances, some portion of fish distribution may be associated with variability in one or more of these parameters in addition to (or more strongly than) the TPI peak-proximity relationship observed in this study. One reason these parameters were not used in the current study was the previously mentioned issue of DEM resolution. The low-relief outcrops of the shale beds rise above the surrounding seafloor a maximum of 2 m, which confounds efforts to accurately derive finer-scale complexity measures such as slope and rugosity from a DEM with a similar (2 m) horizontal resolution. We plan to reprocess and/or acquire new multibeam data that will allow the generation of a 0.5 m resolution DEM, which can then be used with our existing ROV data to further explore the production of habitat suitability models with additional factors included. Unfortunately, the natural history literature contains very little information regarding genus- or species-specific association with ranges of slope and rugosity, and those that do exist may be based on estimates of those parameters made at widely different scales. Presumably, as the potential for the use of these quantitative habitat parameters is realized, biologists may begin to estimate and publish the affinities of organisms for particular habitats in terms of those parameters.

Finally, at least for a few species, there appears to be some depth-associated pattern of fish distribution within our study site, and we hope to examine this further.

Although the habitat suitability model was designed to include only a single data type derived from multibeam bathymetry, the model was capable of capturing an average of approximately 80% for 8 rockfish species on the shale beds. These results show that multibeam bathymetry, when analyzed with GIS landscape analysis tools, can be a powerful tool capable of estimating rockfish abundance and distribution on the shale beds of Monterey Bay. Further study is needed to add greater predictive value to these methods and to ascertain whether these results are applicable to other regions with different landscape types, can be extrapolated over wide geographic areas, or can be applied to different species given their species-specific parameters.

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