

NOAA Technical Report: Integrated Spatial Data
Modeling Tools for auto-classification and delineation of
species-specific habitat maps from high-resolution,
digital hydrographic data

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Integrated Spatial Data Modeling Tools for auto-classification and delineation of
species-specific habitat maps

NOAA TECHNICAL REPORT: INTEGRATED SPATIAL DATA MODELING TOOLS FOR AUTO-CLASSIFICATION AND DELINEATION OF SPECIES-SPECIFIC HABITAT MAPS FROM HIGH-RESOLUTION, DIGITAL HYDROGRAPHIC DATA	I
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Abstract

We used high-resolution multibeam bathymetry, together with precisely geolocated ($\pm 5\text{m}$) ROV observations of fish distribution, to produce species-specific and genus-specific habitat suitability models for eight rockfish (*Sebastodes*) species in the Del Monte shale beds of Monterey Bay, CA., USA. A high-resolution (2m) multibeam bathymetry digital elevation model (DEM) was generated and used to produce derived habitat characteristic layers [slope, rugosity, and Topographic Position Index, (TPI)] using repeatable, non-subjective algorithmic methods. These data layers, together with the positions and counts by species from 229 rockfish observations (2892 total fish) were then used to create predictive models of habitat suitability and fish distribution. Factors evaluated for incorporation in the models included depth, slope, rugosity, and TPI at various scales. Statistical and empirical testing revealed that distance to a TPI_{50} “peak” was the most effective predictor of fish location, while other factors (slope and rugosity) seemed important but less significant. For this reason, distance to TPI_{50} peak was used as a simple indicator of habitat suitability for all species. Between 62% and 89% of fishes from the eight species examined, and 87% of all *Sebastodes*, were found within optimal habitat as defined by this simple model (Model 1), even though the optimal habitat comprised only 22% of the area surveyed for *Sebastodes*. By incorporating depth, a refined suitability model (Model 2) was created for four species. Model 2 optimal habitat contained 89% of olive/yellowtail (*S. serranoides/S. flavidus*), 79% of brown (*S. auriculatus*), 78% of rosy, (*S. rosaceus*), and 78% of flag (*S. rubrivinctus*) rockfish, while accounting for a lower percentage (mean = 13%) of the total area surveyed. Both models were used to produce stock estimates for all species and for all *Sebastodes*, based on observed densities of rockfish within the ROV survey area and total area of habitat suitability classes in the overall shale bed study area. Model 1 estimates approximately 53,000 *Sebastodes* (of the eight spp. studied) in the shale beds; substituting Model 2 estimates for the four relevant species raises this estimate to approximately 54,000 fish.

Summary

The purpose of this project was to integrate high-resolution multibeam bathymetry with ArcGIS landscape analysis tools to create a species-specific, scaleable model capable of classifying habitat and assessing distribution and

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abundance of particular species. Such a tool would be capable of characterizing both small- and large-scale habitat, and could be designed to isolate optimal habitat based on species-specific parameters. In light of recent declines in fish stocks and overall ecosystem health, there is a fundamental need to accurately assess the health and extent of marine resources. Identification of Essential Fish Habitat is fundamental to understanding processes and developing policy that will help rebuild crashing rockfish populations. This project sought to create a tool that would not only be capable of identifying sensitive fish habitat at scales as fine as 1m, but would also be able predict the location of fish based on species-habitat associations. This model will provide a cost-effective, efficient method for habitat mapping which takes advantage of the high-resolution data from multibeam bathymetry, creates derivative products using semi-automated landscape analysis tools, and uses those products to predict distribution and abundance of marine resources given species-specific habitat association parameters.

The general approach of this project was to assess habitat type and extent for the Del Monte shale beds located in the southern part of Monterey Bay in central CA, using a digital elevation model (DEM) generated from high-resolution multibeam bathymetry collected during three survey days in 2000 and 2001. Biological and groundtruth data were collected with a Remotely Operated Vehicle (ROV), during two surveys in fall 2002 and spring 2003. The majority of ROV transect lines fell perpendicular to the strike of the shale reef in order to best ascertain species-habitat associations. Survey linear distance totaled 18015m during the fall 2002 ROV survey over 8 transects; and 22 transect lines covering a linear distance of 49052m for the spring survey. ROV video analysis documented the position, species, and substrate for rockfish (*Sebastodes* spp.) along the transects, and these data were imported into GIS for analysis in combination with the multibeam bathymetry and other data. GIS tools were used to produce derivative grids from the bathymetric DEM data, including slope, topographic position, and rugosity. Species-specific fish distribution and abundance data were correlated with these parameters using multivariate statistics. By isolating significant factors, we were able to create a species-sensitive model, which accurately predicted, for example, the preferred habitat and location of 88% of blue rockfish (*Sebastodes mystinus*), and 79% of flag rockfish (*S. rubrivinctus*) within the survey area (Table 1).

Background

Dramatic declines in fisheries and marine environmental quality, combined with increased human demands for marine ecosystem goods and services, have lead to recent state and federal legislation mandating that resource agencies adopt more integrated, ecosystem-based approaches to the sustainable management of US marine resources. Both NMFS and DFG are now in great need of efficient methods for mapping the distribution and abundance of species and their associated habitats. Because species tend to have predictable affinities

for specific habitats with distinctive physical characteristics, species-specific habitat mapping may serve as a reliable and efficient proxy for species mapping in some instances. Advances in the acquisition and processing of acoustic remote sensing data, most notably multibeam bathymetry, have dramatically improved the resolution, scope and efficiency of our ability to map geophysical seafloor characteristics. High-resolution, georeferenced, underwater video observations taken by acoustically positioned ROVs, submersibles and scuba divers are the tools of choice for accurately defining habitat preferences of individual species based on observed associations with geophysical characteristics. This project attempts to develop methods to link observed species-habitat associations with the processing of hydrographic datasets into biologically relevant, dynamically interpretable and species-specific habitat maps. By addressing the lack of appropriately applied spatial modeling tools, our goal is to overcome a major obstacle to the full utilization of high-resolution hydrographic data for marine resource management.

Traditionally, habitat mapping has relied on using shaded-relief or other multibeam bathymetry, as well as sidescan sonar backscatter images, as reference imagery for hand-tracing polygons delimiting visually discernable outcrop patterns and other geomorphic characteristics. This technique generally yields static categories encompassing wide geographic areas, which is scale-dependent, labor-intensive and very subjective, producing different results depending on the interpreter. Visual interpretation is also often non-repeatable, as the consistency of the same interpreter varies; the same interpreter may not classify a dataset the same way twice. In contrast to this technique, our model seeks to create a more objective, automated, quantitative, algorithm-based, spatial model capable of dynamic analysis. Although the scope of this project originally covered the use of sidescan sonar, sub-bottom profiling and substrate characterization, the use of multibeam bathymetry alone is capable of producing accurate, high-resolution, species-specific habitat maps that fit the needs of marine resource assessment. Thus the amount of time, effort and resources required to produce these habitat maps can be greatly reduced.

The study site for this project is an area commonly known as the Del Monte shale beds, a shallow water area located in the southern portion of Monterey Bay, CA. The shale beds were chosen because they provide a number of unique features, which help to isolate factors important in creating this model. The shale beds are a relatively low-relief environment, characterized by linear ledges dipping down to the northeast, surrounded by unconsolidated sediment. Many fish are known to be attracted to high-relief features, such as pinnacles, but their distribution on lower-relief substrate is less predictable. Creating a model capable of predicting species distributions on all types of relief will be invaluable for characterizing areas with diverse environments.

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Methods

Site description

The Del Monte shale beds cover an area of approximately 10km², located in the southern portion of Monterey Bay, between Cannery Row and Del Monte beach in central California (Figure 1). This collection of rocky outcrops is bounded by sand, and ranges from 10 to 70m in depth. The benthic invertebrate community is dominated by *Metridium senili*, anemones and sea stars, and the reef provides homes for over 20 species of rockfish (*Sebastes* spp.), as well as perch, lingcod, and a variety of other plants and animals. The shale beds are a particularly attractive setting for studies such as this.

Multibeam bathymetry

The multibeam bathymetry survey was completed using the Reson 8101 Seabat multibeam sonar aboard the R/V *MacGinitie*, which is capable of mapping depths from 1 to nearly 300 meters. The 8101 operates at 240 kHz and measures relative water depths within a 150° swath consisting of 101 1.5° x 1.5° beams. This transducer geometry makes the 8101 capable of taking up to 3,000 soundings per second with a swath coverage of up to 7.4 times the water depth. A total of 44 multibeam survey lines were run, generally parallel to depth contours at a spacing of approximately 2-4 times water depth. A Trimble 4700 GPS generated position and attitude data at 5 Hz with U.S. Coast Guard RTCM differential corrections provided by a Trimble ProBeacon receiver. Horizontal positional accuracy of this system is typically +/- 1-2m. Attitude (pitch, roll, yaw, and heave) data were generated at 200 Hz by a TSS Position and Orientation System, Marine Vessel (POS-MV). Attitude accuracy for the POS/MV pitch, roll and yaw measurements averaged +/-0.03°, while heave accuracy was maintained at +/-5% or 5 cm. Sonar, position, and attitude data were logged in XTF format using a Triton Elics Isis data acquisition system running Isis Sonar software. Multibeam data were monitored in real-time using the 8101 Sonar Processor control interface and 2-D and 3-D display windows in the Isis Sonar and DelphMap software. Survey planning and navigation was performed using Coastal Oceanographics Hypack Max software. Surface-to-seafloor profiles of the speed of sound through the water were collected periodically during the surveys with an Applied Microsystems Limited (AML) SV+ sound velocity profiler. These profiles were used to correct for variations in sound velocity due to salinity and temperature changes throughout the water column. Raw XTF files collected in 2001 were corrected for sonar latency errors caused by an issue present in the version of the Isis acquisition software used for that survey.

Shipboard data were post-processed in the lab using CARIS Hydrographic Information Processing System (HIPS) 5.2 software. Tide and SVP (sound velocity profile) corrections were applied, and the sounding data were cleaned to remove erroneous soundings. The HIPS refraction coefficient editor was used where necessary to reduce artifacts due to inadequate sound velocity

compensation. The 44 survey lines yielded a total of 262,779 profiles with 35,009,513 soundings. The cleaned raw soundings were thinned to 2m spacing in HIPS using deep- and shoal-biased selection, and the results were exported as x,y,z text files (2,327,500 soundings) for generation of digital elevation models (DEMs). DEM surface models were generated from the x,y,z text files using the AverageGridder module in IVS's Fledermaus software package version 5.2. Fledermaus was also used for QA/QC; the DEMs were manipulated and examined in 3-D to identify any artifacts or remaining bad soundings which were then removed in HIPS and a new x,y,z file exported. Through this iterative process, final deep- and shoal-biased DEMs (2m cell size) were produced in Fledermaus and exported as ArcInfo ASCII raster files. These files were imported into ArcGIS for further analysis and incorporation into the predictive model. In addition to x,y,z files, grayscale shaded-relief images were exported from HIPS at 0.5, 1, and 2m resolution. These images were used in both GIS and during the ROV survey as background files in the Hypack navigation software. All x,y,z files, DEMs, shaded relief images, and other products were generated in the Universal Transverse Mercator (UTM) coordinate system, Zone 10N, WGS1984 datum.

ROV Data Collection

Biological and groundtruth data were collected using a Hyball remotely operated vehicle (ROV) deployed from the R/V *MacGinitie* to record video transects along the shale beds. Transects were oriented to run perpendicular to the strike of the reef, approximately 100-250m apart (Figure 2) in order to quantify the species associated with the ledge formations characteristic of the area. The ROV was deployed using a 50 Kg down-weight suspended by a steel cable, with 20-100m of free umbilical between the ROV and the down-weight. ROV positioning was done using a Trackpoint II+ ultra-short baseline acoustic tracking system, which determined position of the ROV relative to the vessel. The Trackpoint II+ distance and bearing solutions were integrated with vessel heading & GPS position in real-time in Hypack Max to generate a true x,y,z position for the ROV. The ROV position was displayed in Hypack Max together with the R/V *MacGinitie* position, the planned track lines, shaded-relief imagery from the multibeam survey, and other background data such as nautical charts. Empirical testing determined the accuracy of the ROV position solution to be +/- 2-5m. The R/V *MacGinitie* and ROV were piloted together along the planned transect line at 0.25-0.5 Kts., with the ROV "flown" approximately 1 meter above the seafloor and the camera tilted at a constant 10-15° downward angle. Transects were run only in a southwest-northeasterly direction, which oriented the ROV towards the differentially-eroded, undercut ledges of the reef, allowing a view into the void spaces between rock strata. The ROV camera was tilted upward to view the water column above the ROV periodically to check for non-demersal fishes. Where habitat and biological features were encountered, the ROV was maneuvered and camera angle adjusted so as to best observe and record the fish and their surroundings (including the water column), but generally the ROV was kept to within 10m of the planned survey track line. Water clarity

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during the fall and spring ROV surveys varied, but effective visibility was generally 3-10 meters. Video from the ROV was captured with a JVC 470 line resolution, 0.95 lux color CCD with an F 0.8 Pentax lens, and the data was recorded onto mini-DV tapes. Two parallel laser beams were mounted on the frame of the ROV spaced 20cm apart to determine relative size of objects, relative distance from the bottom, and general water clarity. The Hyball ROV is equipped with two fixed 75 watt quartz halogen lamps aimed forward and two 75 watt lamps mounted on the camera chassis, but in order to reduce backscatter and minimize alteration of fish behavior, these lights were rarely used. ROV depth was measured independently of that calculated by the Trackpoint II acoustic tracking system by a pressure sensor mounted on the vehicle. Telemetry data from the ROV (time, date, depth, heading, velocity, camera angle) were overlaid on the video imagery and recorded on the tape. ROV latitude and longitude, UTC time, and depth information were also recorded on the time code and audio tracks of the videotape using a Horita GPS-3 encoder. Approximately 9.5 hrs of useable ROV footage was recorded in Fall 2002, and 32.2 hrs of footage in Spring 2003. Video analysis was done in the lab with a JVC BR-DV600 mini-DV digital VCR.

ROV Video Analysis

Video analysis of the transects involved watching each tape and logging a position for each fish observation. Single fish observations were captured by logging the position of the ROV on or as near as possible to the location the fish had initially been noted. Areas with more than one fish were logged by taking the position of the ROV at the center of the “school” or group of fish. All fish within the field of view were included in the counts. Depending on the visibility of the transect, the viewable range was 3-5m on either side of the ROV, and several meters into the water column. Species were noted with great care, and any unidentifiable fish were cataloged as either “water column” or “unknown” fish. Still and frame-by-frame analysis of the videotapes allowed greater scrutiny in determining the species of fish. All data, including information on species, depth, substrate and surrounding environment collected from the tapes were collated into spreadsheets and integrated into ArcGIS using latitude/longitude as point identifiers. ROV latitude and longitude was extracted from the videotape in the lab using the Horita GPS-3 encoder, and integrated into spreadsheet data collected while reviewing the tapes. The spreadsheet was imported into GIS as point shapefiles with attribute tables which include data on the species, number, location, substrate type and depth of the animals recorded along the transects.

G/S Analysis

Analysis and further processing of the multibeam DEMs was done using ESRI ArcView 3.2 and ArcGIS 8.3. The deep- and shoal-biased DEMs were evaluated to determine which would be used to produce derivative grids and incorporate into the predictive model. Despite careful cleaning of raw sounding

data in HIPS, some noticeable artifacts often persist into DEMs generated from multibeam data. This often takes the form of across-track undulations or “ribbing”, as was the case in the DEMs produced for the shale bed study site. In addition, some areas of overlap between adjacent lines exhibited slight artifacts. The shoal-biased DEM suffered from these issues to a lesser degree and was chosen as the basis for further analysis and incorporation into the predictive model.

A Digital Elevation Model (DEM) was generated using 2m shoal-biased x,y,z data exported from Caris HIPS (Figure 3). Derivative grids were generated from the bathymetric DEM, including slope, rugosity and Topographic Position Index (TPI), or relative elevation. The majority of DEM analysis was done using the Spatial Analyst extension in ArcGIS 8.3.

Slope Analysis

Slope calculations were made using the Spatial Analyst Slope function, which calculates the steepest slope between each cell and its 8 nearest neighbors (Figure 4).

Rugosity Analysis

Rugosity, or surface “roughness” was calculated in ArcView GIS 3.2 using the “Surface Areas and Ratios from Elevation Grids” extension v.1.2, created by Jenness Enterprises. Rugosity is a measure of surface complexity and can be represented by surface area : planar area (SA) ratio. Areas of rough terrain exhibit high SA ratios, while smoother, flatter areas have SA ratios nearer to 1 [which indicates perfectly flat terrain, (Figure 5)]. The SA calculation algorithm employed in the “Surface Areas and Ratios” extension is intended to calculate SA ratios at the DEM cell resolution; by comparing the elevation of each cell with that of its 8 nearest neighbors, the associated surface area of each cell is calculated, which is then divided by the planar area (cell size). For each cell in the grid, surface areas are based on triangle areas derived from eight triangles.

Each triangle connects the center point of the central cell with the center points of two adjacent cells. These triangles are located in three-dimensional space, so that the area of the triangle represents the true surface area of the space bounded by the three points. Each triangle area is adjusted so that it only represents the portion of the triangle that overlays the central cell. The areas of the eight adjusted triangles are then summed to produce the total surface area of that cell. The surface ratio of the cell is calculated by dividing the surface area of the cell with the planimetric area of the cell. The resulting SA (rugosity) grid has the same cell size as the original DEM grid.

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Topographic Position Analysis

Topographic Position Index (TPI) is a measure of relative elevation, which indicates the position of a given point in the overall surrounding landscape (Figure 6). TPI can be used to identify and delineate landforms such as peaks, ridges, cliffs, slopes, flat plains, and valleys, and is calculated by comparing the elevation of each cell in a DEM to that of its surroundings. Because the neighborhood size of the surroundings used for the elevation comparison can be adjusted, TPI can be calculated at various scales. Thus, an analysis scale can be chosen that will identify features of any desired size, ranging from small-scale features such as the tops of boulders and pinnacles, to entire reefs, to regional-scale features such as seamounts (all classified as “peaks” at different scales). Likewise, TPI can be used to locate fissures and cracks in rock, sand channels, and submarine canyons (TPI “valleys” of increasing scale). In fact, the only limiting factor is the resolution (cell-size) of the DEM, which determines the minimum scale of features that can be delineated.

The TPI analysis employed in this study was done using the algorithm of Weiss (2001), which uses an annulus– (“donut”) shaped neighborhood. TPI is calculated using the formula:

$\text{tpi} < \text{scalefactor} > = \text{int}((\text{dem} - \text{focalmean}(\text{dem}, \text{annulus}, \text{irad}, \text{orad})) + .5)$
where:

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

The scale of the analysis is defined by the inner (*irad*) and outer (*orad*) radii of the annulus neighborhood. The results of this calculation can range from strongly positive (areas that are higher than their surroundings at the specified scale), to strongly negative (areas that are much lower than their surroundings). Intermediate values define irregularly sloping areas, while flat areas and areas of constant slope result in values near zero (Figure 6). Because the magnitude and range of the results are DEM-specific, the initial TPI cell values are classified into standard deviation classes, which are categorized into classes such as “peak”, “slope”, and “valley”. In order to differentiate the ambiguous near-zero TPI values into “slope” and “flat” classes, the previously mentioned slope grid derived from the DEM is used, with a slope value of 5° serving as the break point between the two classes (Table 2). TPI analysis of the study area DEM was done at a variety of scales ranging from 10 to 250m annulus size (*orad*), with a 5-cell (10m) annulus thickness (*orad* - *irad*). Due to the fact that the initial TPI calculation involves conversion of the (DEM – focalmean) result into an integer, special steps had to be taken when calculating TPI for the shale beds DEM, within which maximum elevation differences (relief) are only 1-2m at the range of TPI analysis scales. Rounding error masks these differences and results in intial TPI values of only 0, 1, 2, or 3; subsequent reclassification by standard deviation similarly does not provide the TPI classes desired. To avoid this, the elevation differences were

vertically exaggerated by 10X before integer conversion. Standard deviation reclassification then produced the desired 6 classes (peak, upper slope, etc.).

ROV Video / GIS Integration

Vector data layers (shapefiles) were produced from ROV transect track lines derived from the acoustically tracked ROV position logs. Polygon shapefiles were created by buffering the transect line shapefiles by 5m in order to represent the total area searched during the ROV survey. The 5m buffer distance used was chosen based on the average visibility conditions during the survey, and resulted in an overall transect swath width of 10m. Transect buffer polygons were used to calculate total transect area, fish densities, and within-transect estimates of area for various habitat and feature types.

Fish observation data from video analysis were converted into attributed point shapefiles. Fish location point data were used to visualize the pattern and distribution of rockfish relative to bathymetry and the derived landscape metrics described above (slope, rugosity, and TPI). The cell values of these potential habitat parameter layers were sampled at each fish location point and the results were attached to the attribute table of the point shapefile for use in statistical analyses. Initial evaluation of the visualization and layer sampling results revealed that restricting the analysis to the absolute locations of the fish had great potential for misrepresenting the habitat features and parameters with which the fish were associated (see Results and Discussion). For this reason, an “area of influence” (AOI) around each fish location was created using a 10m buffer. The use of an AOI was introduced because it was felt, from field experience, lab observation of ROV video footage, and GIS visualization, that the position of a given rockfish in the shale bed study area was likely influenced not by the nature of only the 2m patch (raster cell) of seafloor directly under it, but rather by that of its immediate surroundings (all cells in a 10m radius). The AOI buffers were used to sample the bathymetric DEM and other layers in a manner similar to that used for the fish location points, except that summary statistics were generated for the cell values of the raster layers that fell within each AOI buffer. These results were also used for statistical analyses in an attempt to identify which factors were important in determining fish distribution.

Habitat Suitability Models

Based upon the results of visual and statistical analyses of fish distribution relative to the bathymetric and derived surfaces (slope, TPI, and rugosity), factors were identified that might prove useful in determining relative habitat suitability for the 8 species of *Sebastes* studied (both as a group and individually on a species-specific basis). The surfaces representing these factors were reclassified and the classes ranked according to relative “attractiveness” or suitability (again, both for all *Sebastes* spp. and on a species-specific basis). These reclassified grids were used to construct simple additive models to predict

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overall habitat suitability (see Results for details on model construction and efficiency).

Statistical Analyses

In order to isolate landscape features that might influence species distribution, multivariate statistical analyses were applied to fish distribution and landscape metric data sampled from fish observation points and AOIs using SPSS 11.5 statistical software. Hierarchical cluster analysis was used to identify whether fish distribution suggested the presence of any functional groups of species (i.e., whether some species tended to co-occur).

Results

Generation of the predictive model required extensive data preparation and exploration. The multibeam bathymetry DEM was the foundation of our model, and bathymetric data were rigorously processed prior to GIS analysis to eliminate residual artifacts. Once in GIS, derivative surface grids were generated with relative ease, and were not affected by subjective decisions based on data appearance. The grids were classified into binned categories based on the data range of each particular grid and natural history data from literature (Table 3). Binning the categories for each grid allowed data to be reclassified based on common scales with standardized values.

Sebastes Data

The data collected from the ROV videotapes provided information on the species, number and location of all fish observed along the transects (Table 4). A total of 2904 individual adult rockfish were identified to species and used for further analysis in this study. Of these, the eight most abundant rockfish species (those accounting for >0.5% of total rockfish) were used to construct habitat suitability models, including blue (*Sebastes mystinus*), olive/yellowtail (*S. serranoides*, *S. flavidus*), vermillion (*S. miniatus*), brown (*S. auriculatus*), gopher (*S. carnatus*), canary (*S. pinniger*), rosy (*S. rosaceus*), and flag (*S. rubrivinctus*) rockfish. These eight species accounted for 2892 fish, and all calculations of total adult rockfish abundance and density reported hereafter in this report are constrained to these eight species.

Video analysis showed distinct patterns of rockfish distribution and abundance relative to substrate and depth, which were documented and compiled into the database. In most cases, rockfish tended to be found on or near high-relief terrain. Shale ledges seemed to be an attractive feature for most fish, as expected. To verify this pattern, the video analysis spreadsheets were imported into ArcGIS and displayed relative to the bathymetry and derivative grids (Figures 3-6). Rockfish preference tables were generated for each surface

(bathymetry and derived products such as slope) specifying number of rockfish per binned category (Table 3) in order to ascertain trends in distribution between categories.

Depth

The survey area ranges from 2m to 70m in depth (Figure 3). The ROV transects covered depths ranging from 10m to 65m, and *Sebastes* spp. fishes were found in all depth ranges. There were some species, however, that were only found at certain depths (Table 3).

Slope

The results of the slope analysis of the bathymetric DEM indicated slopes ranging from 0-32° within the study area (Figure 4). Due to the low-relief nature of the shale bed outcrops (maximum height 1-2m), and the relative resolution of the multibeam bathymetry DEM (2m), the slope values calculated were lower than expected (see Discussion). The majority of both the survey areas (96%) and the transect area (92%) had a slope value of 0-5° (Table 5). Very little of both the survey area (0.07%) and the transect area (0.12%) had a slope greater than 15°. As a result, the majority of the rockfish were found directly over seafloor areas with calculated slope values of 0-5° (Table 3). The results from video analysis suggested that rockfish were associated with high-relief features, and thus with areas of higher slope. Initial analysis of rockfish distribution relative to slope in GIS, however, showed the opposite. When the Area of Influence (AOI) approach was used, and maximum slope within a 10m radius was examined, most rockfish were found to be associated with slopes ranging from 5-10° (47.5%), followed by 0-5° (28.0%, Table 6).

Rugosity

The rugosity (SA ratio) values calculated from the bathymetric DEM ranged from 1-1.22 in the survey area (Figure 5). Again, due to the low-relief nature of the shale beds, and the relative resolution of the multibeam bathymetry data, rugosity estimates were low. When rugosity was classified into four equal interval categories, over 99% of both the survey and transect areas fell into the lowest rugosity category, suggesting that the area was largely flat (Table 5). Video analysis and images generated from the multibeam bathymetry showed a more rugged terrain than these values suggested. So although we expected rockfish to fall on areas of rugged terrain, the number of rockfish found on areas with high rugosity values was very low (Table 3). When AOI was examined, the majority of fish were still associated with the “flat” rugosity class (84%, Table 6).

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Topographic Position Index (TPI)

Topographic Position Indices (TPI) were generated using various search radii ranging from 10m to 150m. TPI with a radius of 50m (TPI_{50}) was chosen for further analysis and incorporation into habitat suitability models in this study, as it appeared to be a good fit with the geomorphology observed during video analysis (Appendix A). Although nearly half of both the survey and transect areas were classified as “flat,” the area of the other categories was fairly evenly distributed (Table 5). Rockfish distribution relative to TPI_{50} categories showed that rockfish were often found over “peaks” (Table 3, Figure 6). Rockfish density (constrained to within transect buffers) calculations showed the greatest density of rockfish fell on “flat” areas. Areas classified as “flat” by TPI include both sandy areas and areas without elevation changes or slope gradient, which can include the tops of mesa-like plateaus, depending on the TPI scale. Although flat areas had the greatest rockfish density, more individual rockfish were found on peaks. In addition, those rockfish found in “flat” areas were invariably in very close proximity to a “peak” area. This was in agreement with the logic used when deciding to examine AOI for the fish locations, wherein it was determined that a given fish’s location was not necessarily due to the nature of the seafloor directly below it, but by the nature of the immediate surroundings. The observed tendency of fish to be found near “peaks” suggested that distance to TPI_{50} peaks might be an effective metric for use in modeling habitat suitability.

Habitat Suitability Models

The AOI results suggested that proximity to features classified as “peaks” by a 50m scale Topographic Position Index analysis (TPI_{50}) seemed to be the most significant factor affecting rockfish distribution of the four factors analyzed: depth, slope, rugosity and TPI. A grid representing distance to TPI_{50} peaks was generated and reclassified into 10 categories at 10m intervals, with category 1 representing 0-10m to a peak (including peak features) and the last category (10) representing ≥ 90 m distance to a peak. “Optimal” habitat was considered to be 0-10m to a peak (category 1). A comparison of number of rockfish and transect area along a gradient of distance to peak suggests that the cumulative increase in rockfish abundance as distance increases is not due to the accompanying increase in area alone (Table 6, Figure 7). All rockfish were found to be within 70m of a peak (Figures 9-17). In order to assess the efficiency of this model, the proportion of area with fish to area without fish was calculated (Appendix B). This efficiency ratio is a measure of what proportion of the total area searched is classified into each habitat suitability category, and what proportion of the fish observed were found in that category. For example, category 1 (0-10m to a peak) is considered “optimal,” and supports 87% of *Sebastodes* spp., but this category accounts for only 39.6% of the total transect area.

In order to increase the efficiency of the model, a second habitat suitability model was constructed using species-specific depth trends in addition to distance to TPI_{50} peak as parameters. Depth did not appear to be a factor in the

distribution of all species included in this study, and habitat suitability for these species was not modeled a second time. Models were generated for *S. serranoides*/*S. flavidus*, *S. auriculatus*, *S. rosaceus*, and *S. rubrivinctus*, as their depth distributions were non-uniform (Table 3). The bathymetric DEM was reclassified and the classes ranked on a scale of 1-10 according to suitability for each species (Table 7). The species-specific reclassified depth grid was then combined with the distance to peak grid in a simple additive model using the raster algebra. Both rasters were equally weighted with fractional coefficients (0.5) in the calculation, yielding a grid of habitat suitability ranked on a scale from 1-10, with 1 as “optimal” habitat:

$$\text{Habitat suitability} = [(\text{species-specific reclassified depth grid} * 0.5) + (\text{distance to peak grid} * 0.5)]$$

The incorporation of depth as a factor greatly improved the predictive capabilities of the habitat suitability model (Figures 18-21). The efficiency of this model was calculated to assess percent area with and without species (Appendix B).

In order to compare the efficiency of both Habitat Suitability Models, an efficiency ratio was calculated for Model 1 (Distance to TPI₅₀ Peaks) and Model 2 (Distance to TPI₅₀ Peaks + Depth) (Table 8). The ratio is generated by calculating the (percent species) / (percent transect) by category. The efficiency for Model 2, which includes species-specific preference for depth, is greater for most categories, most notably, the “optimal” habitat category (category 1).

Stock Estimates

With the habitat suitability models generated for this project, we are able to provide species-specific and *Sebastodes* stock estimates within the shale bed study area for all species observed. Stock estimates were calculated by extrapolating the within-transect density estimates across the entire study area for each suitability class. The density results were standardized to 100m² (Figures 9-21). Stock estimates were then calculated by multiplying the density estimate for each suitability class by the total area of that class, which were then summed to yield estimates for the entire study area.

Discussion

ROV Video Survey

The use of ROV video data was fundamental to building these models. Precise position of each fish observation allowed the overall resolution of the model to remain at 2m. Such high resolution has rarely been achieved in habitat assessment models of either terrestrial or marine environments. The video transects covered approximately 3% of the multibeam survey area at an average 0.2Km spacing, running perpendicular to the strike of the shale reef (Figure 2).

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Thus, the design of the ROV survey allowed for optimal species-habitat assessment.

Model Parameters

Design of the habitat suitability models required determining which input parameters most significantly affected *Sebastes* distribution and abundance. Four initial parameters were investigated, including depth, slope, rugosity and Topographic Position Index. Each factor was analyzed with varying classification schemes, both alone and in combination with other factors. Multivariate statistical analyses suggested that both bathymetry and TPI₅₀ class might be important factors influencing the distribution of rockfish in the study area (these factors were retained in a stepwise multiple regression equation when all four factors were included), but the results were not statistically significant. Despite these results, there appear to be strong correlations between both depth and TPI₅₀ class, and fish distribution. Transformation of the data and re-analysis may yield more conclusive statistical test results, and this is currently being done.

Concurrent with statistical testing, much effort was made to incorporate all four factors into a model using GIS techniques. The methods employed failed to indicate that slope and rugosity, as calculated from the bathymetric DEM, were significant factors affecting rockfish location. Due to the low-relief nature of the shale bed outcrops (maximum height 1-2m), and the relative resolution of the multibeam bathymetry DEM (2m), the slope values calculated were lower than expected. While a DEM cell-size of 2m is very high resolution, (higher resolution DEMs are a rarity), the low level of relief in the shale beds yields underestimates of slope at this resolution. Likewise, our rugosity results were likely a poor measure of surface roughness for the low-relief shale bed study area. It is possible that reclassification and /or recalculation of slope and rugosity using vertically exaggerated elevations (as was done for TPI analysis) may increase the utility of these data layers for incorporation in the habitat suitability models generated, and this is planned. But within the context of this study, these factors were eliminated from the models, due to time constraints. It is also quite possible that these factors are correlated with one another and with TPI, which is an undesirable attribute when choosing which factors to include in a model.

Topographic Position Index, however, appeared to be a useful parameter for predicting fish distribution, and was analyzed to determine the most effective scale. Substrate and relief information collected during the ROV survey proved that TPI with a 50m neighborhood radius fit the data most accurately. Further analysis of rockfish distribution showed that *Sebastes* were found most frequently on either TPI₅₀ peaks or flat areas. Patterns observed during the video analysis showed rockfish were most abundant on or near high relief landforms. Since flat areas themselves did not seem to be the attractive feature, but rather their proximity to a peak, peak areas were isolated and a grid representing the distance to peak features was calculated. In addition to distance from peak features, depth appeared to be an important factor in species distribution. It is important to note that the TPI algorithm classified the edges of the survey as

“peak.” The shallow edges of the survey area to the south and east (Figure 6) are near shore, and thus will be classified as a peak relative to its neighbors due to decreasing depth approaching the shoreline. The deep edge of the survey, however, is classified as a peak due to residual multibeam artifact. Although the effect is not pronounced, it is a confounding factor in the generation of habitat suitability models based on distance to TPI peak. Adjustment of the TPI algorithm to minimize these artifacts in an objective, repeatable fashion is being examined and will help improve the effectiveness with which this data type can be used in model creation.

Information from the ROV survey showed that certain species appeared to have depth-dependent distributions. Four species (*S. serranoides/S. flavidus*, *S. auriculatus*, *S. rosaceus*, *S. rubrivinctus*) showed a discernable pattern of depth distribution, thus depth was included as a parameter in the suitability models for these species.

Habitat Suitability Models

Two sets of habitat suitability models were created. Model 1 uses distance to TPI₅₀ peaks as the only parameter. This simple, single-parameter measure of habitat suitability correlates well with fish distributions for *Sebastes* spp. as a whole, as well as for each individual species (Figures 9-17). Each map represents category values as species-specific densities (number of rockfish/area of transect by category). Categories are ranked in ascending order from 1 to 10, with category 1 as “optimal” habitat. In Model 1, optimal habitat is determined to be 0-10m to TPI₅₀ peaks, and includes the peak areas. Using this model, 87% of *Sebastes* individuals, and an average of 81% of fish of each species fell within the predicted optimal habitat (Table 1A).

The second habitat suitability model included both distance to TPI₅₀ peaks and species-specific depth distributions as parameters for each of the four species for which there was a discernable depth pattern (Figures 18-21). Again, each map represents category values as densities (number of rockfish/area of transect by category). Categories are ranked in ascending order from 1 to 9, with category 1 as “optimal” habitat. For this model, optimal habitat requires both a distance to peak of 0-10m and a location within the most preferred depth zone as determined from the ROV survey data. Model 2 also predicts an average of 81% of fish to be within the optimal habitat category, however, the optimal habitat area in Model 2 is nearly a quarter less than for Model 1 (Table 1, Appendix B). Therefore, the efficiency of predicting the location of species relative to optimal habitat has increased by over 50% from Model 1 to Model 2. Thus, the predictive power of these habitat suitability models is dramatically increased when using species-specific parameters to refine the model’s input parameters.

Stock Estimates

Model 1 predicts an estimated stock size of approximately 53,000 *Sebastes* belonging to the eight species enumerated in this project (Table 9).

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Comparisons between the stock estimates of Model 1 (Distance to TPI₅₀) and Model 2 (Distance to TPI₅₀ + Depth) show that Model 2 predicts an average 12% larger stock size (Table 9). Model 2 appears to be more efficient, and thus may be more accurate, as it incorporates species-specific depth distributions, which should predict where fish of different species should be located with greater precision. As Model 2 is likely to be a more efficient and accurate model of species distribution, the larger stock size may be the more accurate figure.

As stock estimates are often used in making management and policy decisions, however, care must be taken to validate these results further before basing any action on them (see below). Future research might compare the numbers generated with the habitat suitability model to stock estimates from fisheries data, or from other independently gathered fish population data. In addition, results from this study, including habitat suitability models and stock estimates, should not be applied blindly to other sites of interest, as these results have not yet been validated satisfactorily for the shale beds, let alone for other sites. While the hope is that habitat models can be used to produce accurate fish stock estimates without actually counting fish, this should be avoided unless it is the only option available. Even after a model has been properly validated for a given site and time period, it may not be appropriate to apply it in another space or time. Physical habitat availability, as described by seafloor morphology, is but one factor that may influence rockfish distribution; many other factors exist, including recruitment, water temperature, food availability, and predation / fishing pressure, to name a few. The fact that plenty of suitable rocky reef habitat exists in a location does not necessarily mean that fish abundance will be comparable to that found in similar reef habitats at other locations. Models can provide a first estimate of population size, but there is simply no substitute for actually counting fish, at least as a means of model validation if not outright stock estimation.

Model Validation

The estimation and discussion of model efficiency given here is hampered by the tautological nature of how the models were produced. Because the models were based (to at least some extent) on observed patterns of fish distribution, using the same observation data to test model efficiency is an incomplete evaluation. Validation of the model using data gathered independent from those used to generate the model is preferable, and we are currently doing this using data gathered during the Fall 2002 ROV surveys. Analysis of the Fall ROV data will also allow us to examine any potential seasonality in fish distribution, which might then be incorporated into the model as a factor. In addition to using independent data for model validation, bootstrapping and jackknifing methods for statistically testing model efficiency are being explored.

Conclusions

The methods and models developed for this project are geared to assess *Sebastodes* species on the shale beds of Monterey Bay, CA, and appear to be an

accurate predictive model of distribution and abundance. With these habitat suitability models, we can accurately predict type of habitat within which approximately 90% of *Sebastodes* spp. fishes in the shale beds will be found.

The use of multibeam bathymetry to generate habitat suitability models has potential to be an effective tool in predicting *Sebastodes* species distribution and abundance. While somewhat expensive to acquire and process, multibeam bathymetry is of extreme value for use in characterizing benthic marine habitats, and as the costs decrease, availability of high-resolution multibeam data is increasing. This project has shown that using repeatable algorithmic terrain analysis techniques, products can be derived from high-resolution multibeam DEMs that can be used to develop cost-effective, non-subjective, scaleable habitat suitability models and stock estimates. As natural history information increases for the species concerned, including habitat associations and life-history information, species-specific suitability models can be refined and improved.

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Figures

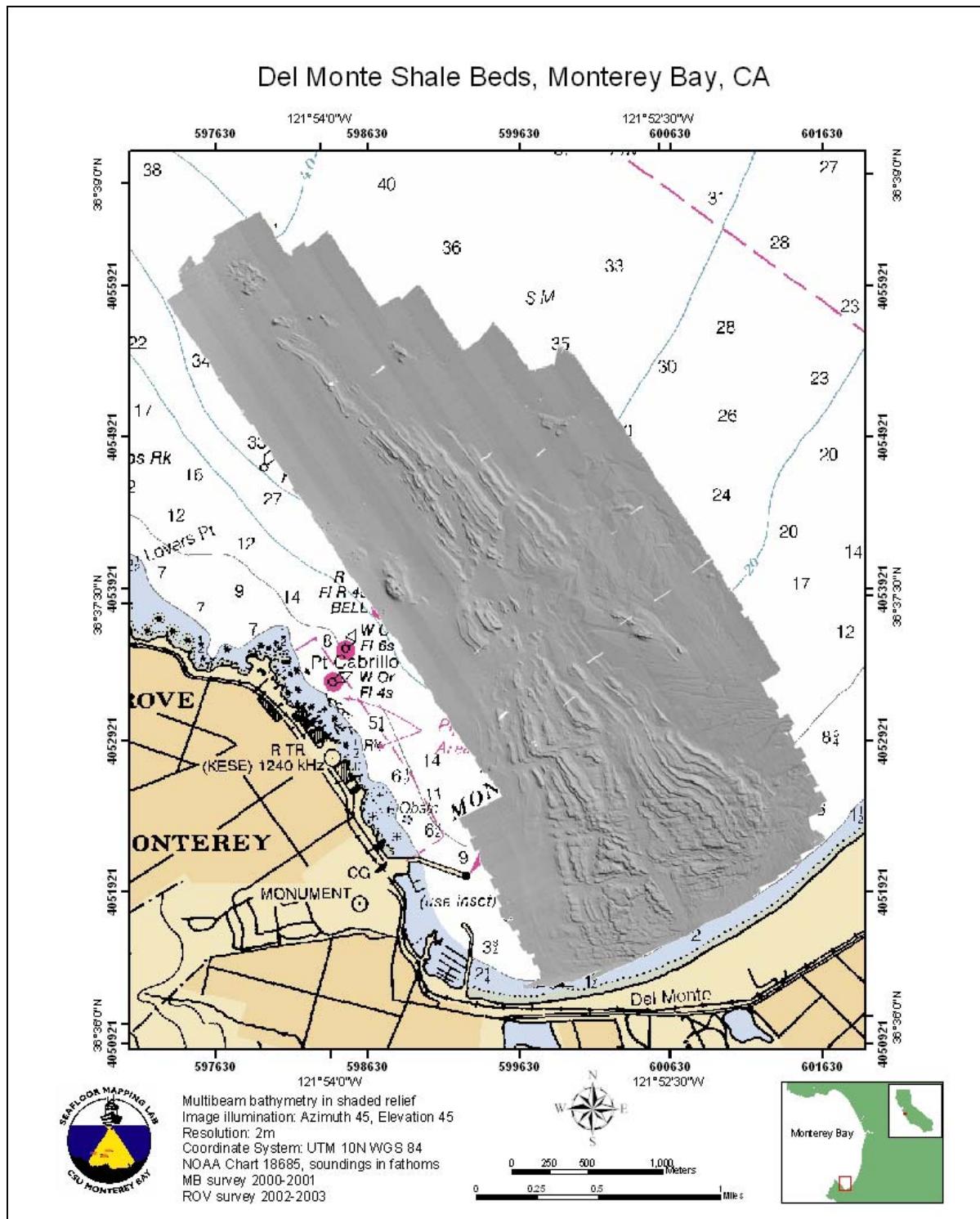


FIG 1. Shaded-relief grayscale image of multibeam bathymetry DEM for Del Monte shale beds study site, Monterey Bay, CA.

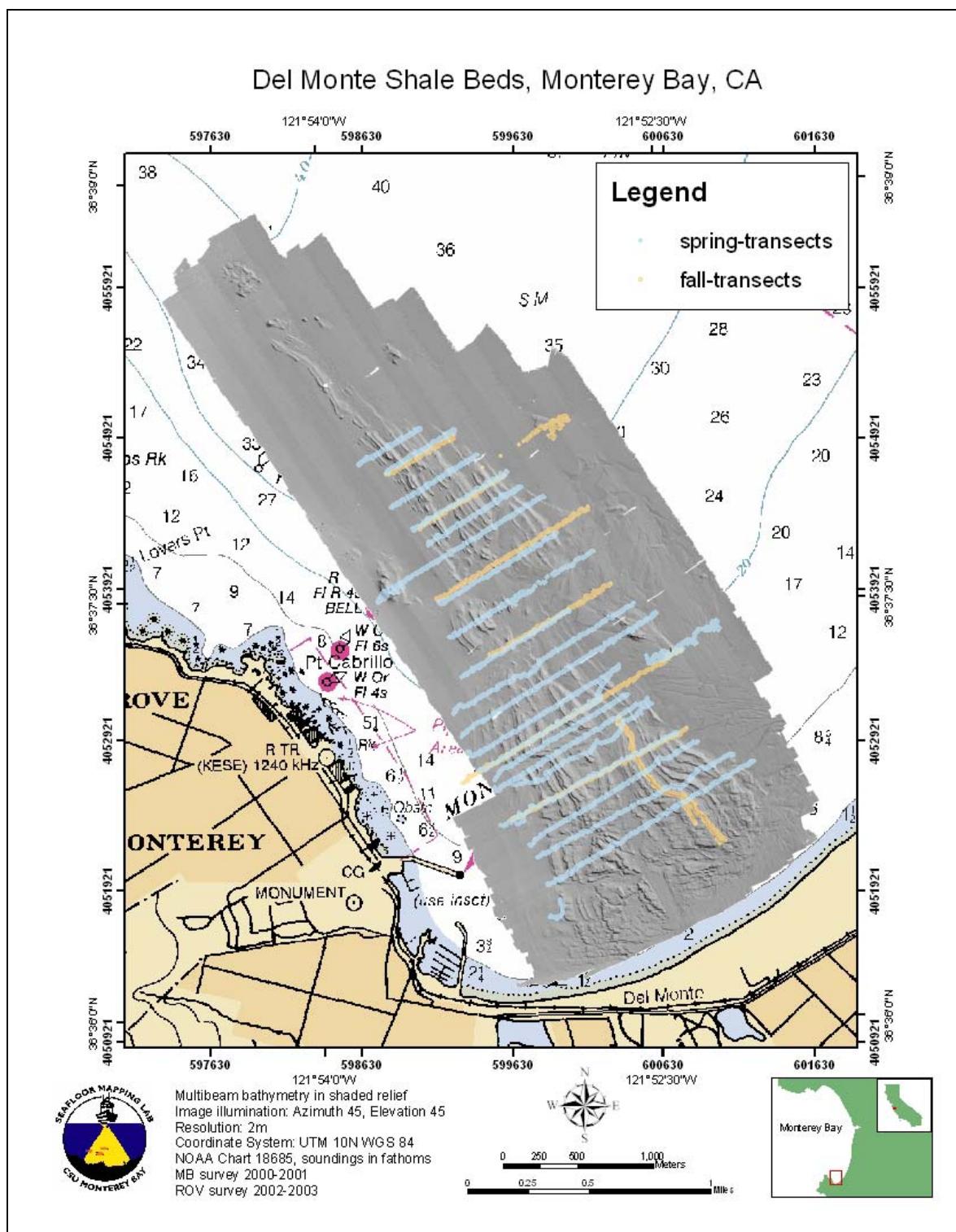


FIG 2. ROV survey track lines for Fall 2002 and Spring 2003.

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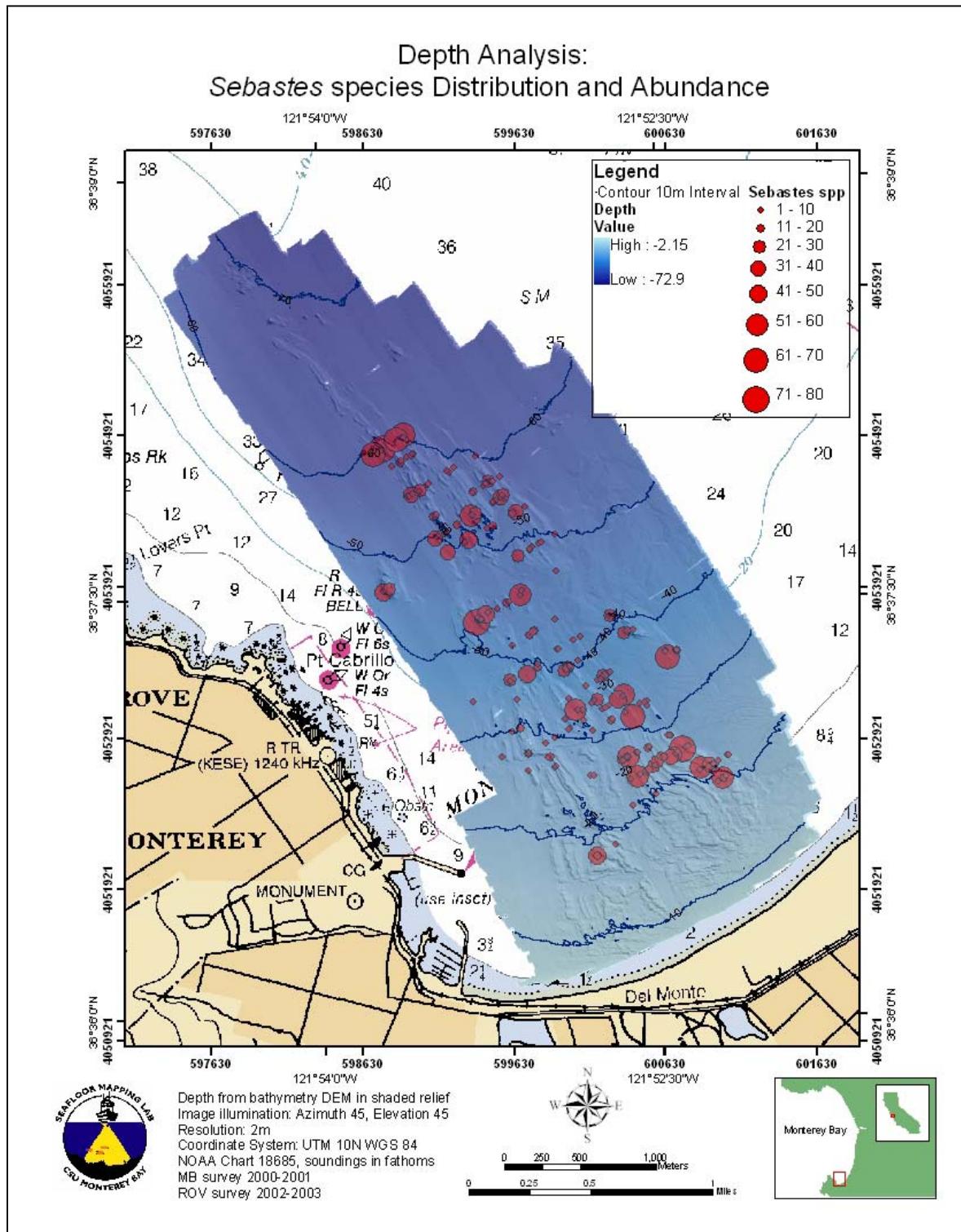


FIG 3. Distribution and abundance of *Sebastes* spp. (rockfish) observed during Spring 2003 ROV survey, with shaded-relief bathymetry DEM. Size of symbol is proportional to number of fish observed, and DEM color indicates depth.

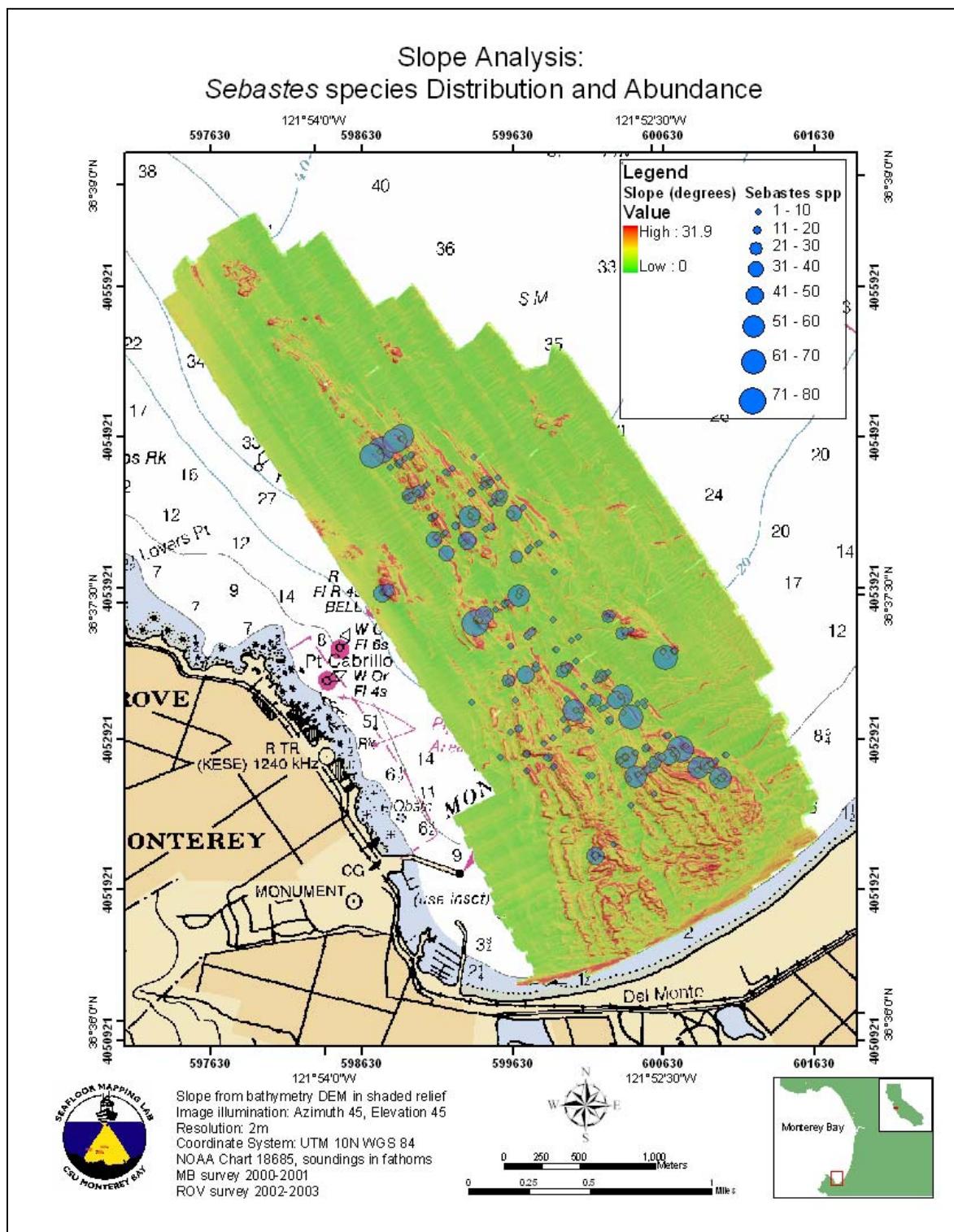


FIG 4. Distribution and abundance of *Sebastes* spp. (rockfish) observed during Spring 2003 ROV survey, with slope grid derived from bathymetry DEM. Size of symbol is proportional to number of fish observed, and grid color indicates slope.

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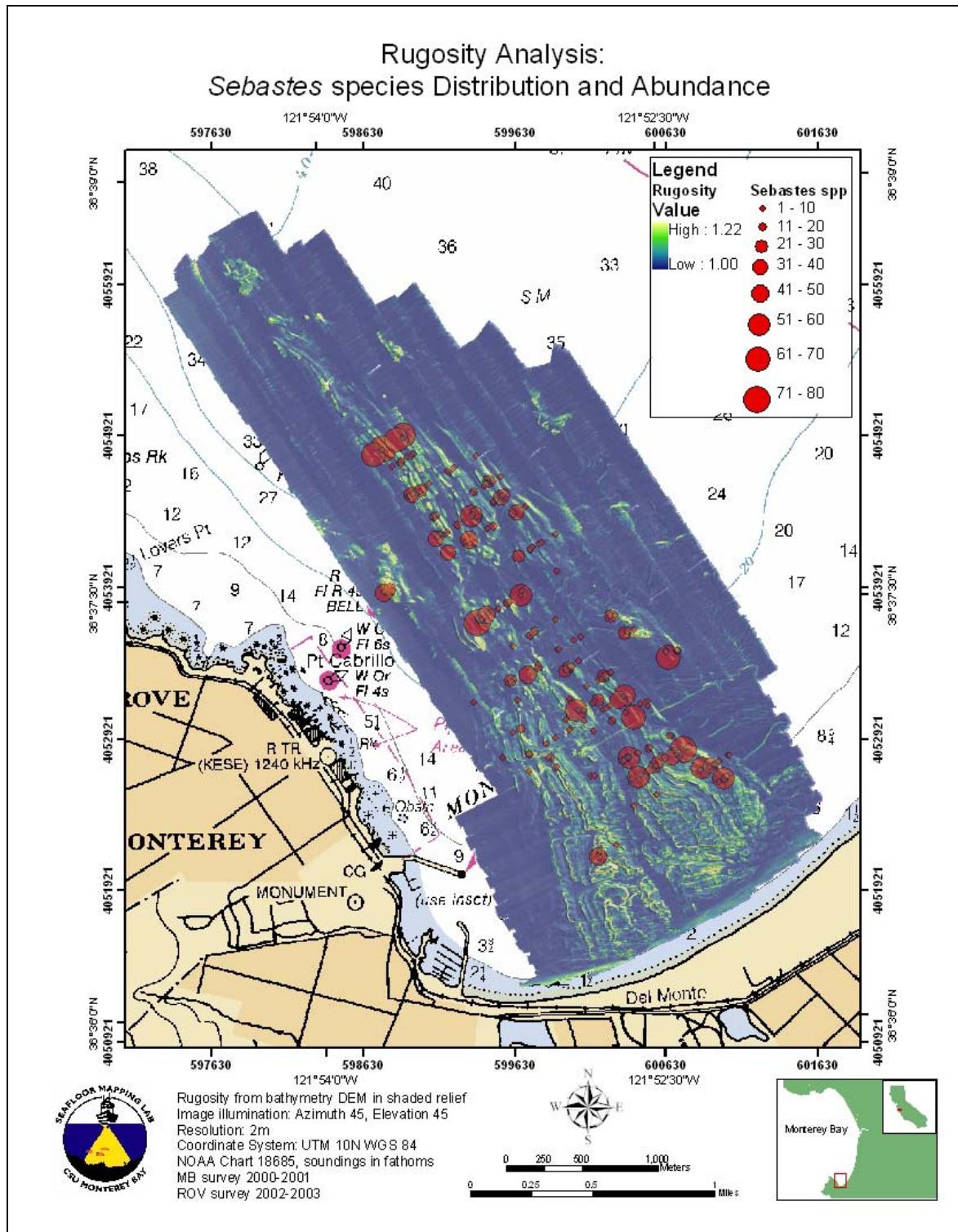


FIG 5. Distribution and abundance of *Sebastes* spp. (rockfish) observed during Spring 2003 ROV survey, with rugosity derived from bathymetry DEM. Size of symbol is proportional to number of fish observed, and grid color indicates rugosity (surface area : planar area ratio).

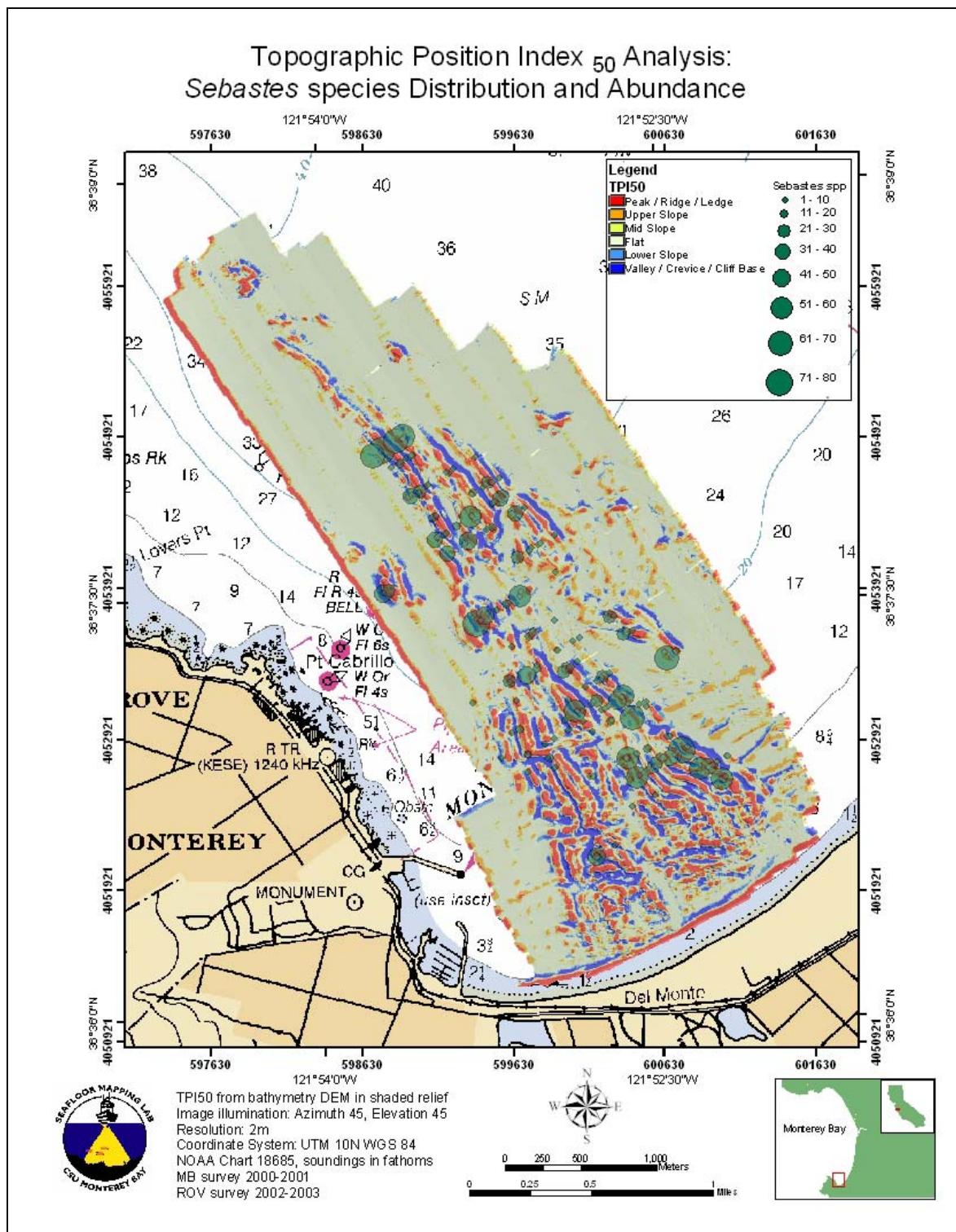


FIG 6. Distribution and abundance of *Sebastes* spp. (rockfish) observed during Spring 2003 ROV survey, with TPI₅₀ classes derived from bathymetry DEM. Size of symbol is proportional to number of fish observed, and grid color indicates TPI₅₀ class.

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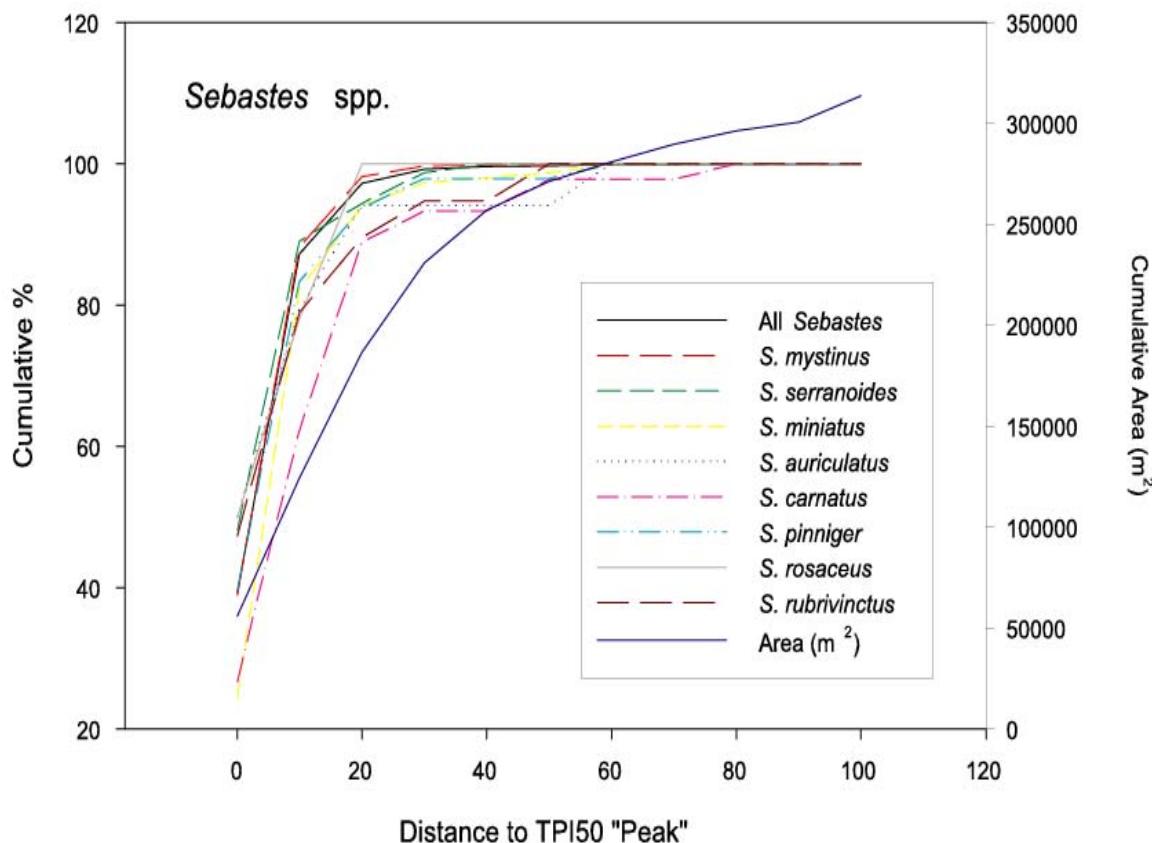


Fig. 7a. Cumulative percent abundance of *Sebastes* spp. and cumulative area (within transect buffers) vs. distance to TPI₅₀ "peak". Abundance of *S. mystinus* (blue), *S. serranoides/S. flavidus* (olive/yellowtail), *S. miniatus* (vermillion), *S. auriculatus* (brown), *S. carnatus* (gopher), *S. pinniger* (canary), *S. rosaceus* (rosy), and *S. rubrivinctus* (flag) rockfish increase sharply while area increases more gradually.

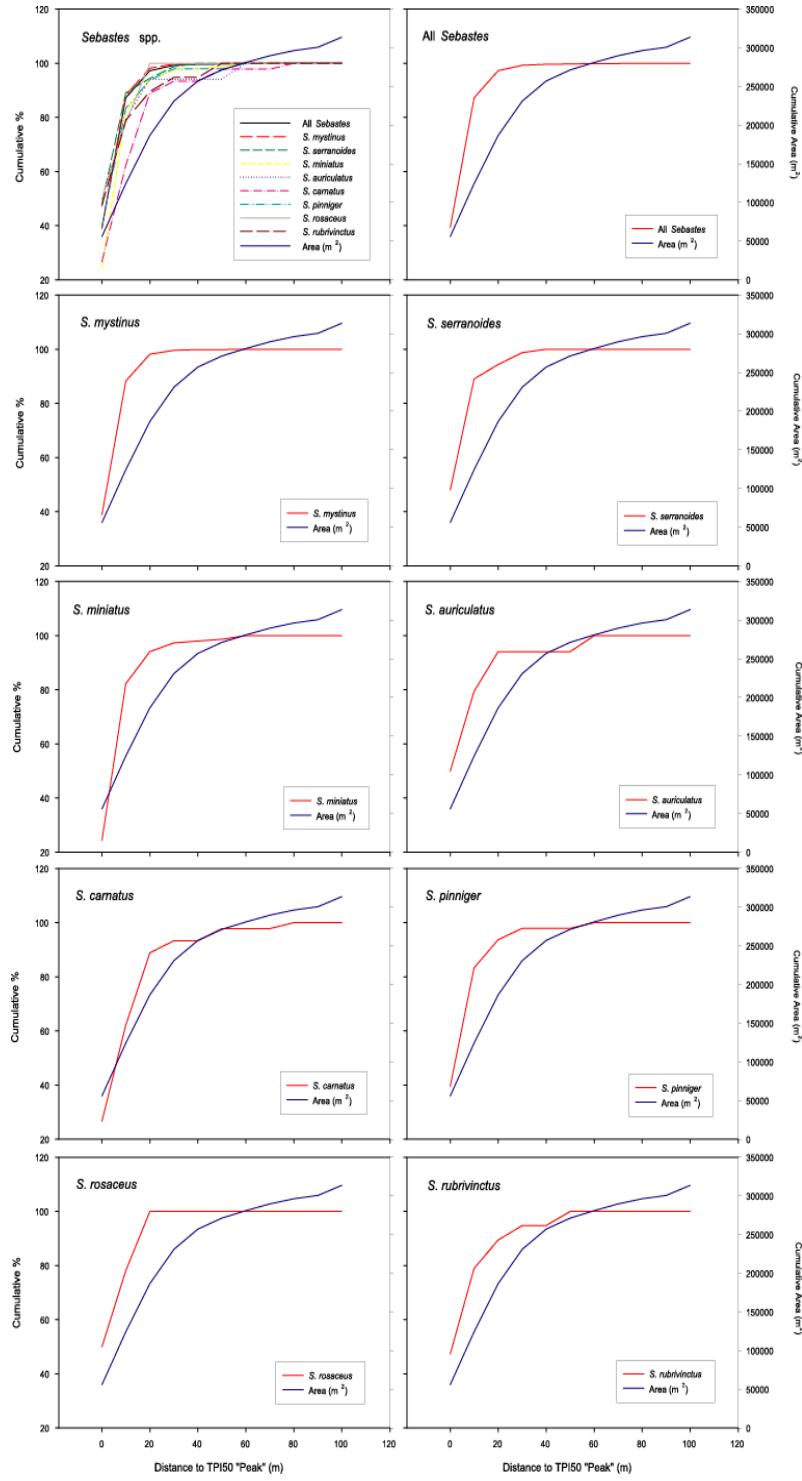


Fig. 7b. Cumulative percent abundance of *Sebastes* spp. and cumulative area (within transect buffers) vs. distance to TPI₅₀ “peak”. Abundance of *S. mystinus* (blue), *S. serranoides/S. flavidus* (olive/yellowtail), *S. miniatus* (vermillion), *S. auriculatus* (brown), *S. carnatus* (gopher), *S. pinniger* (canary), *S. rosaceus* (rosy), and *S. rubrivinctus* (flag) rockfish increase sharply while area increases more gradually.

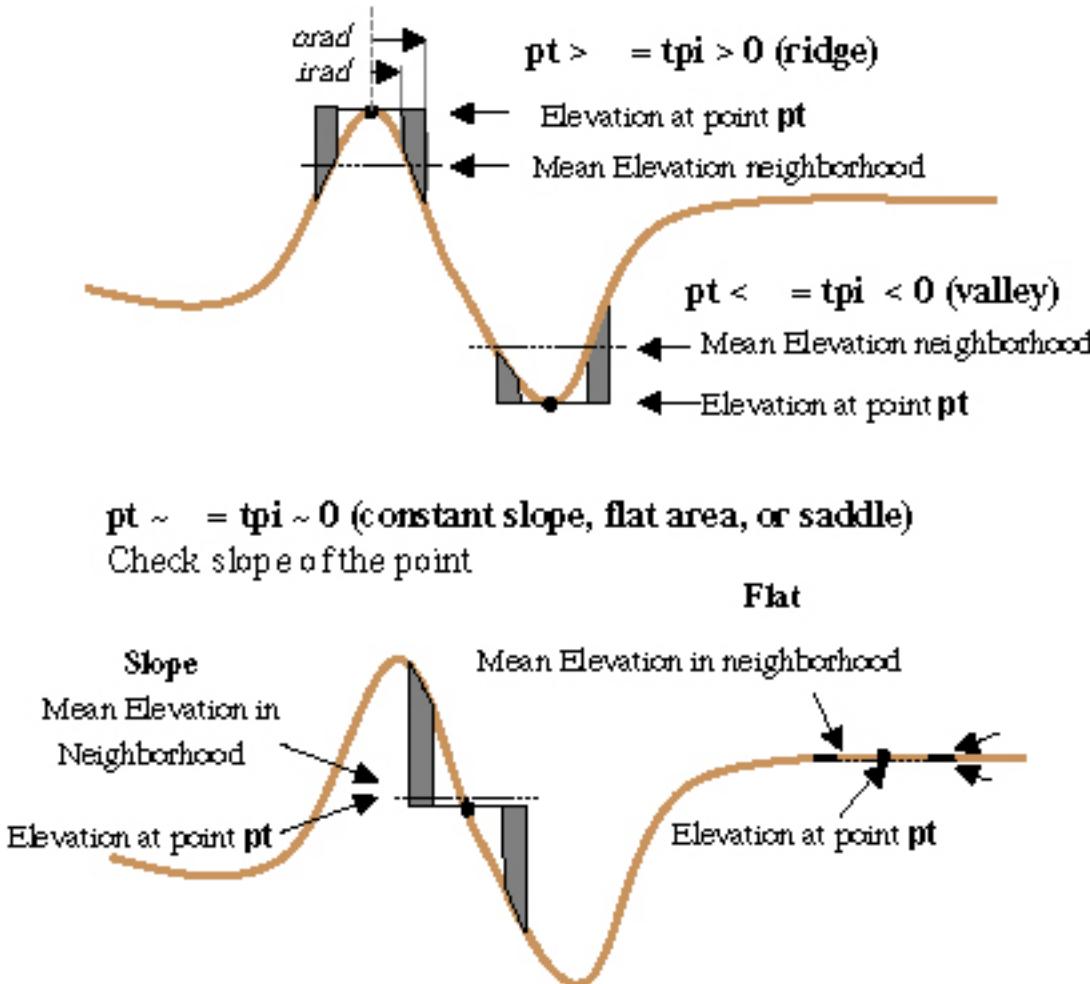


Fig. 8. Schematic depiction of TPI calculation. Brown line represents a hypothetical cross-section view of a DEM, with cases illustrated showing TPI calculation of various feature types (peak, valley, etc.). Positive TPI values represent locations that are higher than the average of their surroundings, as defined by the neighborhood (ridges). 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). (After Weiss, 2001)

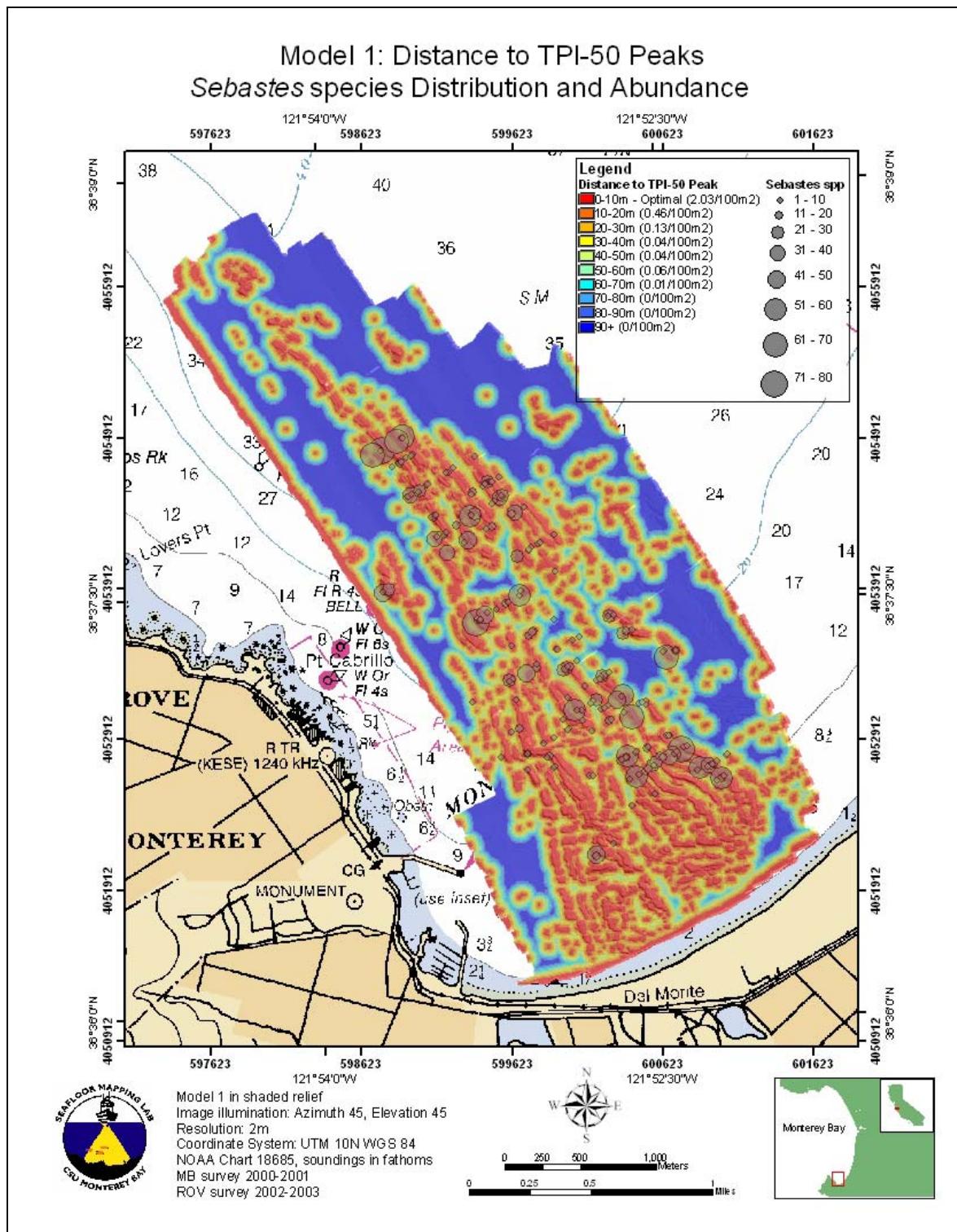


FIG 9. Distribution and abundance of *Sebastodes* spp. (rockfish) observed during Spring 2003 ROV survey, with Model 1 (distance to TPI₅₀ peak) habitat suitability results for *Sebastodes* spp. Size of symbol is proportional to number of fish observed, and grid color indicates Model 1 habitat suitability.

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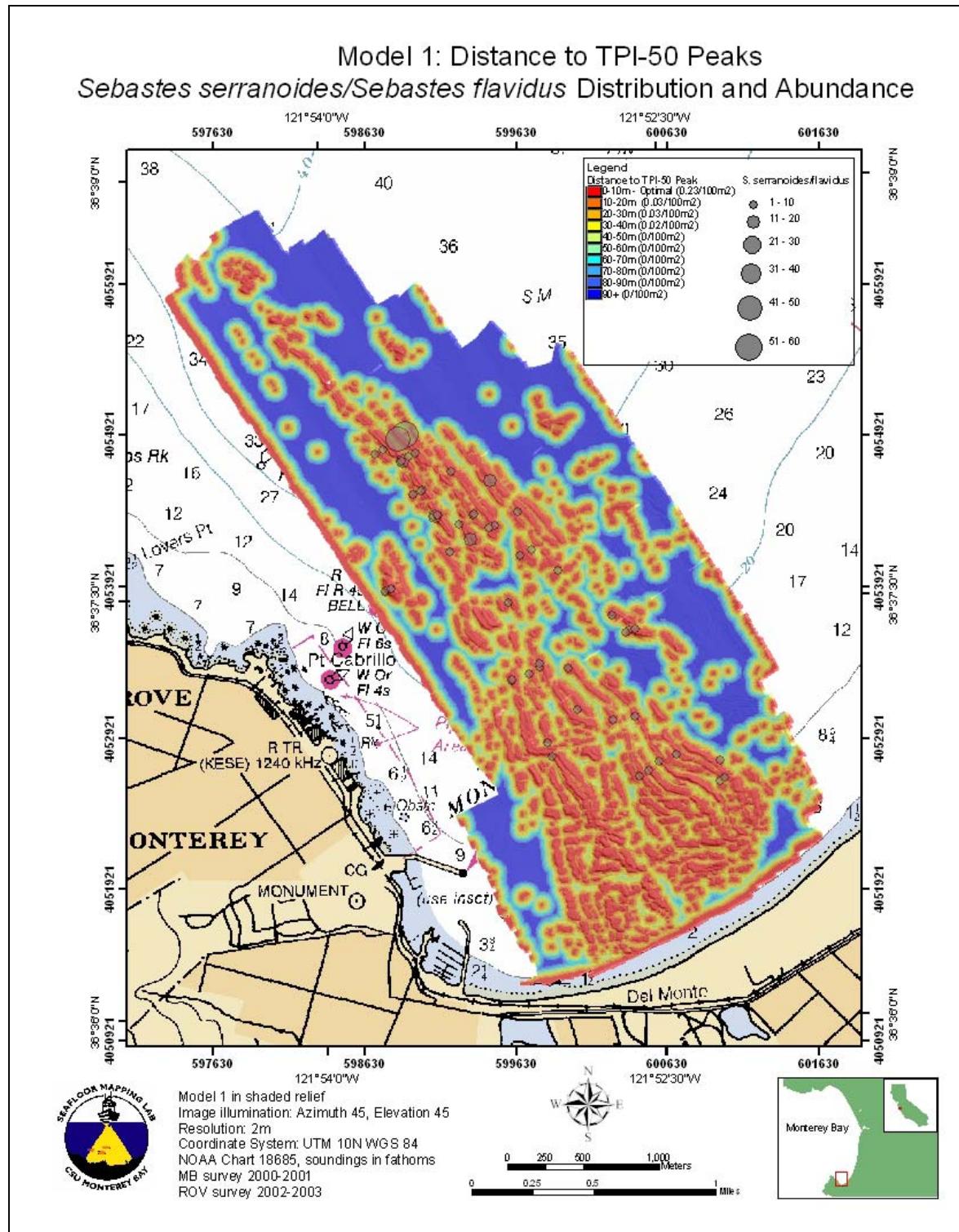


FIG 10. Distribution and abundance of *S. serranoides/S. flavidus* (olive/yellow rockfish) observed during Spring 2003 ROV survey, with Model 1 (distance to TPI₅₀ peak) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 1 habitat suitability.

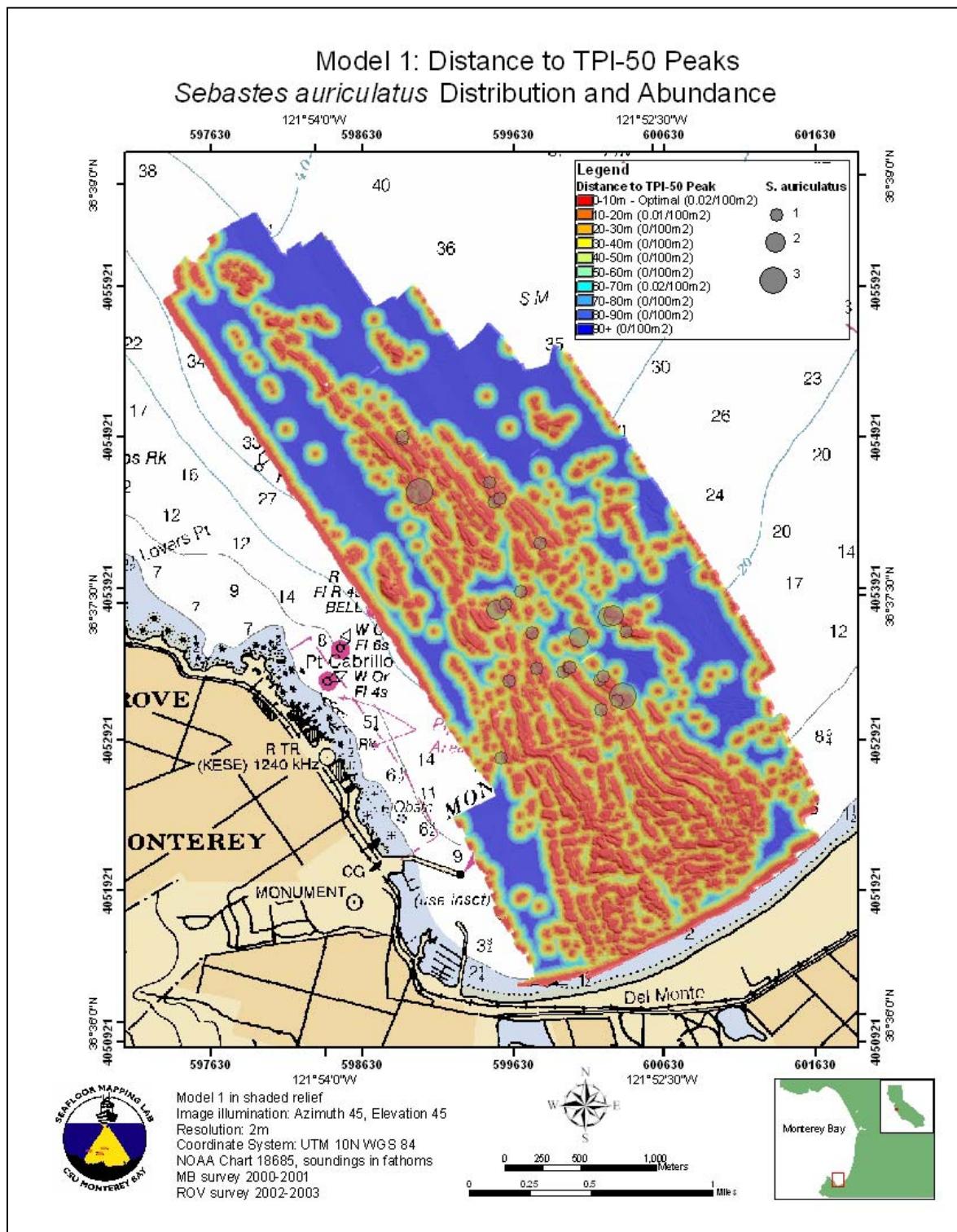


Fig 11. Distribution and abundance of *S. auriculatus* (brown rockfish) observed during Spring 2003 ROV survey, with Model 1 (distance to TPI₅₀ peak) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 1 habitat suitability.

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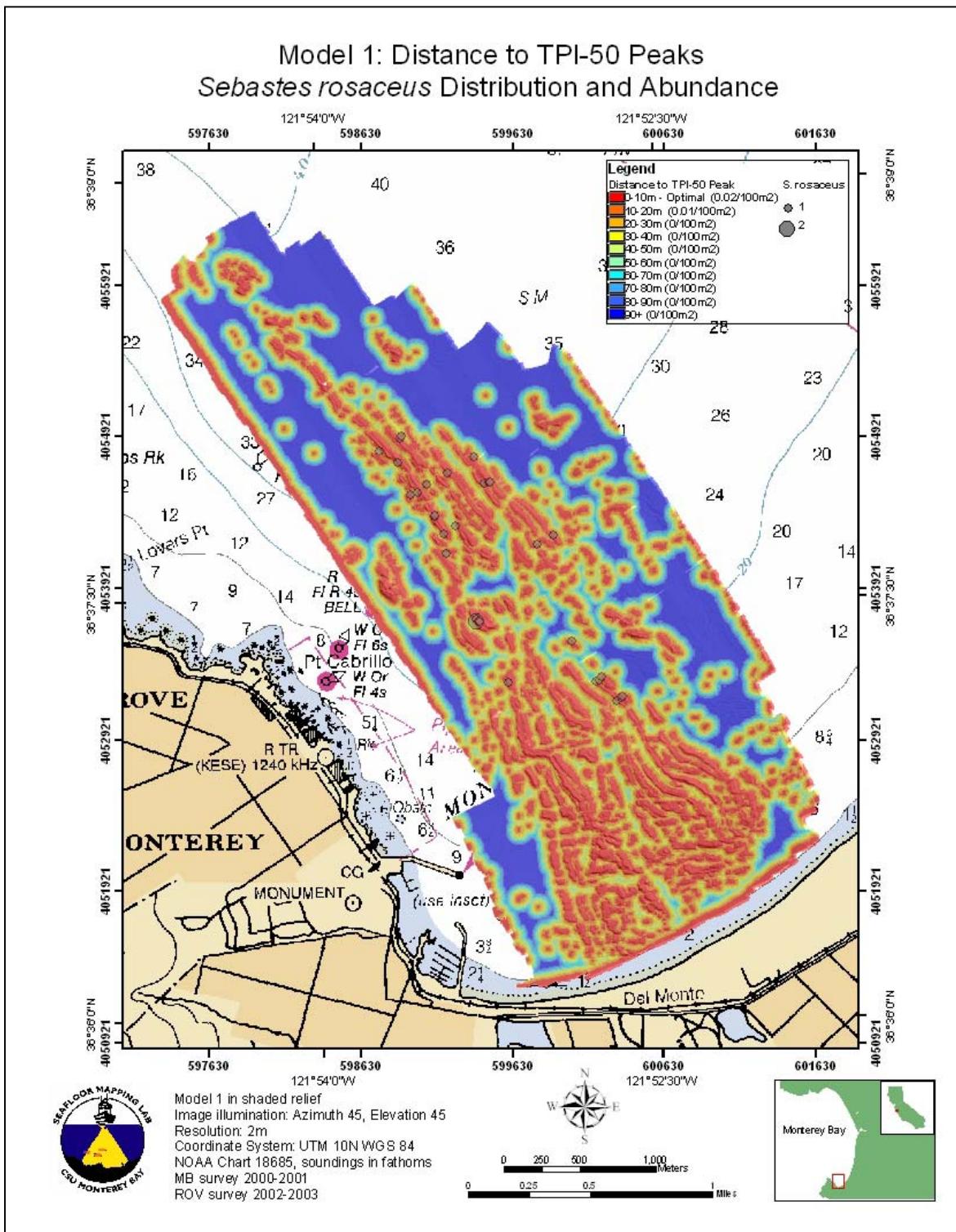


FIG 12. Distribution and abundance of *S. rosaceus* (rosy rockfish) observed during Spring 2003 ROV survey, with Model 1 (distance to TPI₅₀ peak) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 1 habitat suitability.

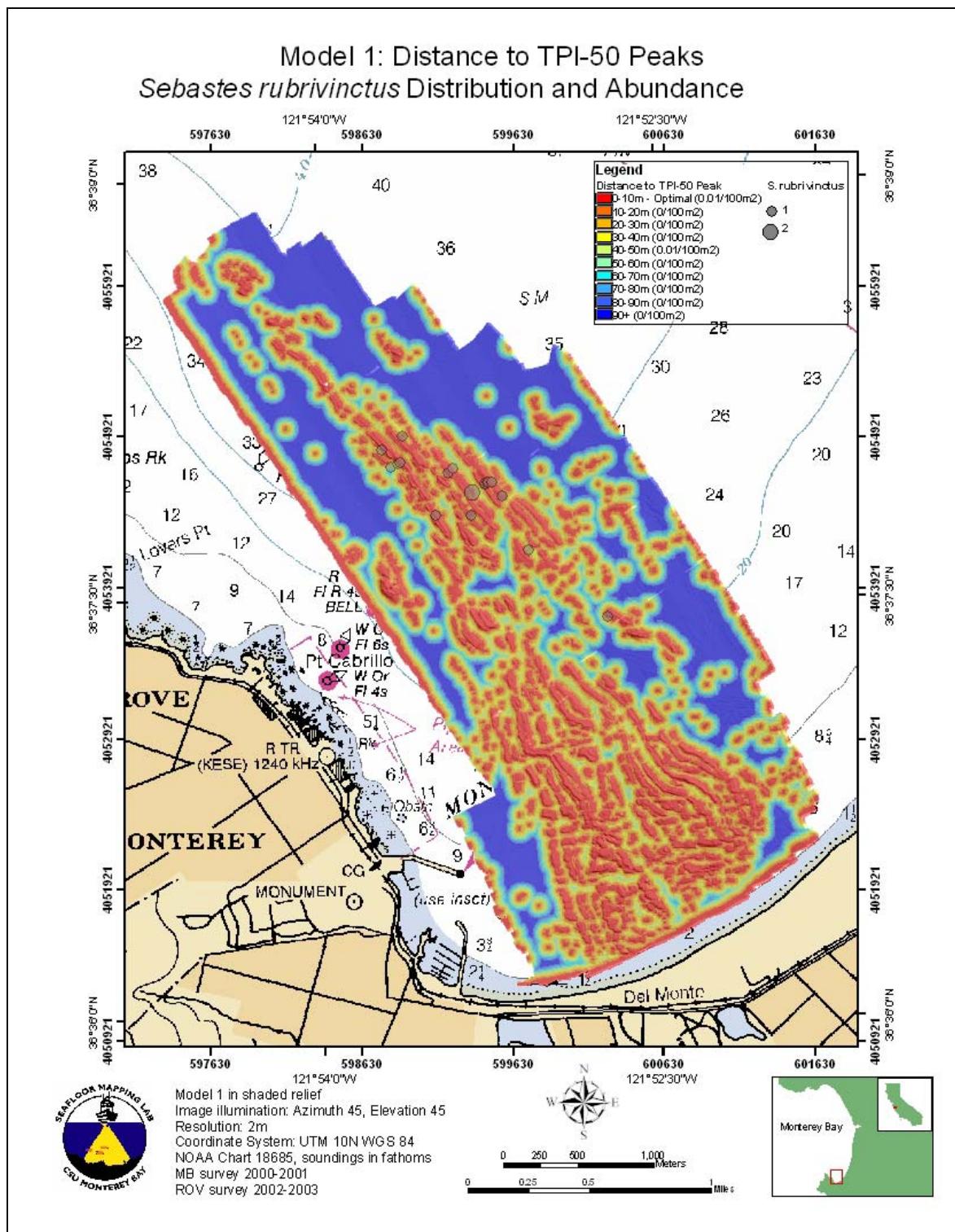


Fig 13. Distribution and abundance of *S. rubrivinctus* (flag rockfish) observed during Spring 2003 ROV survey, with Model 1 (distance to TPI₅₀ peak) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 1 habitat suitability.

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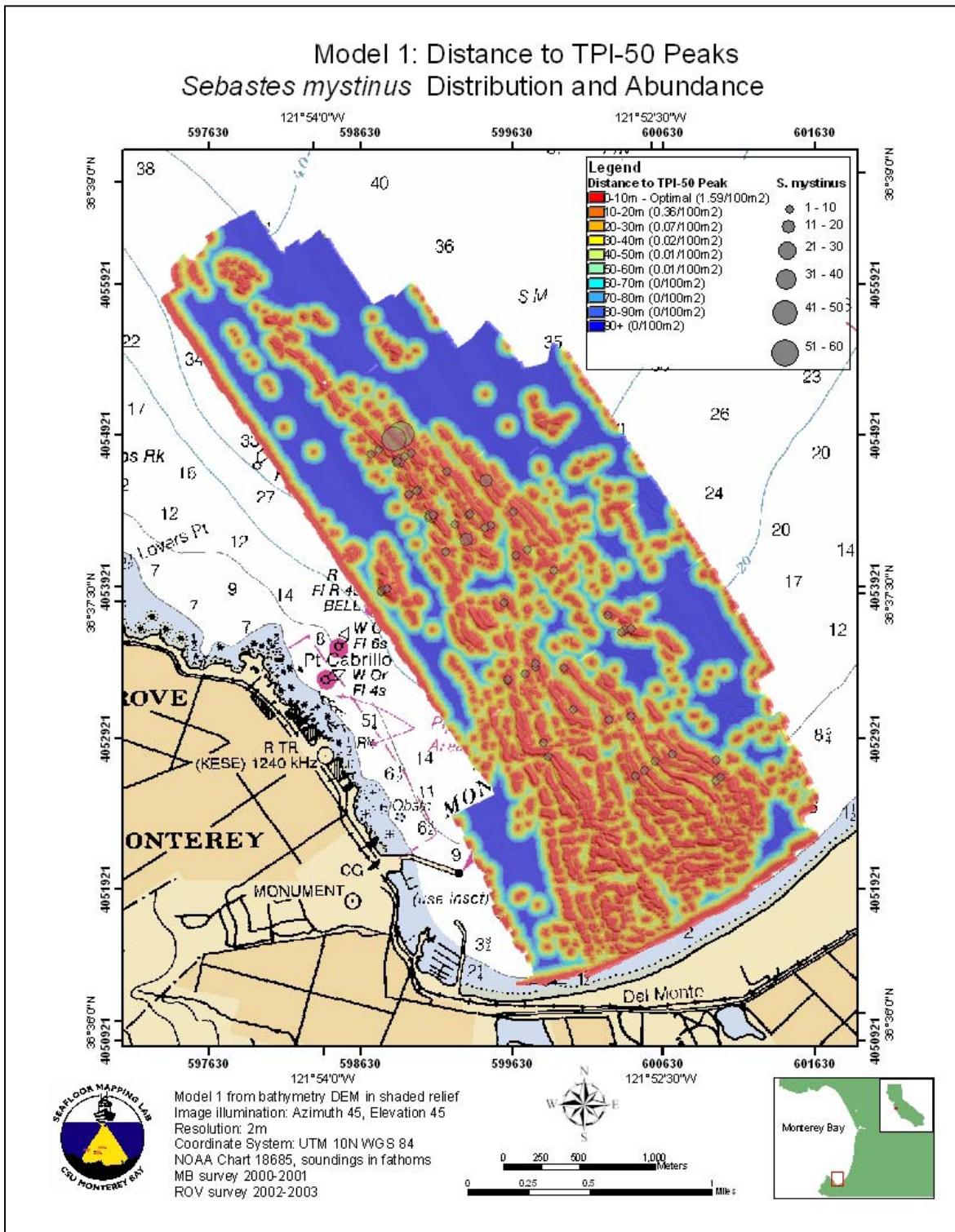


Fig 14. Distribution and abundance of *S. mystinus* (blue rockfish) observed during Spring 2003 ROV survey, with Model 1 (distance to TPI₅₀ peak) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 1 habitat suitability.

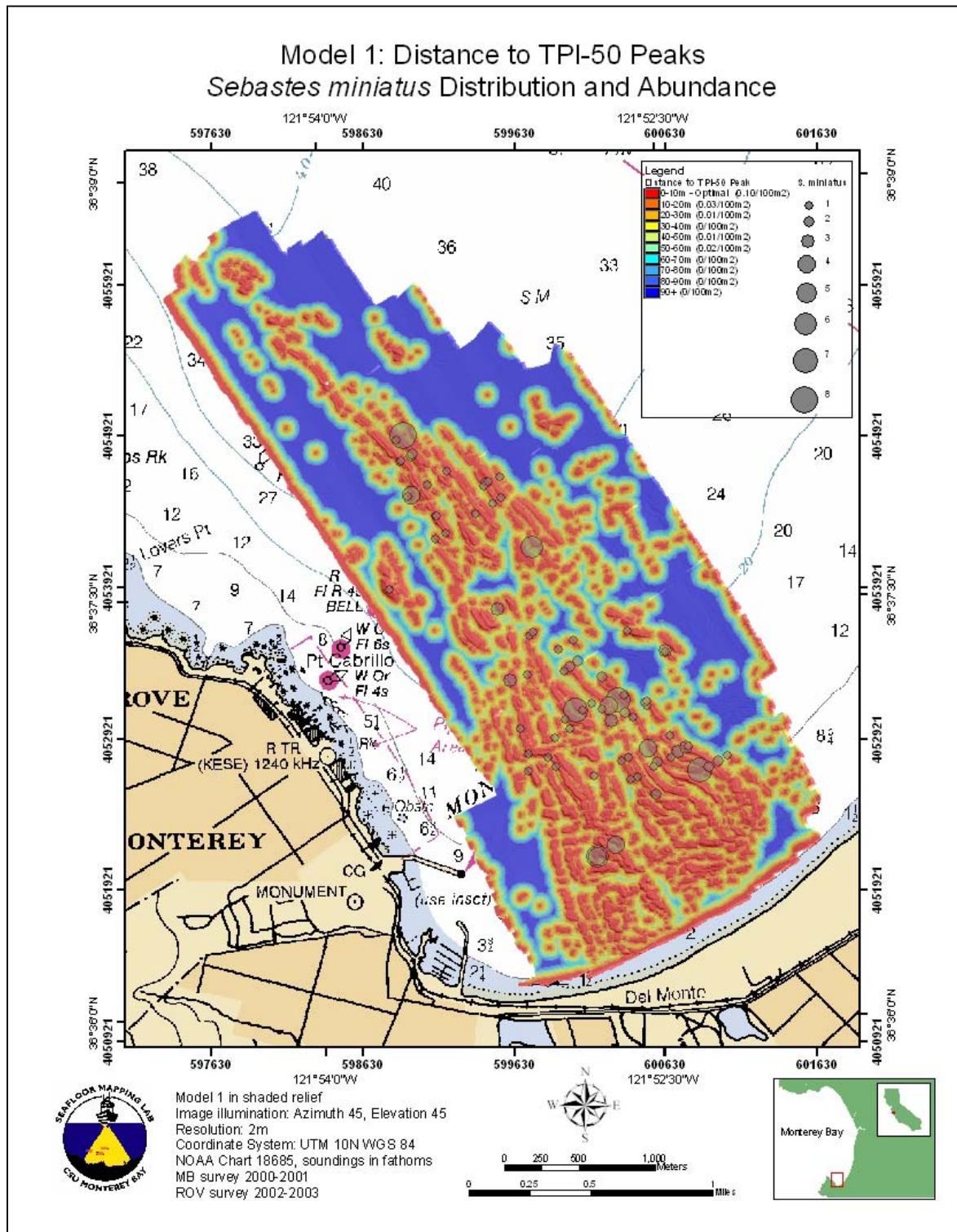


Fig 15. Distribution and abundance of *S. miniatus* (vermillion rockfish) observed during Spring 2003 ROV survey, with Model 1 (distance to TPI₅₀ peak) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 1 habitat suitability.

Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

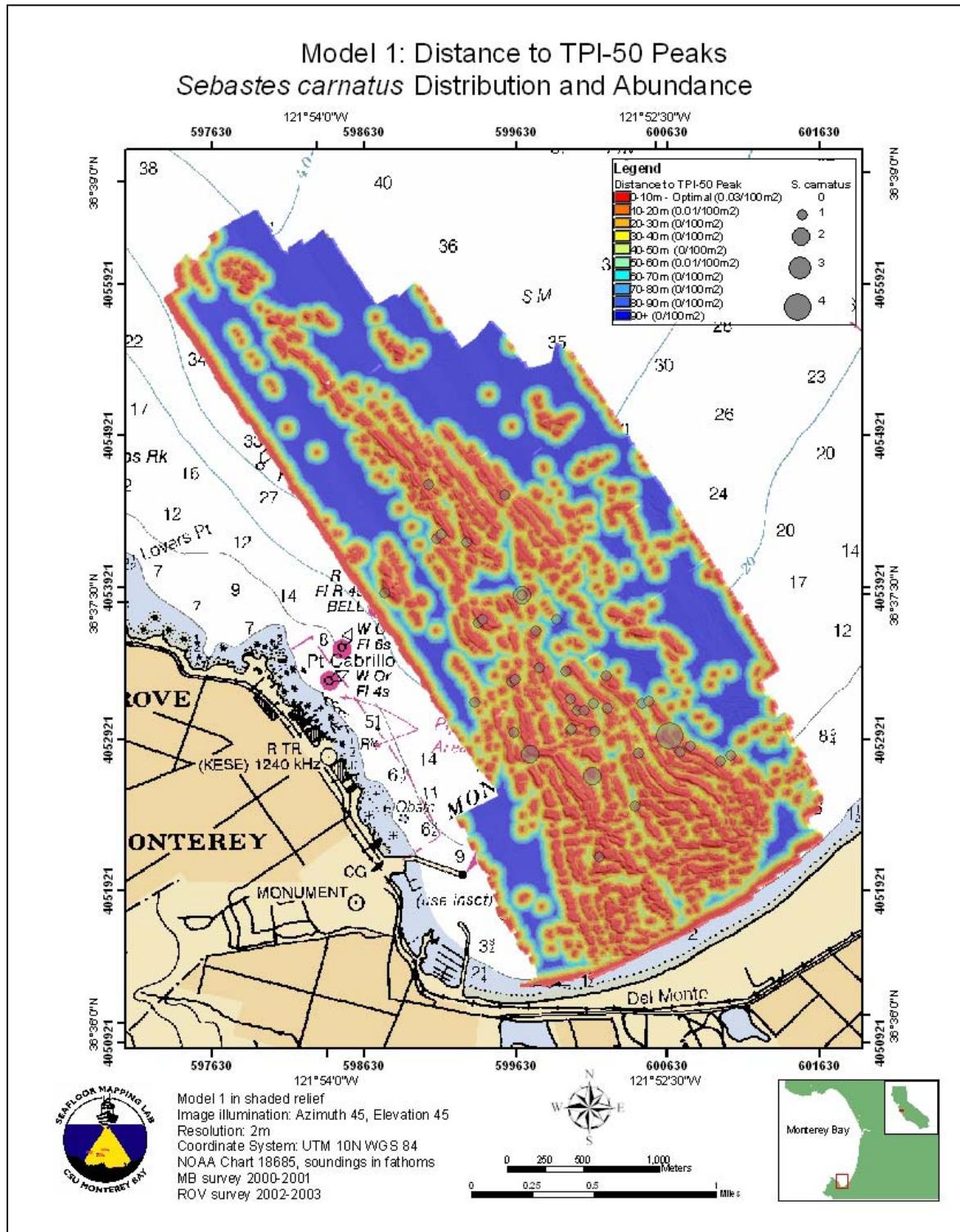


Fig 16. Distribution and abundance of *S. carnatus* (gopher rockfish) observed during Spring 2003 ROV survey, with Model 1 (distance to TPI₅₀ peak) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 1 habitat suitability.

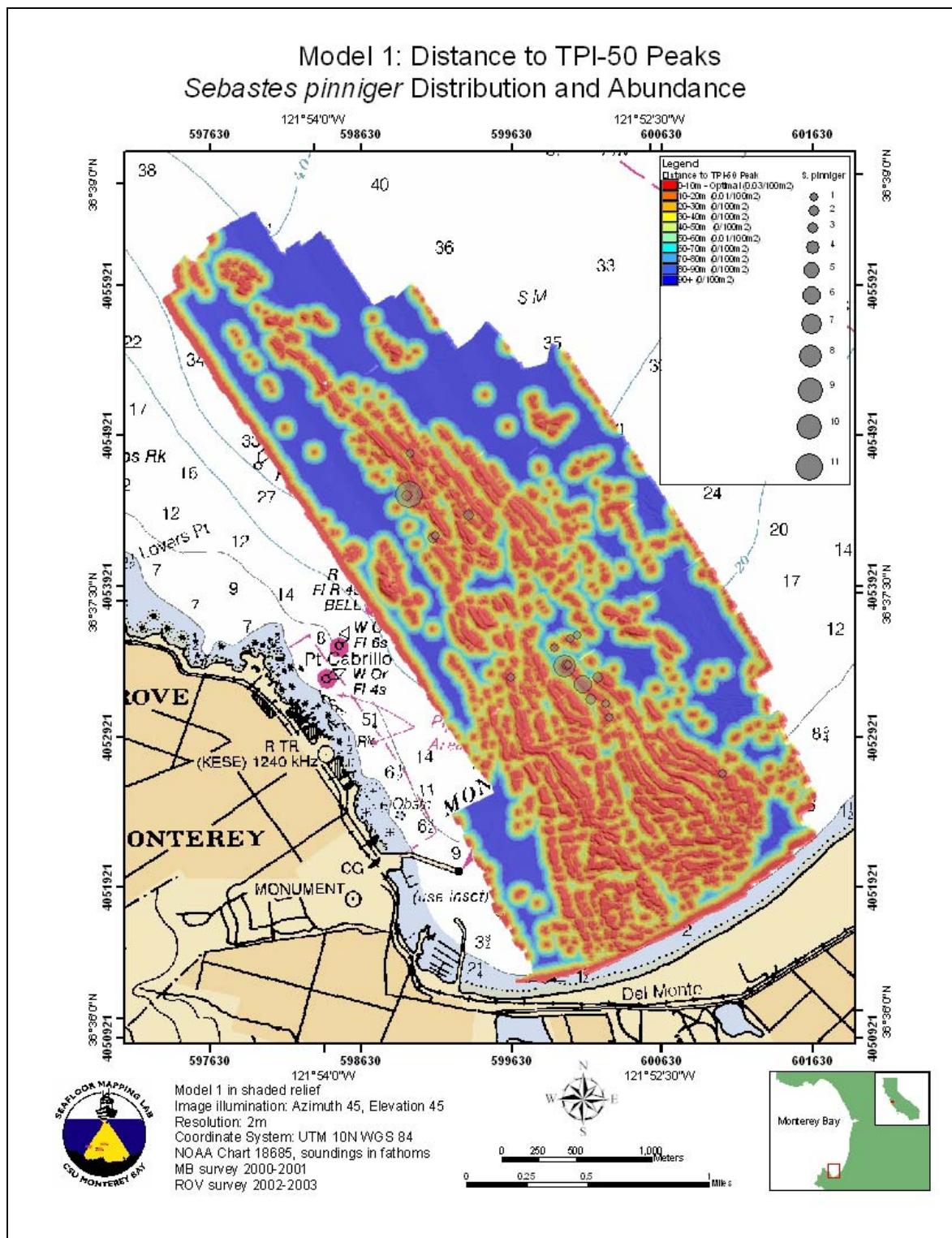


Fig 17. Distribution and abundance of *S. pinniger* (canary rockfish) observed during Spring 2003 ROV survey, with Model 1 (distance to TPI₅₀ peak) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 1 habitat suitability.

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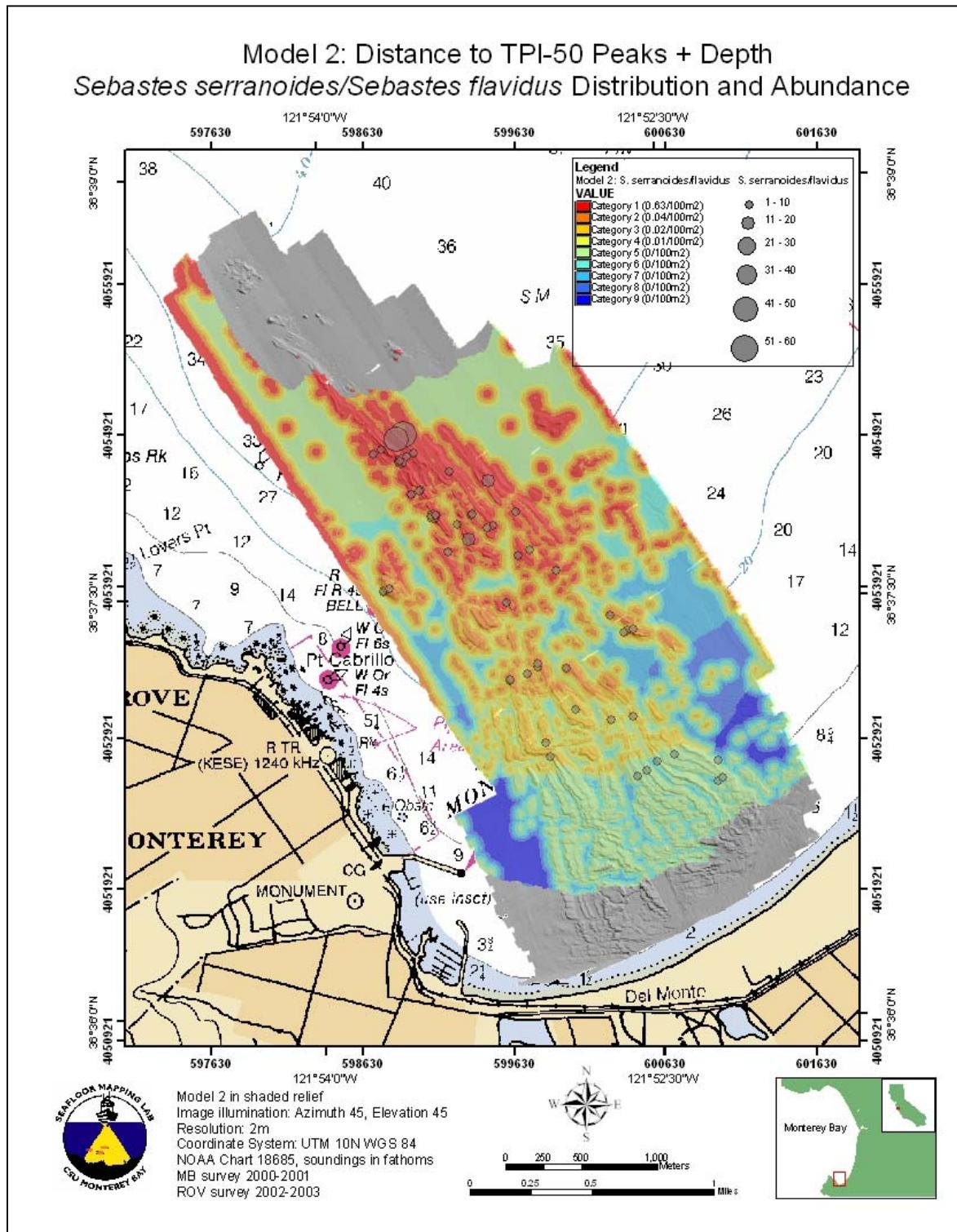


Fig 18. Distribution and abundance of *S. serranoides/S. flavidus* (olive/yellow rockfish) observed during Spring 2003 ROV survey, with Model 2 (distance to TPI₅₀ peak + depth) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 2 habitat suitability.

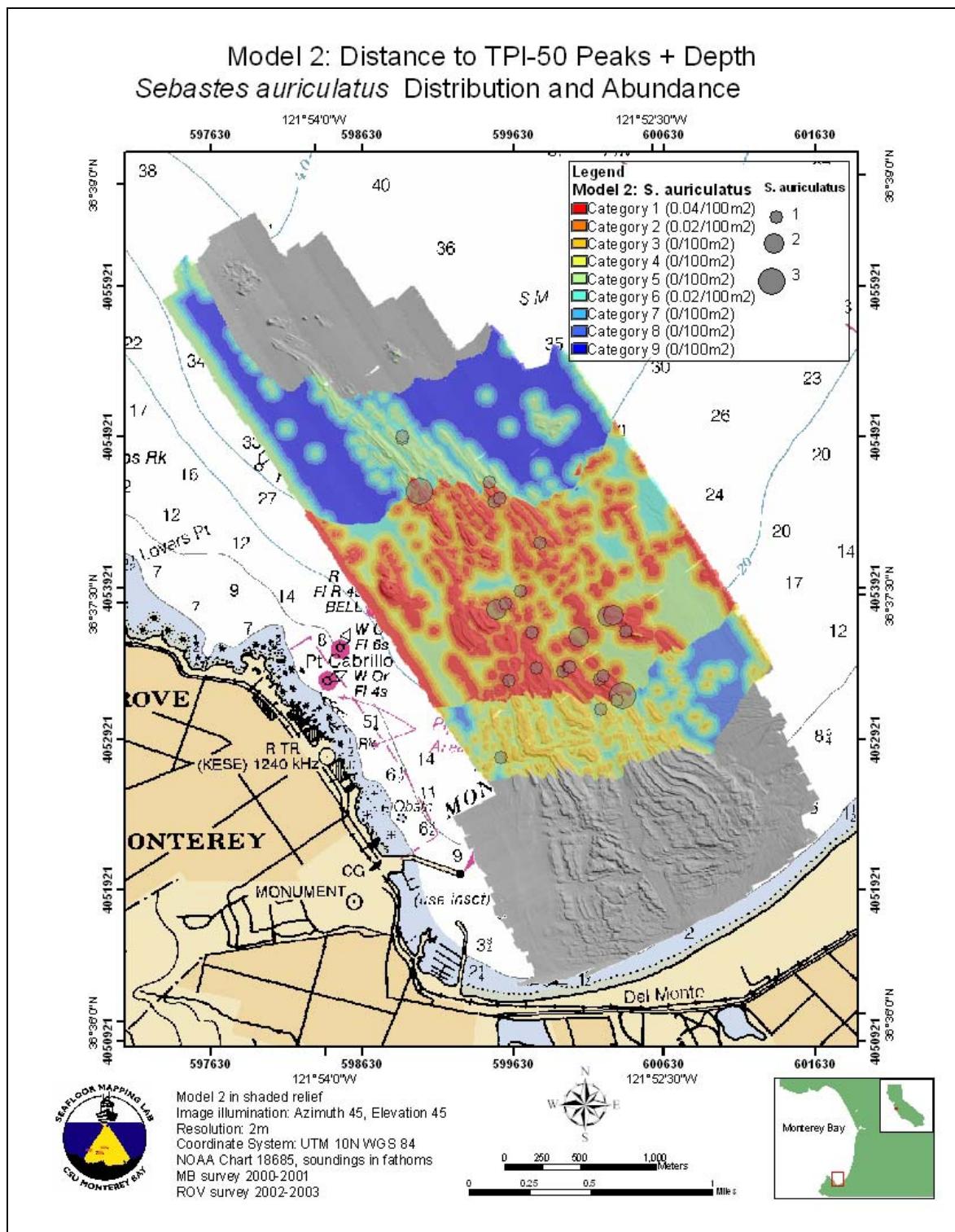


FIG 19. Distribution and abundance of *S. auriculatus* (brown rockfish) observed during Spring 2003 ROV survey, with Model 2 (distance to TPI₅₀ peak + depth) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 2 habitat suitability.

Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

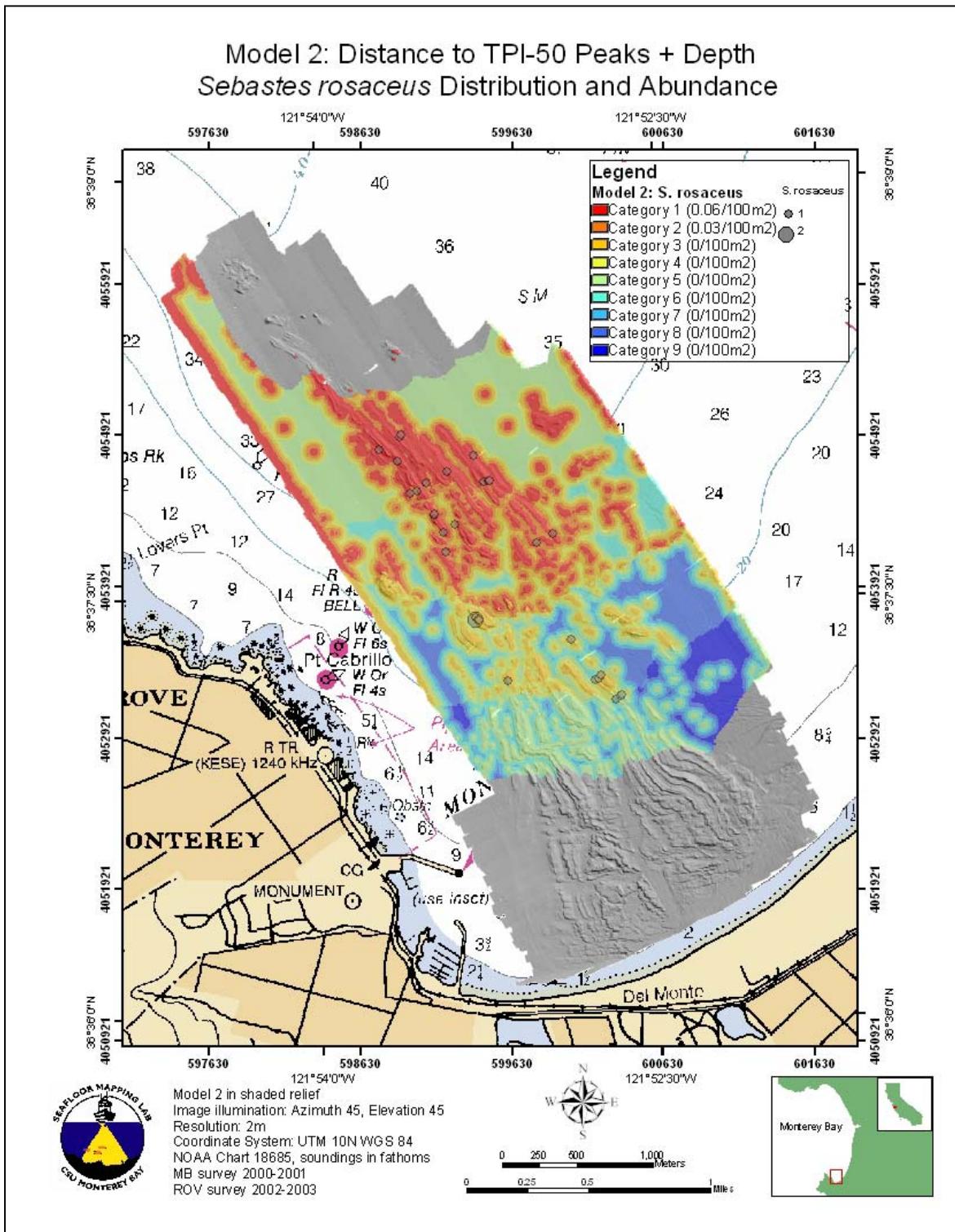


FIG 20. Distribution and abundance of *S. rosaceus* (rosy rockfish) observed during Spring 2003 ROV survey, with Model 2 (distance to TPI₅₀ peak + depth) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 2 habitat suitability.

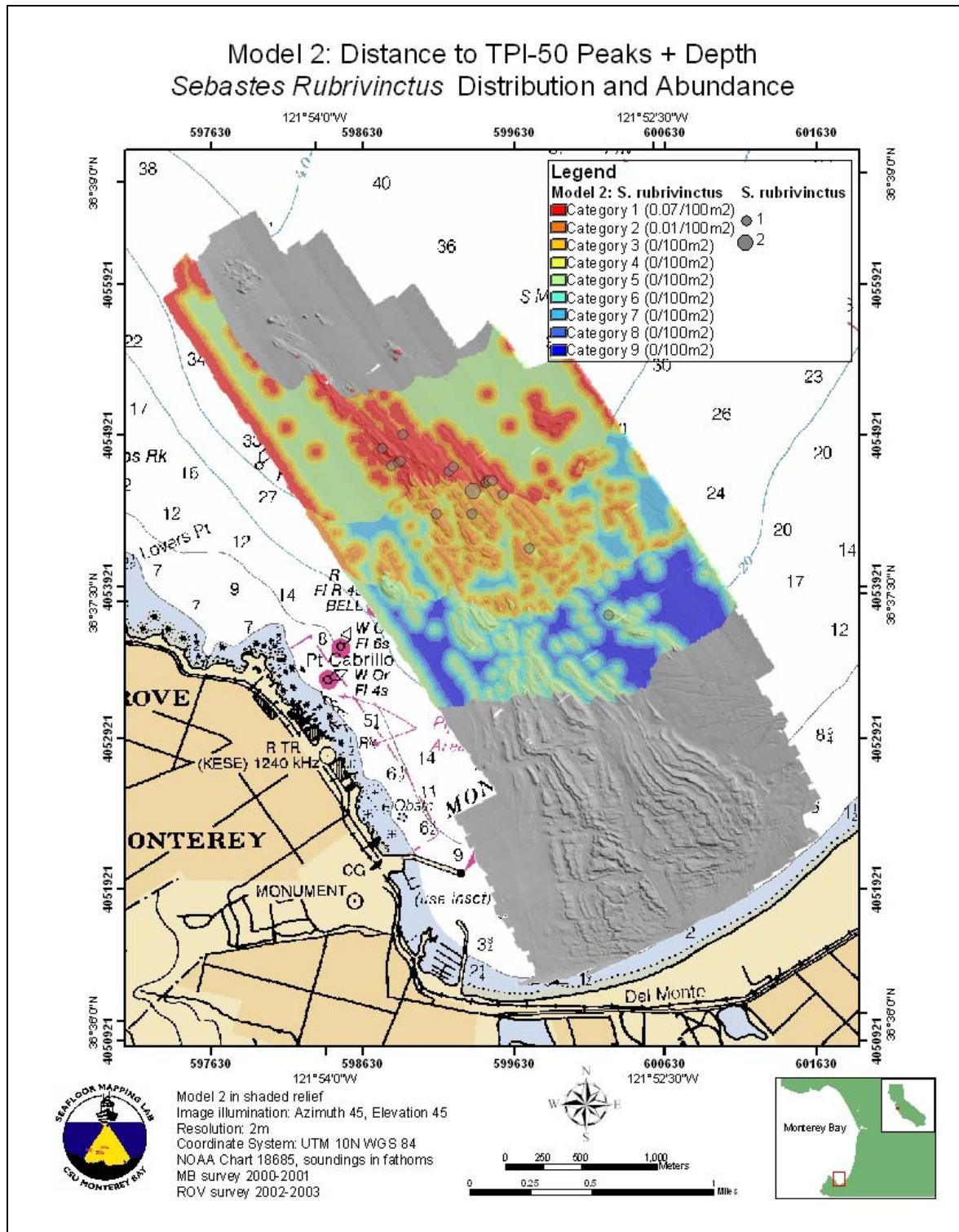


FIG 21. Distribution and abundance of *S. rubrivinctus* (flag rockfish) observed during Spring 2003 ROV survey, with Model 2 (distance to TPI₅₀ peak + depth) habitat suitability results for the species. Size of symbol is proportional to number of fish observed, and grid color indicates Model 2 habitat suitability.

Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

TABLE 1A. Comparison of fish distribution among suitability classes defined by Model 1 habitat suitability model. Counts and percentages of *Sebastes* spp. fishes observed in Spring 2003 ROV surveys are listed according to the modeled suitability of the habitat in which they were observed. Area (m²) and percentage of transect area of each suitability class within ROV transects are also listed.

Model 1: Distance to TPI ₅₀ Peak											
	Category	1	2	3	4	5	6	7	8	9	10
	Distance to Peak	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90+
Transect Area	Transect area (m²)	124228	62360	44460	25912	14256	9712	8812	6736	4300	12848
	Percent transect	39.61	19.88	14.18	8.26	4.55	3.10	2.81	2.15	1.37	4.10
<i>Sebastes</i> spp.	Count	2524	288	57	11	5	6	1	0	0	0
	Percent	87.28	9.96	1.97	0.38	0.17	0.21	0.03	0.00	0.00	0.00
<i>S. serranoides</i>/ <i>S. flavidus</i>	Count	285	17	14	4	0	0	0	0	0	0
	Percent	89.06	5.31	4.38	1.25	0.00	0.00	0.00	0.00	0.00	0.00
<i>S. auriculatus</i>	Count	27	5	0	0	0	2	0	0	0	0
	Percent	79.41	14.71	0.00	0.00	0.00	5.88	0.00	0.00	0.00	0.00
<i>S. rosaceus</i>	Count	25	7	0	0	0	0	0	0	0	0
	Percent	78.13	21.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>S. rubrivinctus</i>	Count	15	2	1	0	1	0	0	0	0	0
	Percent	78.95	10.53	5.26	0.00	5.26	0.00	0.00	0.00	0.00	0.00
<i>S. mystinus</i>	Count	1979	222	33	6	1	1	0	0	0	0
	Percent	88.27	9.90	1.47	0.27	0.04	0.04	0.00	0.00	0.00	0.00
<i>S. miniatus</i>	Count	125	18	5	1	1	2	0	0	0	0
	Percent	82.24	11.84	3.29	0.66	0.66	1.32	0.00	0.00	0.00	0.00
<i>S. carnatus</i>	Count	28	12	2	0	2	0	1	0	0	0
	Percent	62.22	26.67	4.44	0.00	4.44	0.00	2.22	0.00	0.00	0.00
<i>S. pinniger</i>	Count	40	5	2	0	0	1	0	0	0	0
	Percent	83.33	10.42	4.17	0.00	0.00	2.08	0.00	0.00	0.00	0.00

TABLE 1B. Comparison of fish distribution among suitability classes defined by Model 2 habitat suitability model. Counts and percentages of *Sebastes* spp. fishes observed in Spring 2003 ROV surveys are listed according to the modeled suitability of the habitat in which they were observed. Area (m²) and percentage of transect area of each suitability class within ROV transects are also listed.

Model 2: Distance to TPI₅₀ Peak + Depth

Category	1	2	3	4	5	6	7	8	9	total	
<i>S. serranoides/S. flavidus</i>	Transect area (m ²)	44984	46168	61664	45948	69412	24792	12044	3288	2684	310984
	Percent transect	14.47	14.85	19.83	14.78	22.32	7.97	3.87	1.06	0.86	100.00
	Survey area (m ²)	938140	965256	1112712	1009772	2139724	678688	444260	192652	204180	7685384
	Percent survey	12.21	12.56	14.48	13.14	27.84	8.83	5.78	2.51	2.66	100.00
	Number	285	17	14	4	0	0	0	0	0	320
	Percent	89.06	5.31	4.38	1.25	0.00	0.00	0.00	0.00	0.00	100.00
<i>S. auriculatus</i>	Transect area (m ²)	61432	30428	49228	40400	37044	11900	4704	3348	96	238580
	Percent transect	25.75	12.75	20.63	16.93	15.53	4.99	1.97	1.40	0.04	100.00
	Survey area (m ²)	968228	699232	770792	663616	1003704	513564	300888	343844	908100	6171968
	Percent survey	15.69	11.33	12.49	10.75	16.26	8.32	4.88	5.57	14.71	100.00
	Number	27	5	0	0	0	2	0	0	0	34
	Percent	79.41	14.71	0.00	0.00	0.00	5.88	0.00	0.00	0.00	100.00
<i>S. rosaceus</i>	Transect area (m ²)	44984	25084	31368	21416	64760	27060	11056	10868	1984	238580
	Percent transect	18.85	10.51	13.15	8.98	27.14	11.34	4.63	4.56	0.83	100.00
	Survey area (m ²)	938140	684628	791572	733080	1637748	611612	267564	348376	159248	6171968
	Percent survey	15.20	11.09	12.83	11.88	26.54	9.91	4.34	5.64	2.58	100.00
	Number	25	7	0	0	0	0	0	0	0	32
	Percent	78.13	21.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
<i>S. rubrivinctus</i>	Transect area (m ²)	21872	28332	22128	8744	34540	15188	8536	6728	11168	157236
	Percent transect	13.91	18.02	14.07	5.56	21.97	9.66	5.43	4.28	7.10	100.00
	Survey area (m ²)	575808	612000	655288	508156	1438004	416508	367024	170108	326564	5069460
	Percent survey	11.36	12.07	12.93	10.02	28.37	8.22	7.24	3.36	6.44	100.00
	Number	15	2	1	0	1	0	0	0	0	19
	Percent	78.95	10.53	5.26	0.00	5.26	0.00	0.00	0.00	0.00	100.00

Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

TABLE 2. Classification of raw TPI values into feature categories using standard deviation classes and slope.

Class	Description	Raw TPI Range (Std Dev)		
		From	To	
6	Peak / Ridge	1	>	
5	Upper Slope	0.5	1	
4	Middle Slope	-0.5	0.5	Slope > 5°
3	Flat	-0.5	0.5	Slope < 5°
2	Lower Slope	-1	-0.5	
1	Valley	<	-1	

TABLE 3. Counts and percentages of *Sebastes* spp. fishes observed in Spring 2003 ROV surveys according to derived habitat parameter classes for the locations in which they were observed. Habitat parameters listed were derived from bathymetry DEM and include depth, slope, rugosity, and TPI₅₀.

<i>Sebastes</i> spp.		<i>Sebastes serranoides/ Sebastes flavidus</i>		<i>Sebastes auriculatus</i>		<i>Sebastes rosaceus</i>		<i>Sebastes rubrivinctus</i>		<i>Sebastes mystinus</i>		<i>Sebastes miniatus</i>		<i>Sebastes carnatus</i>		<i>Sebastes</i>	
		Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	
SLOPE																	
0-5	2621	90.63	293	91.56	29	85.29	27	84.38	15	78.95	2051	91.48	128	84.21	41	91.11	37
5-10	242	8.37	26	8.13	5	14.71	5	15.63	4	21.05	168	7.49	22	14.47	1	2.22	11
10-15	10	0.35	1	0.31	0	0.00	0	0.00	0	0.00	7	0.31	1	0.66	1	2.22	0
15+	19	0.66	0	0.00	0	0.00	0	0.00	0	0.00	16	0.71	1	0.66	2	4.44	0
total	2892	100.00	320	100	34	100	32	100	19	100	2242	100	152	100	45	100	48
RUGOSITY																	
1.00-1.02	2398	82.92	275	85.94	26	76.47	23	71.88	14	73.68	1865	83.18	124	81.58	37	82.22	34
1.02-1.04	482	16.67	44	13.75	8	23.53	9	28.13	5	26.32	366	16.32	28	18.42	8	17.78	14
1.04-1.06	482	16.67	1	0.31	0	0.00	0	0.00	0	0.00	11	0.49	0	0.00	0	0.00	0
1.06+	12	0.41	1	0.31	0	0.00	0	0.00	0	0.00	11	0.49	0	0.00	0	0.00	0
total	2892	100.00	320	100	34	100	32	100	19	100	2242	100	152	100	45	100	48
TPI₅₀																	
peak	1138	39.35	154	48.13	17	50.00	16	50.00	9	47.37	874	38.98	37	24.34	12	26.67	19
upper slope	475	16.42	64	20.00	4	11.76	6	18.75	1	5.26	344	15.34	41	26.97	9	20.00	6
mid slope	130	4.50	9	2.81	2	5.88	0	0.00	1	5.26	96	4.28	11	7.24	0	0.00	11
flat	872	30.15	57	17.81	10	29.41	7	21.88	7	36.84	729	32.52	43	28.29	11	24.44	8
lower slope	128	4.43	15	4.69	1	2.94	1	3.13	0	0.00	103	4.59	2	1.32	3	6.67	3
valley	149	5.15	21	6.56	0	0.00	2	6.25	1	5.26	96	4.28	18	11.84	10	22.22	1
total	2892	100.00	320	100	34	100	32	100	19	100	2242	100	152	100	45	100	48
DEPTH																	
15-20	143	4.94	4	1.25	0	0.00	0	0.00	0	0.00	121	5.40	16	10.53	1	2.22	1
20-25	544	18.81	15	4.69	0	0.00	0	0.00	0	0.00	495	22.08	27	17.76	7	15.56	0
25-30	149	5.15	7	2.19	1	2.94	0	0.00	0	0.00	121	5.40	12	7.89	8	17.78	0
30-35	407	14.07	11	3.44	5	14.71	3	9.38	0	0.00	339	15.12	34	22.37	11	24.44	4
35-40	282	9.75	16	5.00	10	29.41	4	12.50	0	0.00	213	9.50	13	8.55	5	11.11	21
40-45	293	10.13	7	2.19	5	14.71	6	18.75	1	5.26	259	11.55	7	4.61	5	11.11	3
45-50	286	9.89	34	10.63	5	14.71	3	9.38	1	5.26	226	10.08	10	6.58	5	11.11	2
50-55	426	14.73	78	24.38	6	17.65	8	25.00	7	36.84	295	13.16	13	8.55	3	6.67	16
55-60	291	10.06	96	30.00	0	0.00	6	18.75	9	47.37	167	7.45	12	7.89	0	0.00	1
60-65	71	2.46	52	16.25	2	5.88	2	6.25	1	5.26	6	0.27	8	5.26	0	0.00	0
total	2892	100.00	320	100	34	100	32	100	19	100	2242	100	152	100	45	100	48

Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

TABLE 4. Total number of *Sebastes* spp. fishes observed during Spring 2003 ROV survey.

Rockfish Counts	
	Count
<i>Sebastes</i> spp.	2892
<i>S. serranoides/S. flavidus</i>	320
<i>S. auriculatus</i>	34
<i>S. rosaceus</i>	32
<i>S. rubrivinctus</i>	19
<i>S. mystinus</i>	2242
<i>S. miniatus</i>	152
<i>S. carnatus</i>	45
<i>S. pinniger</i>	48

Table 5. Area and percent area, both within transects and for the entire shale bed study area, of habitat parameter classes evaluated for use in creation of habitat suitability models.

CATEGORY	DEPTH	TRANSECT AREA	PERCENT OF TRANSECT AREA	SURVEY AREA	PERCENT OF SURVEY AREA
DEPTH					
14	2-10	0	0.00	347284	3.47
13	10-15	0	0.00	735316	7.34
12	15-20	32412	8.86	827388	8.26
11	20-25	52832	14.44	686028	6.85
10	25-30	44508	12.17	541812	5.41
9	30-35	50988	13.94	560696	5.60
8	35-40	46468	12.70	673512	6.72
7	40-45	36540	9.99	801900	8.01
6	45-50	36460	9.97	818732	8.17
5	50-55	29788	8.14	713196	7.12
4	55-60	27076	7.40	832268	8.31
3	60-65	8776	2.40	1229852	12.28
2	65-70	0	0.00	961784	9.60
1	70-72	0	0.00	287044	2.87
	<i>total</i>	<i>365848</i>	<i>100</i>	<i>10016812</i>	<i>100</i>
SLOPE					
1	0-5	289040	92.16	9628548	96.12
2	5-10	22012	7.02	347156	3.47
3	10-15	2184	0.70	34348	0.34
4	15+	388	0.12	6760	0.07
	<i>total</i>	<i>313624</i>	<i>100</i>	<i>10016812</i>	<i>100</i>
RUGOSITY					
1	1.00-1.02	311224	99.39	9923992	99.65
2	1.02-1.04	1504	0.48	27880	0.28
3	1.04-1.06	308	0.10	5080	0.05
4	1.06+	100	0.03	1820	0.02
	<i>total</i>	<i>313136</i>	<i>100</i>	<i>9958772</i>	<i>100</i>
TPI₅₀					
6	peak	56164	17.91	934556	9.33
5	upper slope	39152	12.48	958760	9.57
4	mid slope	6060	1.93	108208	1.08
3	flat	141368	45.08	6705344	66.94
2	lower slope	21848	6.97	478188	4.77
1	valley	49032	15.63	831756	8.30
	<i>total</i>	<i>313624</i>	<i>100</i>	<i>10016812</i>	<i>100</i>

Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

TABLE 6. Area and percent area of habitat parameter classes evaluated for use in creation of habitat suitability models. Maximum values for slope, rugosity, and TPI₅₀ found within the 10m diameter “area of influence” around fish locations are listed.

Area of Interest (AOI) in m ²															
<i>Sebastes</i> spp.		<i>S. serranoides</i> / <i>S.</i>		<i>S. auriculatus</i>		<i>S. rosaceus</i>		<i>S. rubrivinctus</i>		<i>S. mystinus</i>		<i>S. miniatus</i>		<i>S. carnatus</i>	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count
SLOPE															
0-5°	812	28.08	93	29.06	13	38.24	9	28.13	2	10.53	623	27.79	48	31.58	15
5-10°	1373	47.48	142	44.38	15	44.12	17	53.13	13	68.42	1052	46.92	74	48.68	23
10-15°	593	20.50	61	19.06	6	17.65	6	18.75	4	21.05	483	21.54	27	17.76	4
>15°	114	3.94	24	7.50	0	0.00	0	0.00	0	0.00	84	3.75	3	1.97	3
Total		100		100		100		100		100		100		100	
RUGOSITY															
1-1.02	2444	84.51	251	78.44	30	88.24	28	87.50	15	78.95	1894	84.48	138	90.79	40
1.02-1.04	335	11.58	45	14.06	4	11.76	4	12.50	4	21.05	264	11.78	12	7.89	2
1.04-1.06	2	0.07	1	0.31	0	0.00	0	0.00	0	0.00	1	0.04	0	0.00	0
>1.06	111	3.84	23	7.19	0	0.00	0	0.00	0	0.00	83	3.70	2	1.32	3
Total		100		100		100		100		100		100		100	
TPI₅₀															
Peak	2536	87.69	286	89.38	27	79.41	25	78.13	15	78.95	1990	88.76	125	82.24	28
Upper Slope	127	4.39	6	1.88	4	11.76	2	6.25	2	10.53	85	3.79	16	10.53	5
Mid Slope	47	1.63	3	0.94	0	0.00	1	3.13	0	0.00	32	1.43	4	2.63	7
Flat	173	5.98	17	5.31	3	8.82	4	12.50	1	5.26	135	6.02	7	4.61	5
Lower Slope	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Valley	9	0.31	8	2.50	0	0.00	0	0.00	1	5.26	0	0.00	0	0.00	0
Total		100		100		100		100		100		100		100	

TABLE 7. Reclassification tables used to rank distance to TPI₅₀ and depth for use in Model 1 and Model 2 habitat suitability models.**Reclass Distance to TPI₅₀ Peaks**

distance to peak	reclass value
0-10	1
10-20	2
20-30	3
30-40	4
40-50	5
50-60	6
60-70	7
70-80	8
80-90	9
90+	10

Reclass Depth

depth (m)	reclass value
2-10	14
10-15	13
15-20	12
20-25	11
25-30	10
30-35	9
35-40	8
40-45	7
45-50	6
50-55	5
55-60	4
60-65	3
65-70	2
70-72	1

Model 2: Reclass Depth

<i>S. serranoides/ S. flavidus</i>		<i>S. auriculatus</i>		<i>S. rosaceus</i>		<i>S. rubrivinctus</i>	
depth (m)	reclass value	Depth (m)	reclass value	Depth (m)	reclass value	Depth (m)	reclass value
55-65	1	35-45	1	55-65	1	55-65	1
45-55	3	45-55	3	45-55	3	45-55	5
35-45	5	25-35	7	35-45	7	40-45	10
25-35	7	60-65	10	35-45	10		
15-25	10						

TABLE 8. Efficiency estimation for Model 1 and Model 2 habitat suitability models. Efficiency estimates are calculated for each habitat class using the ratio of (percentage of fish observed in each habitat suitability class) to (percentage of transect area comprised of the habitat class).

Category	1	2	3	4	5	6	7	8	9	10
Distance to TPI₅₀ Peak	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90+
Sebastes spp.	2.20	0.50	0.14	0.05	0.04	0.07	0.00	0.02	0.00	0.00
S. serranoides/ S. flavidus	2.24	0.27	0.31	0.15	0.00	0.00	0.00	0.00	0.00	0.00
S. auriculatus	2.00	0.74	0.00	0.00	0.00	1.93	0.00	0.00	0.00	0.00
S. rosaceus	1.97	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S. rubrivinctus	1.99	0.53	0.37	0.00	1.16	0.00	0.00	0.00	0.00	0.00
S. mystinus	2.23	0.50	0.10	0.03	0.01	0.01	0.00	0.02	0.00	0.00
S. miniatus	2.08	0.60	0.23	0.08	0.14	0.42	0.00	0.00	0.00	0.00
S. carnatus	1.57	1.34	0.31	0.00	0.98	0.00	0.00	1.04	0.00	0.00
S. pinniger	2.10	0.52	0.29	0.00	0.00	0.67	0.00	0.00	0.00	0.00
Model 2: Efficiency Ratios										
Category	1	2	3	4	5	6	7	8	9	
S. serranoides/ S. flavidus	5.18	0.82	0.35	0.00	0.22	0.12	0.00	0.00	0.00	
S. auriculatus	2.51	0.46	1.00	0.17	0.38	0.00	0.00	0.00	0.00	
S. rosaceus	2.65	0.89	1.66	1.04	0.35	0.00	0.00	0.00	0.00	
S. rubrivinctus	3.40	2.04	0.75	0.00	0.24	0.00	0.00	0.00	0.00	

TABLE 9A.. Model 1 stock estimates for *Sebastes* spp. fishes in the Del Monte shale bed study area calculated using density of fishes observed along transect area and total survey area for each habitat suitability class.

Model 1: Stock Estimate											
	category	1	2	3	4	5	6	7	8	9	10
	Distance to Peak	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90+
Transect Area	Transect area (m²)	124228	62360	44460	25912	14256	9712	8812	6736	4300	12848
	Percent transect	39.61	19.88	14.18	8.26	4.55	3.10	2.81	2.15	1.37	4.10
Survey Area	Survey area (m²)	2210220	1285836	1068112	821720	653080	550380	480900	418192	374692	2152268
	Percent survey area	22.07	12.84	10.66	8.20	6.52	5.50	4.80	4.18	3.74	21.49
<i>Sebastes</i> spp.	Number	2524	288	57	11	5	6	1	0	0	0
	Stock Estimate	44906	5938	1369	349	229	340	55	0	0	0
<i>S. serranoides/ S. flavidus</i>	Number	285	17	14	4	0	0	0	0	0	0
	Stock Estimate	5071	351	336	127	0	0	0	0	0	0
<i>S. auriculatus</i>	Number	27	5	0	0	0	2	0	0	0	0
	Stock Estimate	480	103	0	0	0	113	0	0	0	0
<i>S. rosaceus</i>	Number	25	7	0	0	0	0	0	0	0	0
	Stock Estimate	445	144	0	0	0	0	0	0	0	0
<i>S. rubrivinctus</i>	Number	15	2	1	0	1	0	0	0	0	0
	Stock Estimate	267	41	24	0	46	0	0	0	0	0
<i>S. mystinus</i>	Number	1979	222	33	6	1	1	0	0	0	0
	Stock Estimate	35210	4578	793	190	46	57	0	0	0	0
<i>S. miniatus</i>	Number	125	18	5	1	1	2	0	0	0	0
	Stock Estimate	2224	371	120	32	46	113	0	0	0	0
<i>S. carnatus</i>	Number	28	12	2	0	2	0	1	0	0	0
	Stock Estimate	498	247	48	0	92	0	55	0	0	0
<i>S. pinniger</i>	Number	40	5	2	0	0	1	0	0	0	0
	Stock Estimate	712	103	48	0	0	57	0	0	0	0

TABLE 9B. Model 2 stock estimates for *Sebastes* spp. fishes in the Del Monte shale bed study area calculated using density of fishes observed within transect area and total survey area for each habitat suitability class.

MODEL 2: Stock Estimate: Distance to TPI-50 Peak + Depth

	category	1	2	3	4	5	6	7	8	9	Total
<i>S. serranoides/ S. flavidus</i>	Transect area (m²)	44984	46168	61664	45948	69412	24792	12044	3288	2684	310984
	Percent transect	14.47	14.85	19.83	14.78	22.32	7.97	3.87	1.06	0.86	100.00
	Survey area (m²)	938140	965256	1112712	1009772	2139724	678688	444260	192652	204180	7685384
	Percent survey area	12.21	12.56	14.48	13.14	27.84	8.83	5.78	2.51	2.66	100.00
	Number	285	17	14	4	0	0	0	0	0	320
	Stock Estimate	5944	355	253	88	0	0	0	0	0	6640
<i>S. auriculatus</i>	Transect area (m²)	61432	30428	49228	40400	37044	11900	4704	3348	96	238580
	Percent transect	25.75	12.75	20.63	16.93	15.53	4.99	1.97	1.40	0.04	100.00
	Survey area (m²)	968228	699232	770792	663616	1003704	513564	300888	343844	908100	6171968
	Percent survey area	15.69	11.33	12.49	10.75	16.26	8.32	4.88	5.57	14.71	100.00
	Number	27	5	0	0	0	2	0	0	0	34
	Stock Estimate	426	115	0	0	0	86	0	0	0	627
<i>S. rosaceus</i>	Transect area (m²)	44984	25084	31368	21416	64760	27060	11056	10868	1984	238580
	Percent transect	18.85	10.51	13.15	8.98	27.14	11.34	4.63	4.56	0.83	100.00
	Survey area (m²)	938140	684628	791572	733080	1637748	611612	267564	348376	159248	6171968
	Percent survey area	15.20	11.09	12.83	11.88	26.54	9.91	4.34	5.64	2.58	100.00
	Number	25	7	0	0	0	0	0	0	0	32
	Stock Estimate	521	191	0	0	0	0	0	0	0	712
<i>S. rubrivinctus</i>	Transect area (m²)	21872	28332	22128	8744	34540	15188	8536	6728	11168	157236
	Percent transect	13.91	18.02	14.07	5.56	21.97	9.66	5.43	4.28	7.10	100.00
	Survey area (m²)	575808	612000	655288	508156	1438004	416508	367024	170108	326564	5069460
	Percent survey area	11.36	12.07	12.93	10.02	28.37	8.22	7.24	3.36	6.44	100.00
	Number	15	2	1	0	1	0	0	0	0	19
	Stock Estimate	395	43	30	0	42	0	0	0	0	509

Appendix A

APPENDIX A. Evaluation of TPI analysis at various scales. Number and percentage of fish observed in each of 6 TPI classes is listed for TPI scales ranging from 10-150m, along with the qualitative habitat category assigned during video analysis.

Video Analysis: Substrate Category	NUMBER OF FISH OBSERVATIONS							PERCENT OF FISH OBSERVATIONS							
	TPI ₁₀ : NUMBER OF FISH OBSERVATIONS							TPI ₁₀ : PERCENT OF FISH OBSERVATIONS							
	TPI Category	valley	lower slope	flat	mid slope	upper slope	peak	totals	TPI Category	valley	lower slope	flat	mid slope	upper slope	peak
boulders	1	N/A	2	0	N/A	2	5		boulders	20.0	N/A	40.0	0.0	N/A	40.0
ledges	11	N/A	36	6	N/A	16	69		ledges	15.9	N/A	52.2	8.7	N/A	23.2
outcrop		N/A	1	0	N/A	12	13		outcrop	0.0	N/A	7.7	0.0	N/A	92.3
rubble	3	N/A	43	0	N/A	14	60		rubble	5.0	N/A	71.7	0.0	N/A	23.3
sand		N/A	8	0	N/A	5	13		sand	0.0	N/A	61.5	0.0	N/A	38.5
small ledges	7	N/A	52	4	N/A	30	93		small ledges	7.5	N/A	55.9	4.3	N/A	32.3
no relief	0	N/A	1	0	N/A	2	3		no relief	0.0	N/A	33.3	0.0	N/A	66.7
low relief	9	N/A	100	4	N/A	58	171		low relief	5.3	N/A	58.5	2.3	N/A	33.9
high relief	13	N/A	41	6	N/A	19	79		high relief	16.5	N/A	51.9	7.6	N/A	24.1
TPI₂₀: NUMBER OF FISH OBSERVATIONS															
boulders	1	1	0	1	1	1	5		boulders	20.0	20.0	0.0	20.0	20.0	20.0
ledges	14	11	17	4	7	16	69		ledges	20.3	15.9	24.6	5.8	10.1	23.2
outcrop	0	0	1	0	1	11	13		outcrop	0.0	0.0	7.7	0.0	7.7	84.6
rubble	3	9	27	0	6	15	60		rubble	5.0	15.0	45.0	0.0	10.0	25.0
sand	0	0	5	0	3	5	13		sand	0.0	0.0	38.5	0.0	23.1	38.5
small ledges	4	5	33	2	14	35	93		small ledges	4.3	5.4	35.5	2.2	15.1	37.6
no relief	0	0	0	0	0	3	3		no relief	0.0	0.0	0.0	0.0	0.0	100.0
low relief	7	12	63	2	24	63	171		low relief	4.1	7.0	11.7	1.2	14.0	36.8
high relief	15	14	20	5	8	17	79		high relief	19.0	17.7	25.3	6.3	10.1	21.5
TPI₃₀: NUMBER OF FISH OBSERVATIONS															
boulders	1	1	0	1	0	2	5		boulders	20.0	20.0	0.0	20.0	0.0	40.0
ledges	14	9	19	4	4	19	69		ledges	20.3	13.0	27.5	5.8	5.8	27.5
outcrop	0	0	1	0	2	10	13		outcrop	0.0	0.0	7.7	0.0	15.4	76.9
rubble	11	6	19	1	7	16	60		rubble	18.3	10.0	31.7	1.7	11.7	26.7
sand	0	0	5	0	4	4	13		sand	0.0	0.0	38.5	0.0	30.8	30.8
small ledges	8	8	26	4	7	40	93		small ledges	8.6	8.6	28.0	4.3	7.5	43.0
no relief	0	0	1	0	1	1	3		no relief	0.0	0.0	33.3	0.0	33.3	33.3
low relief	18	14	48	5	17	69	171		low relief	10.5	8.2	12.3	2.9	9.9	40.4
high relief	16	10	21	5	4	21	77		high relief	20.8	13.0	27.3	6.5	5.2	27.3

Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

APPENDIX A (continued) Evaluation of TPI analysis at various scales. Number and percentage of fish observed in each of 6 TPI classes is listed for TPI scales ranging from 10-150m, along with the qualitative habitat category assigned during video analysis.

Video Analysis: Substrate Category	NUMBER OF FISH OBSERVATIONS							PERCENT OF FISH OBSERVATIONS								
	TPI Category		valley	lower slope	flat	mid slope	upper slope	peak	totals	TPI Category		valley	lower slope	flat	mid slope	upper slope
TPI₄₀: NUMBER OF FISH OBSERVATIONS	boulders	2	0	0	1	0	2	5		boulders	40.0	0.0	0.0	20.0	0.0	40.0
	ledges	10	9	16	4	7	23	69		ledges	14.5	13.0	23.2	5.8	10.1	33.3
	outcrop	0	0	1	0	0	12	13		outcrop	0.0	0.0	7.7	0.0	0.0	92.3
	rubble	11	3	21	0	4	21	60		rubble	18.3	5.0	35.0	0.0	6.7	35.0
	sand	0	0	5	0	2	6	13		sand	0.0	0.0	38.5	0.0	15.4	46.2
	small ledges	3	15	16	4	10	45	93		small ledges	3.2	16.1	17.2	4.3	10.8	48.4
	no relief	0	0	1	0	1	1	3		no relief	0.0	0.0	33.3	0.0	33.3	33.3
	low relief	13	18	39	4	16	81	171		low relief	7.6	10.5	11.1	2.3	9.4	47.4
	high relief	13	9	19	5	6	27	79		high relief	16.5	11.4	24.1	6.3	7.6	34.2
TPI₅₀: NUMBER OF FISH OBSERVATIONS	boulders	2	0	0	0	0	3	5		boulders	40.0	0.0	0.0	0.0	0.0	60.0
	ledges	8	5	21	3	7	25	69		ledges	11.6	7.2	30.4	4.3	10.1	36.2
	outcrop	0	0	1	0	1	11	13		outcrop	0.0	0.0	7.7	0.0	7.7	84.6
	rubble	10	2	18	0	13	17	60		rubble	16.7	3.3	30.0	0.0	21.7	28.3
	sand	0	0	5	0	5	3	13		sand	0.0	0.0	38.5	0.0	38.5	23.1
	small ledges	5	5	25	4	12	42	93		small ledges	5.4	5.4	26.9	4.3	12.9	45.2
	no relief	0	0	0	0	3	0	3		no relief	0.0	0.0	0.0	0.0	100.0	0.0
	low relief	14	7	47	4	27	72	171		low relief	8.2	4.1	13.5	2.3	15.8	42.1
	high relief	11	5	23	3	8	29	79		high relief	13.9	6.3	29.1	3.8	10.1	36.7
TPI₆₀: NUMBER OF FISH OBSERVATIONS	boulders	2	0	0	0	1	2	5		boulders	40.0	0.0	0.0	0.0	20.0	40.0
	ledges	9	4	22	3	6	25	69		ledges	13.0	5.8	31.9	4.3	8.7	36.2
	outcrop	0	0	2	0	0	11	13		outcrop	0.0	0.0	15.4	0.0	0.0	84.6
	rubble	10	0	24	2	8	16	60		rubble	16.7	0.0	40.0	3.3	13.3	26.7
	sand	0	1	7	0	2	3	13		sand	0.0	7.7	53.8	0.0	15.4	23.1
	small ledges	7	5	29	4	6	42	93		small ledges	7.5	5.4	31.2	4.3	6.5	45.2
	no relief	0	0	3	0	0	0	3		no relief	0.0	0.0	100.0	0.0	0.0	0.0
	low relief	16	6	56	6	16	71	171		low relief	9.4	3.5	14.6	3.5	9.4	41.5
	high relief	12	4	25	3	7	28	79		high relief	15.2	5.1	31.6	3.8	8.9	35.4

APPENDIX A (continued) Evaluation of TPI analysis at various scales. Number and percentage of fish observed in each of 6 TPI classes is listed for TPI scales ranging from 10-150m, along with the qualitative habitat category assigned during video analysis.

<u>TPI Category</u>	NUMBER OF FISH OBSERVATIONS						PERCENT OF FISH OBSERVATIONS						
	valley	lower slope	flat	mid slope	upper slope	peak	totals	valley	lower slope	flat	mid slope	upper slope	peak
<u>Video Analysis: Substrate Category</u>													
boulders	1	1	0	0	0	3	5	boulders	20.0	20.0	0.0	0.0	0.0
ledges	7	5	12	3	13	29	69	ledges	10.1	7.2	17.4	4.3	18.8
outcrop	0	1	0	0	1	11	13	outcrop	0.0	7.7	0.0	0.0	7.7
rubble	9	4	18	3	9	17	60	rubble	15.0	6.7	30.0	5.0	15.0
sand	1	2	4	0	3	3	13	sand	7.7	15.4	30.8	0.0	23.1
small ledge	5	7	21	2	12	46	93	small ledge	5.4	7.5	22.6	2.2	12.9
no relief	0	0	0	0	2	0	2	no relief	0.0	0.0	0.0	0.0	100.0
low relief	14	14	41	5	22	76	172	low relief	8.1	8.1	8.1	2.9	12.8
high relief	9	6	14	3	14	33	79	high relief	11.4	7.6	17.7	3.8	17.7
TPI₈₀: NUMBER OF FISH OBSERVATIONS													
boulders	1	1	0	0	0	3	5	boulders	20.0	20.0	0.0	0.0	0.0
ledges	7	5	12	3	13	29	69	ledges	10.1	7.2	17.4	4.3	18.8
outcrop	0	1	0	0	1	11	13	outcrop	0.0	7.7	0.0	0.0	7.7
rubble	9	4	18	3	9	17	60	rubble	15.0	6.7	30.0	5.0	15.0
sand	1	2	4	0	3	3	13	sand	7.7	15.4	30.8	0.0	23.1
small ledge	5	7	21	2	12	46	93	small ledge	5.4	7.5	22.6	2.2	12.9
no relief	0	0	0	0	2	0	2	no relief	0.0	0.0	0.0	0.0	100.0
low relief	14	14	41	5	22	76	172	low relief	8.1	8.1	8.1	2.9	12.8
high relief	9	6	14	3	14	33	79	high relief	11.4	7.6	17.7	3.8	17.7
TPI₁₀₀: NUMBER OF FISH OBSERVATIONS													
boulders	0	1	0	1	0	3	5	boulders	0.0	20.0	0.0	20.0	0.0
ledges	8	3	13	3	14	28	69	ledges	11.6	4.3	18.8	4.3	20.3
outcrop	0	1	1	0	1	10	13	outcrop	0.0	7.7	7.7	0.0	7.7
rubble	6	7	21	2	9	15	60	rubble	10.0	11.7	35.0	3.3	15.0
sand	1	3	4	0	1	4	13	sand	7.7	23.1	30.8	0.0	7.7
small ledge	3	10	22	2	10	46	93	small ledge	3.2	10.8	23.7	2.2	10.8
no relief	0	1	1	0	0	1	3	no relief	0.0	33.3	33.3	0.0	0.0
low relief	9	20	45	4	21	72	171	low relief	5.3	11.7	8.8	2.3	12.3
high relief	9	4	15	4	14	33	79	high relief	11.4	5.1	19.0	5.1	17.7
TPI₁₂₀: NUMBER OF FISH OBSERVATIONS													
boulders	1	0	1	0	0	3	5	boulders	20.0	0.0	20.0	0.0	0.0
ledges	6	5	14	4	17	23	69	ledges	8.7	7.2	20.3	5.8	24.6
outcrop	0	0	2	0	1	10	13	outcrop	0.0	0.0	15.4	0.0	7.7
rubble	6	2	22	2	11	17	60	rubble	10.0	3.3	36.7	3.3	18.3
sand	1	0	7	0	1	4	13	sand	7.7	0.0	53.8	0.0	7.7
small ledge	3	7	27	1	14	41	93	small ledge	3.2	7.5	29.0	1.1	15.1
no relief	0	0	2	0	0	1	3	no relief	0.0	0.0	66.7	0.0	0.0
low relief	9	9	54	3	27	69	171	low relief	5.3	5.3	9.9	1.8	15.8
high relief	8	5	17	4	17	28	79	high relief	10.1	6.3	21.5	5.1	21.5
TPI₁₂₀: PERCENT OF FISH OBSERVATIONS													
boulders	20.0	20.0	0.0	20.0	0.0	0.0	0.0	boulders	20.0	0.0	20.0	0.0	0.0
ledges	10.1	7.2	17.4	4.3	18.8	4.3	20.3	ledges	11.6	4.3	18.8	4.3	20.3
outcrop	0.0	7.7	0.0	0.0	0.0	0.0	0.0	outcrop	0.0	7.7	7.7	0.0	7.7
rubble	15.0	6.7	30.0	5.0	15.0	28.3	25.0	rubble	10.0	11.7	35.0	3.3	15.0
sand	7.7	15.4	30.8	0.0	23.1	30.8	30.8	sand	7.7	23.1	30.8	0.0	7.7
small ledge	5.4	7.5	22.6	2.2	12.9	49.5	49.5	small ledge	3.2	10.8	23.7	2.2	10.8
no relief	0.0	0.0	0.0	0.0	0.0	0.0	0.0	no relief	0.0	33.3	33.3	0.0	0.0
low relief	8.1	8.1	8.1	2.9	12.8	44.2	44.2	low relief	5.3	11.7	8.8	2.3	12.3
high relief	11.4	7.6	17.7	3.8	17.7	41.8	41.8	high relief	11.4	5.1	19.0	5.1	17.7

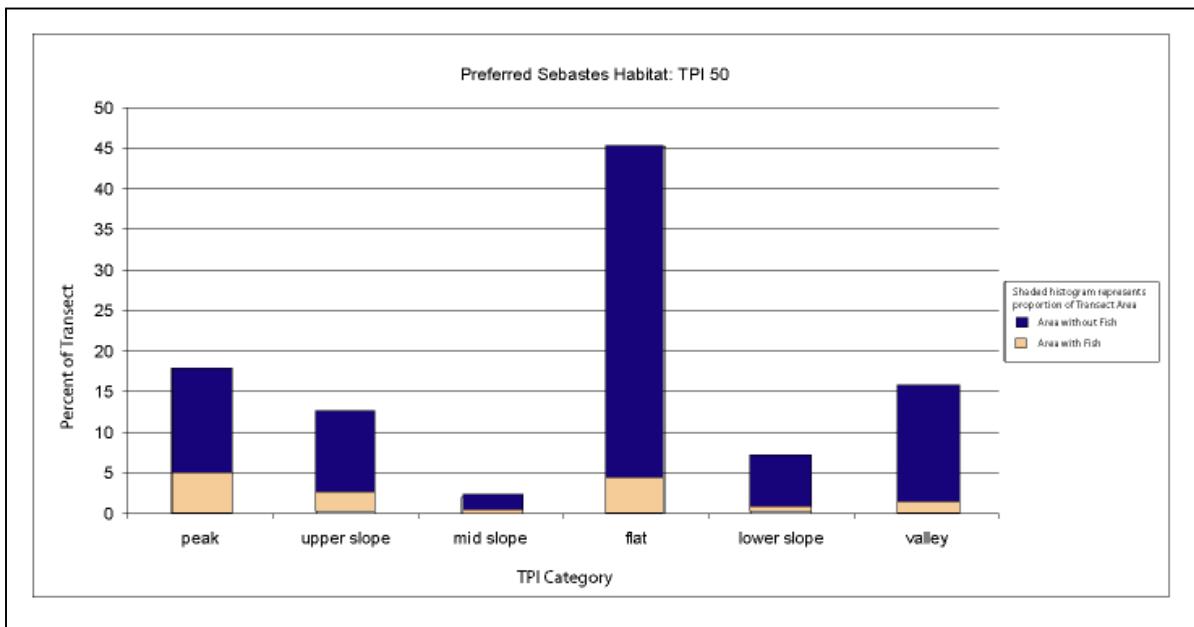
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APPENDIX A (continued) Evaluation of TPI analysis at various scales. Number and percentage of fish observed in each of 6 TPI classes is listed for TPI scales ranging from 10-150m, along with the qualitative habitat category assigned during video analysis.

Video Analysis: Substrate Category	NUMBER OF FISH OBSERVATIONS						PERCENT OF FISH OBSERVATIONS							
	TPI Category		valley	lower slope	flat	mid slope	upper slope	peak	valley	lower slope	flat	mid slope	upper slope	
	TPI ₁₅₀ : NUMBER OF FISH OBSERVATIONS	TPI ₁₅₀ : PERCENT OF FISH OBSERVATIONS											peak	
boulders	1	0	0	0	0	4	5	boulders	20.0	0.0	0.0	0.0	0.0	80.0
ledges	3	7	23	4	7	25	69	ledges	4.3	10.1	33.3	5.8	10.1	36.2
outcrop	0	0	2	1	0	10	13	outcrop	0.0	0.0	15.4	7.7	0.0	76.9
rubble	5	6	25	2	6	16	60	rubble	8.3	10.0	41.7	3.3	10.0	26.7
sand	1	2	6	0	1	3	13	sand	7.7	15.4	46.2	0.0	7.7	23.1
small ledges	4	7	33	1	13	35	93	small ledges	4.3	7.5	35.5	1.1	14.0	37.6
no relief	0	0	1	0	0	1	2	no relief	0.0	0.0	50.0	0.0	0.0	50.0
low relief	9	15	62	4	20	62	172	low relief	5.2	8.7	15.1	2.3	11.6	36.0
high relief	5	7	26	4	7	30	79	high relief	6.3	8.9	32.9	5.1	8.9	38.0

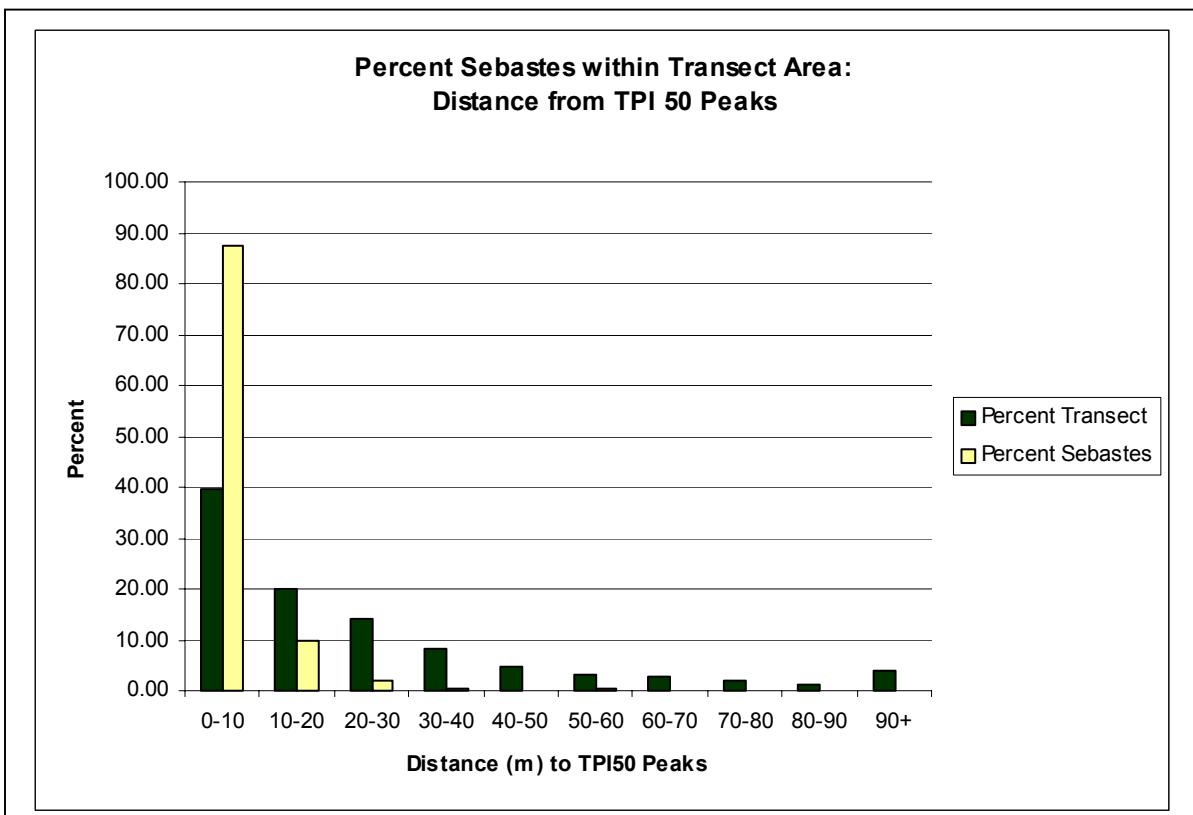
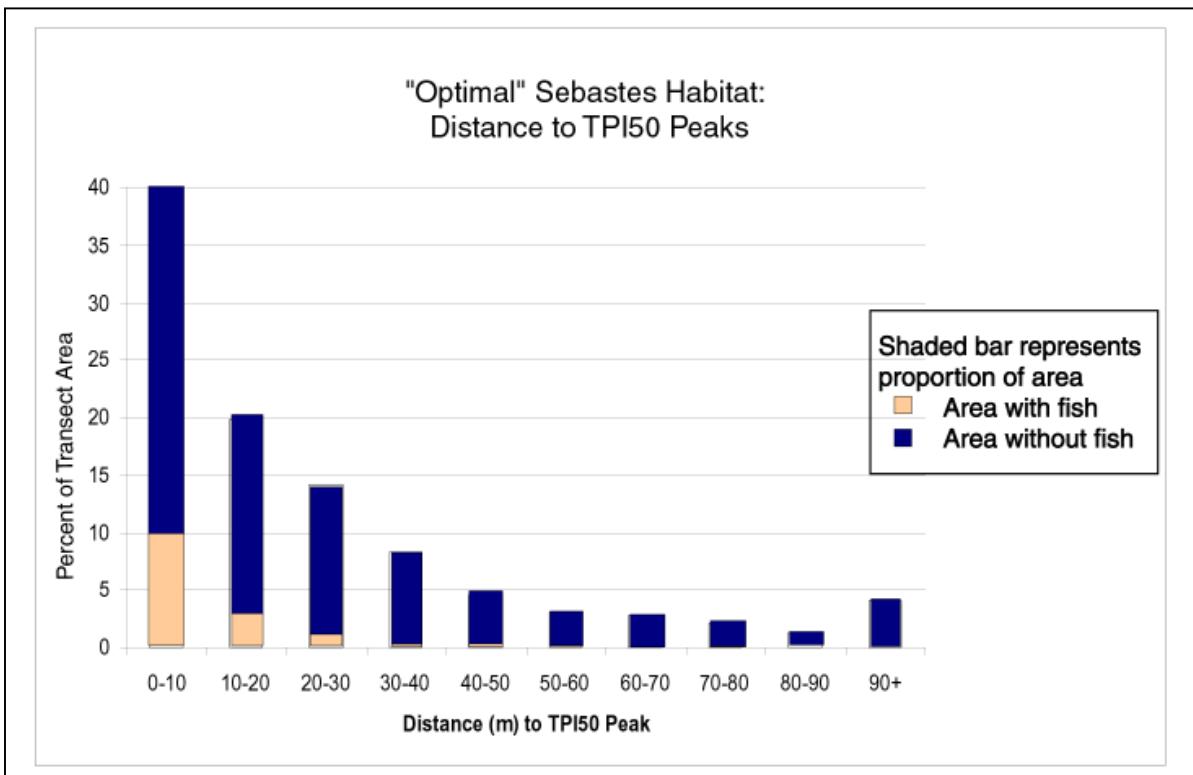
Appendix B

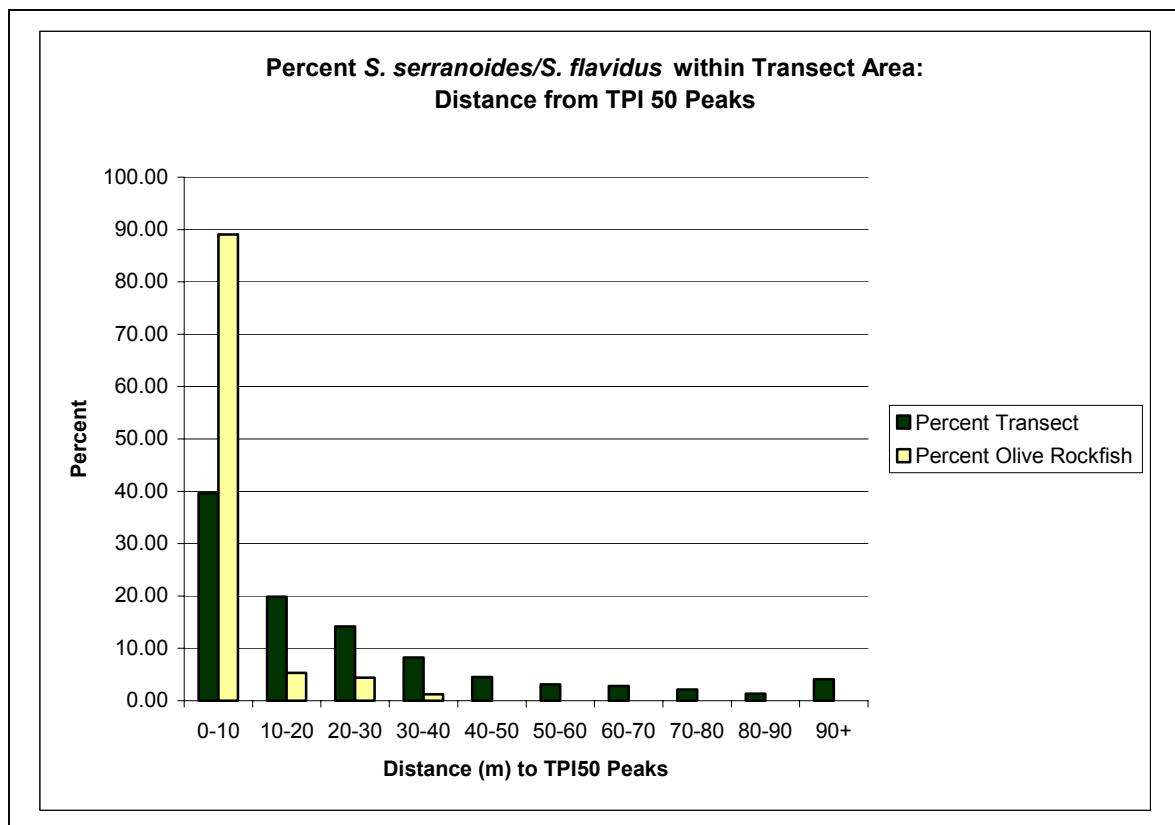
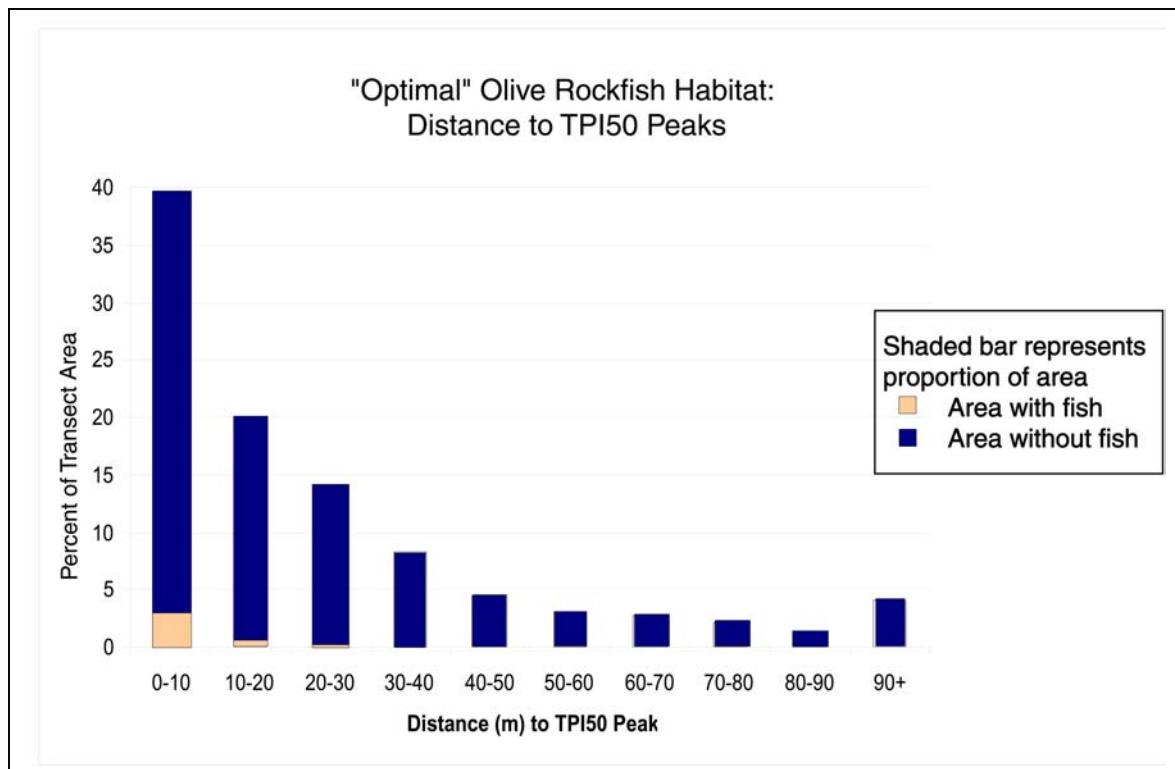
Appendix B. Comparisons of areas with and without fish within transects, classified by TPI₅₀ class, distance to TPI₅₀ peak (Model 1), and distance to TPI₅₀ peak + depth (Model 2). Comparison of percent of fish observed vs. percent area for Model 1 & Model 2 habitat suitability classes is shown as well, for all *Sebastes* and by species.



Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

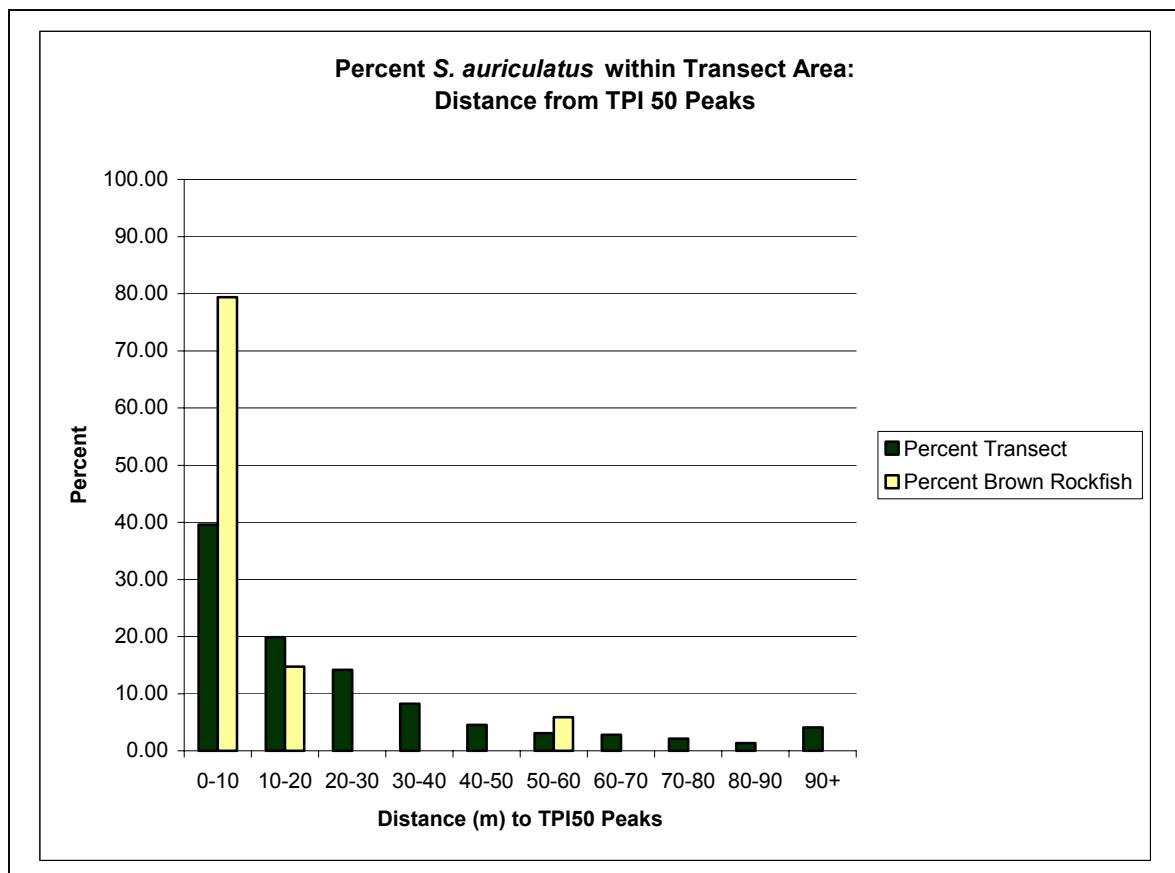
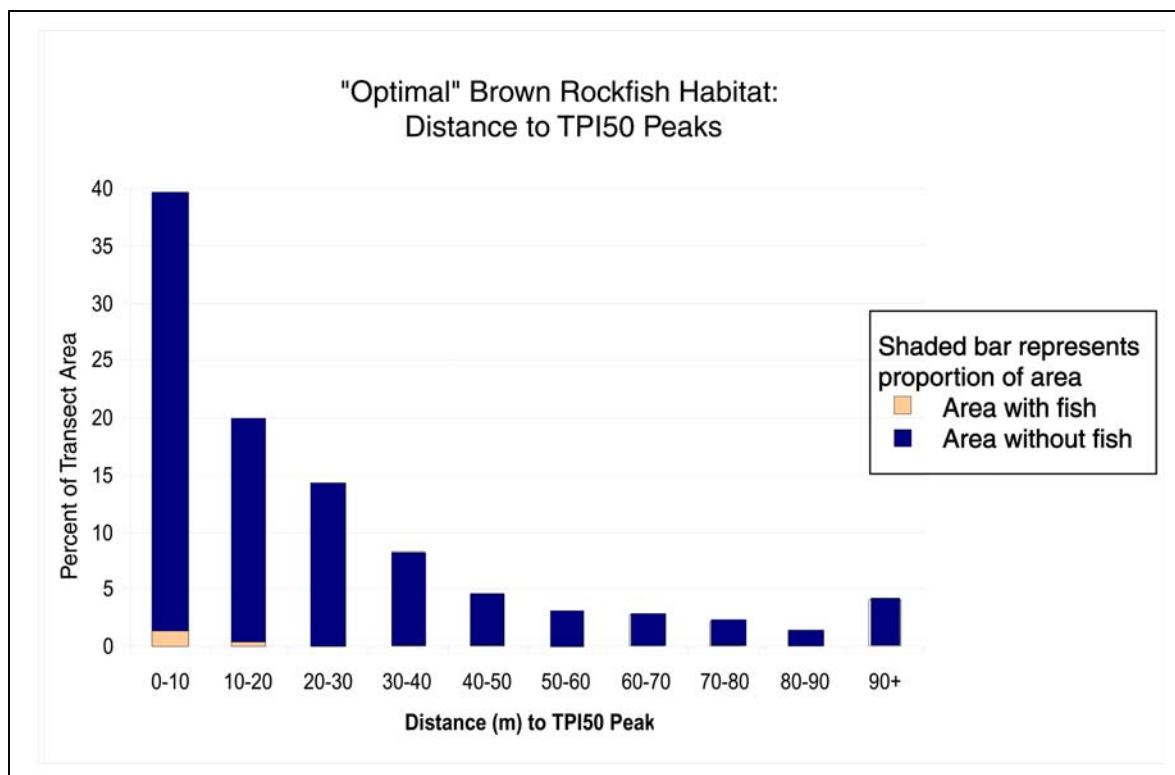
Appendix B (continued)

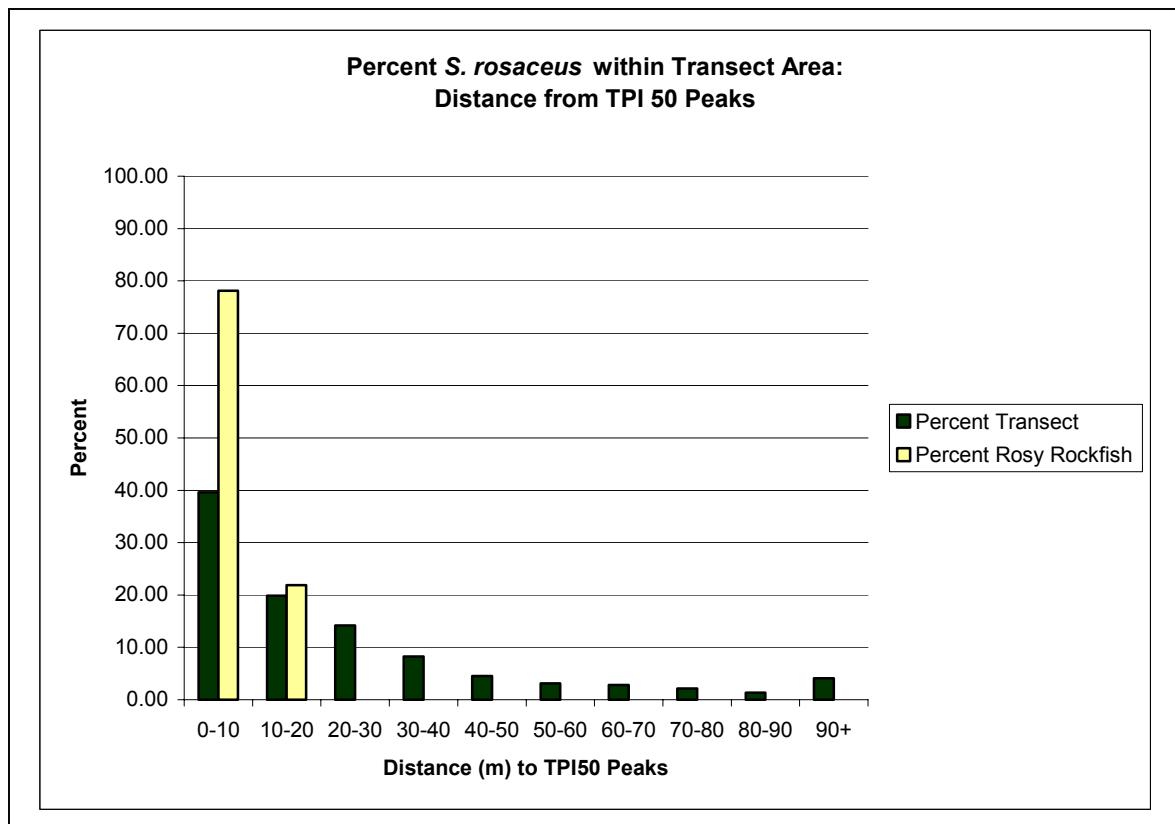
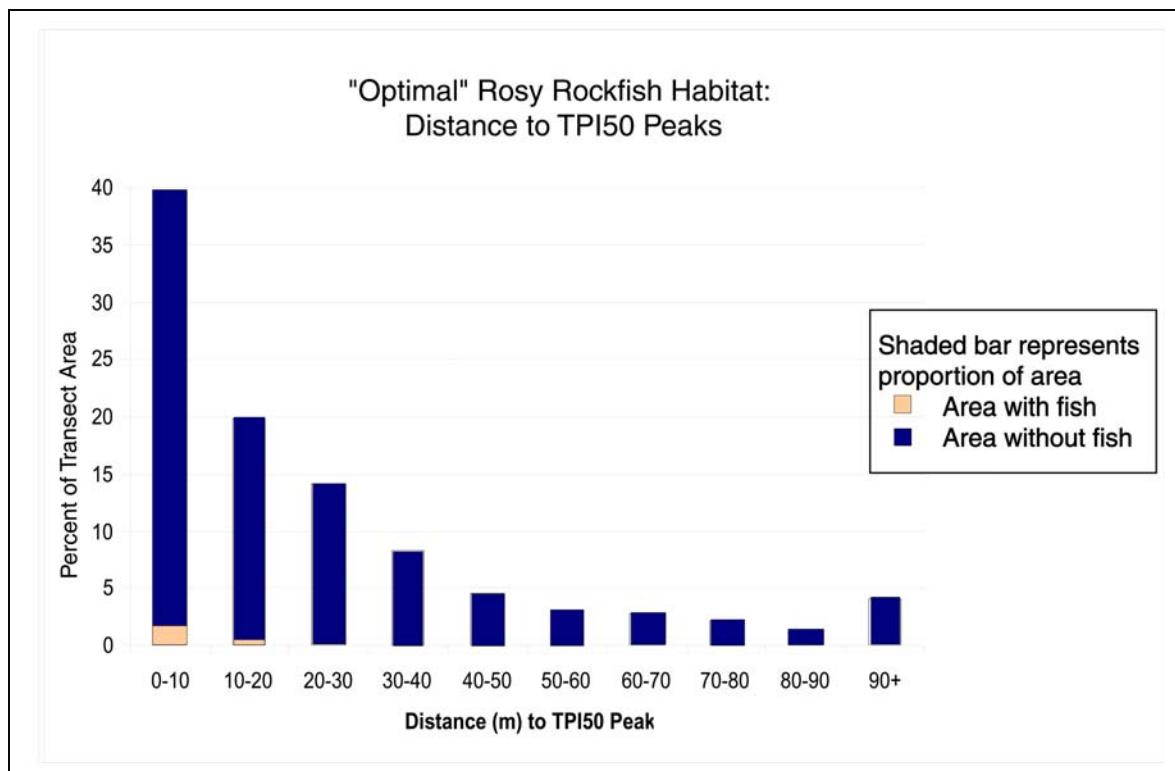


Appendix B (continued)

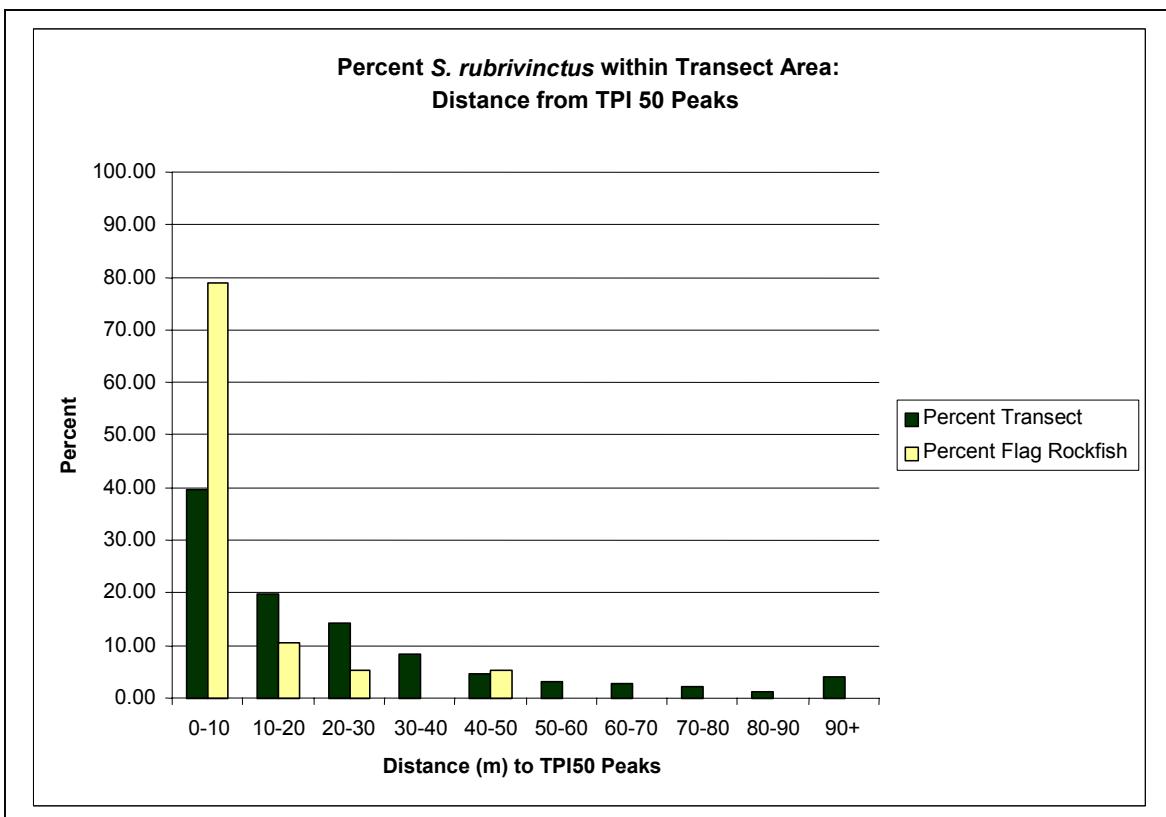
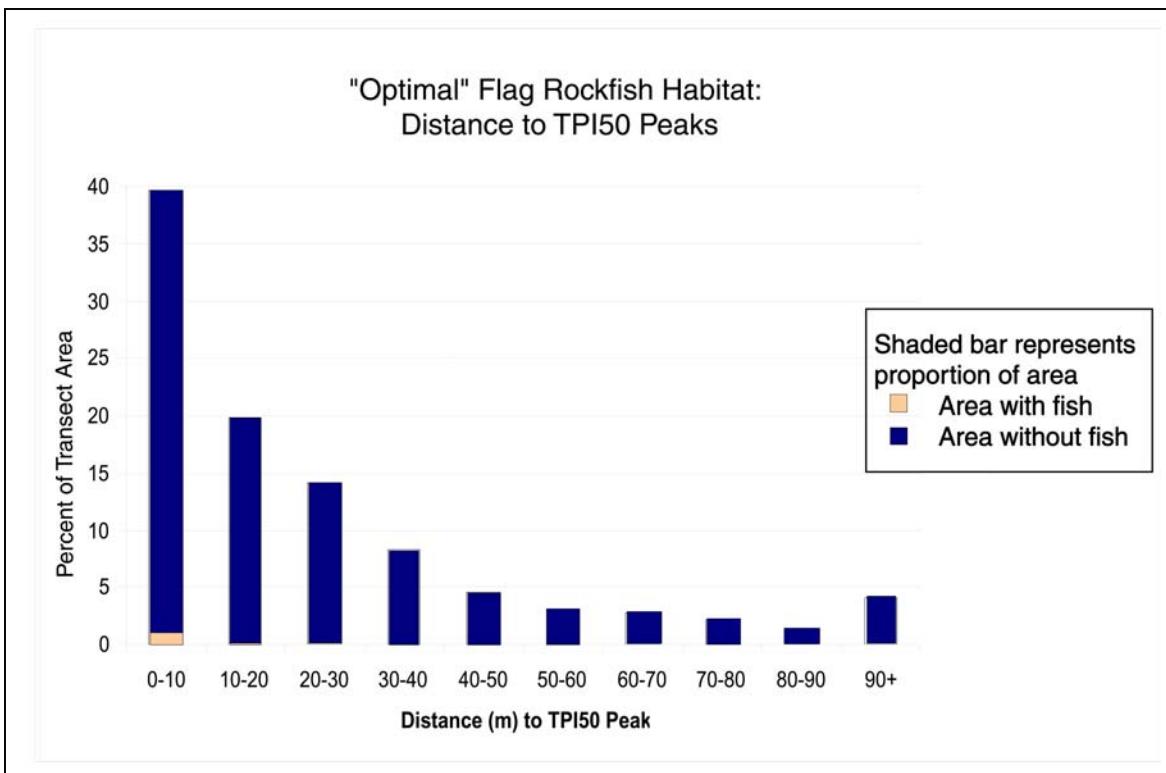
Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

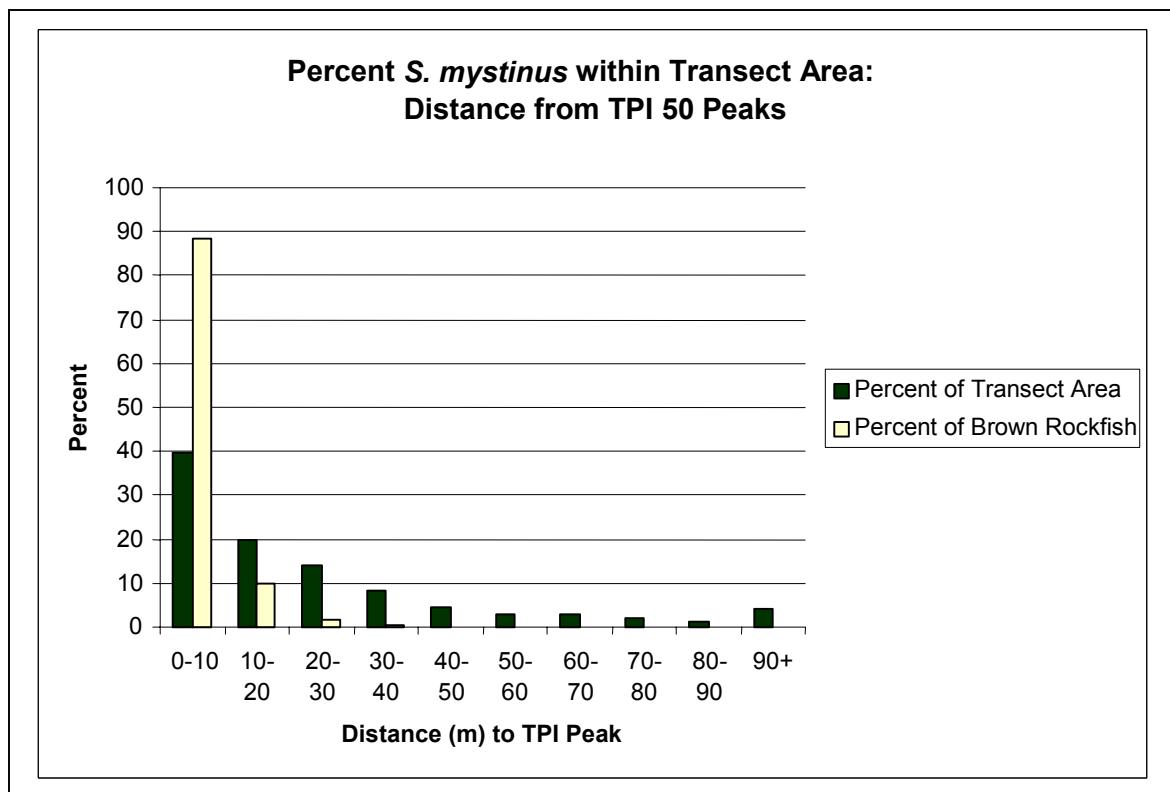
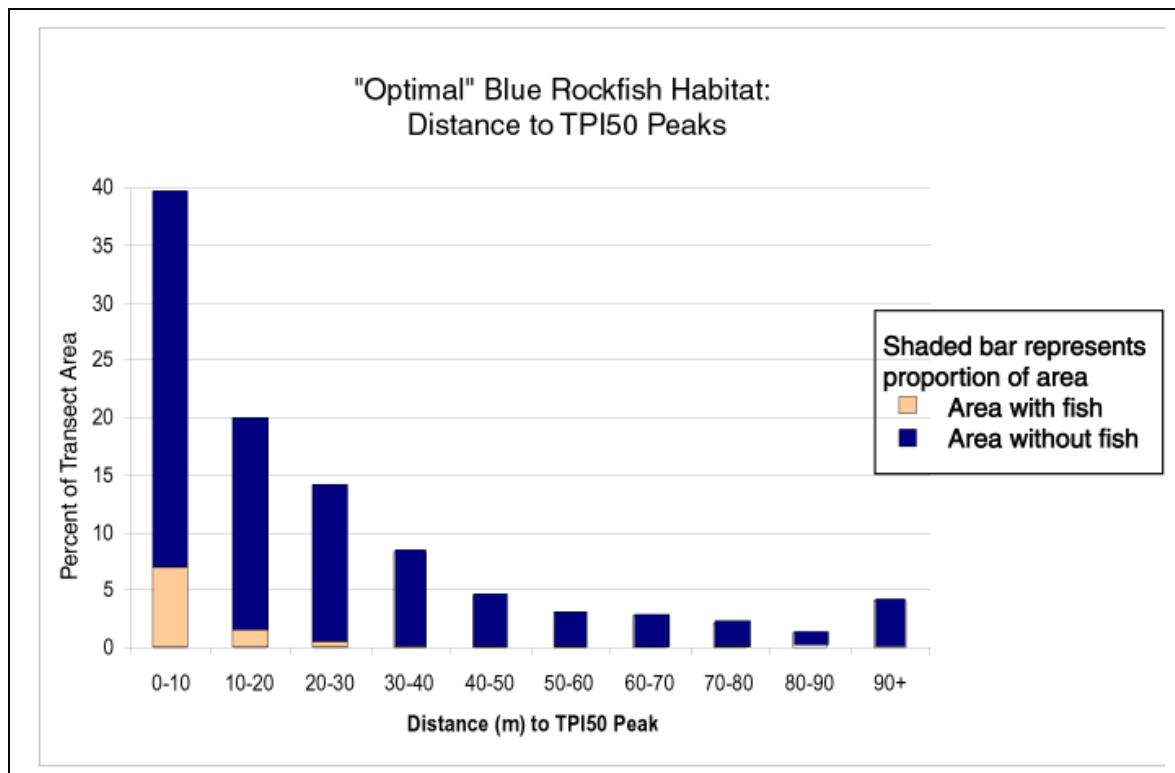
Appendix B (continued)



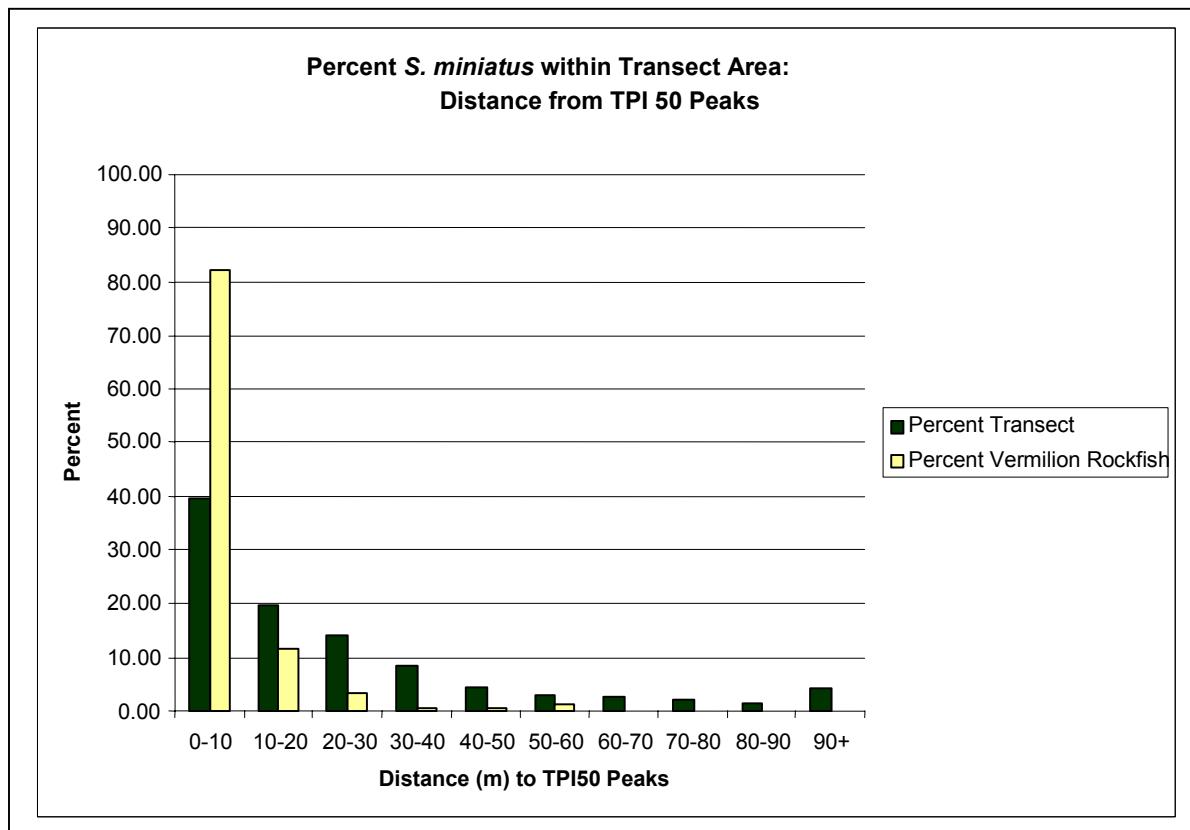
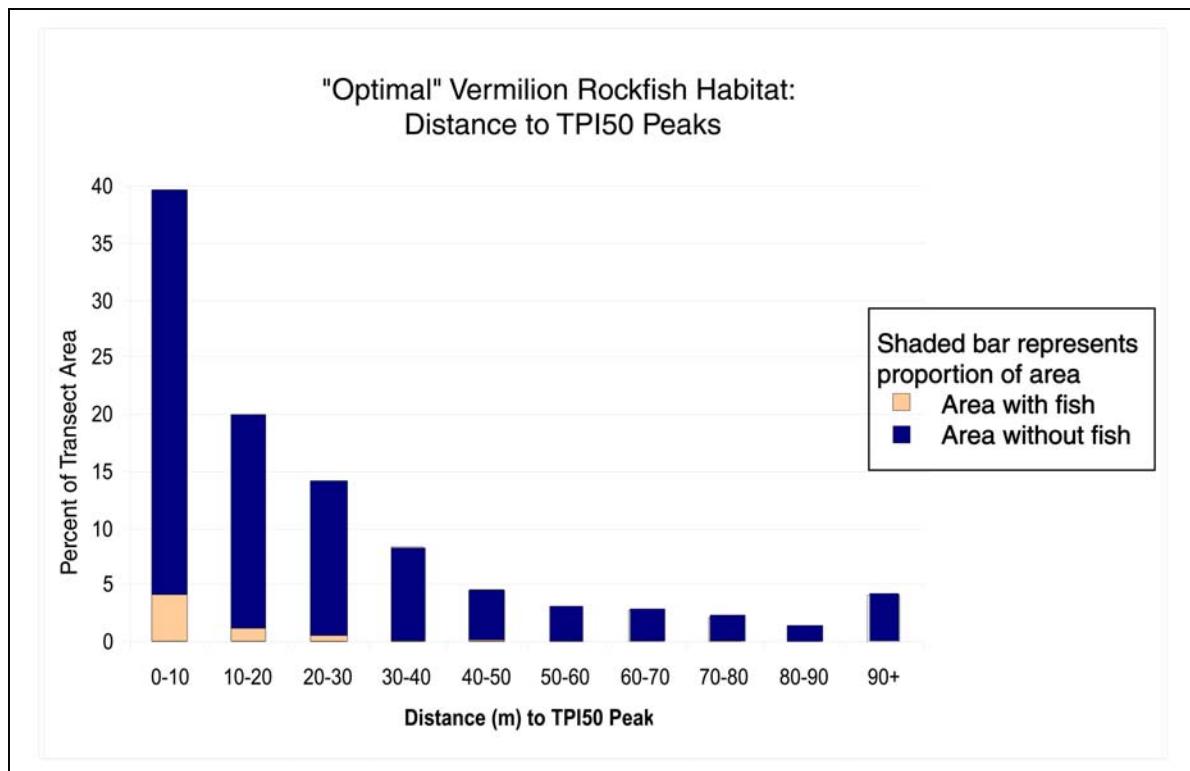
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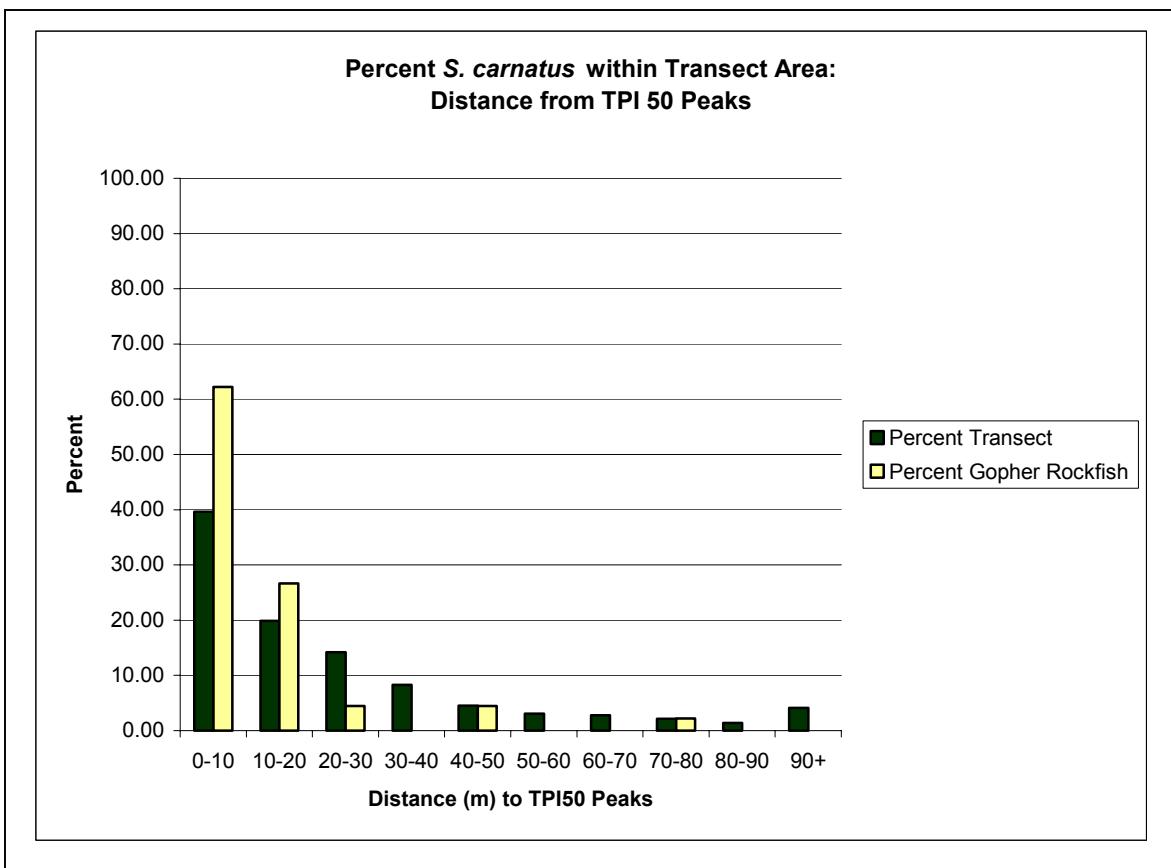
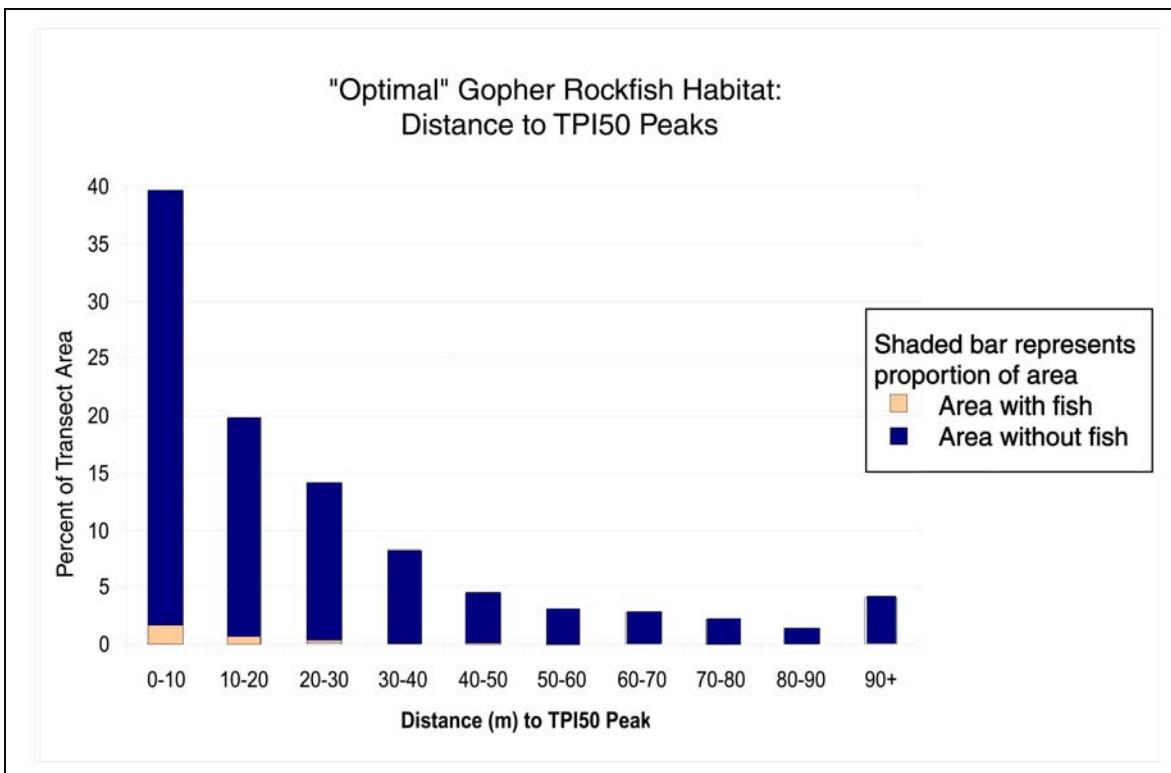
Appendix B (continued)



Appendix B (continued)

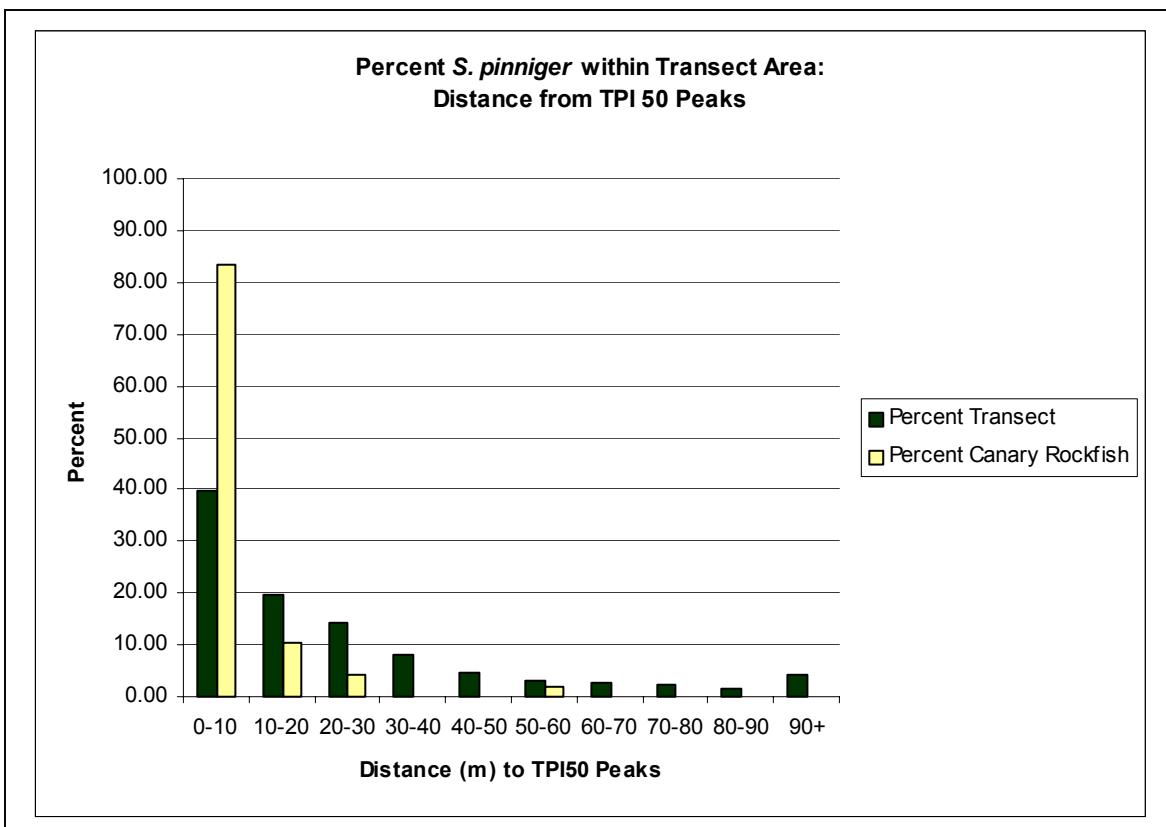
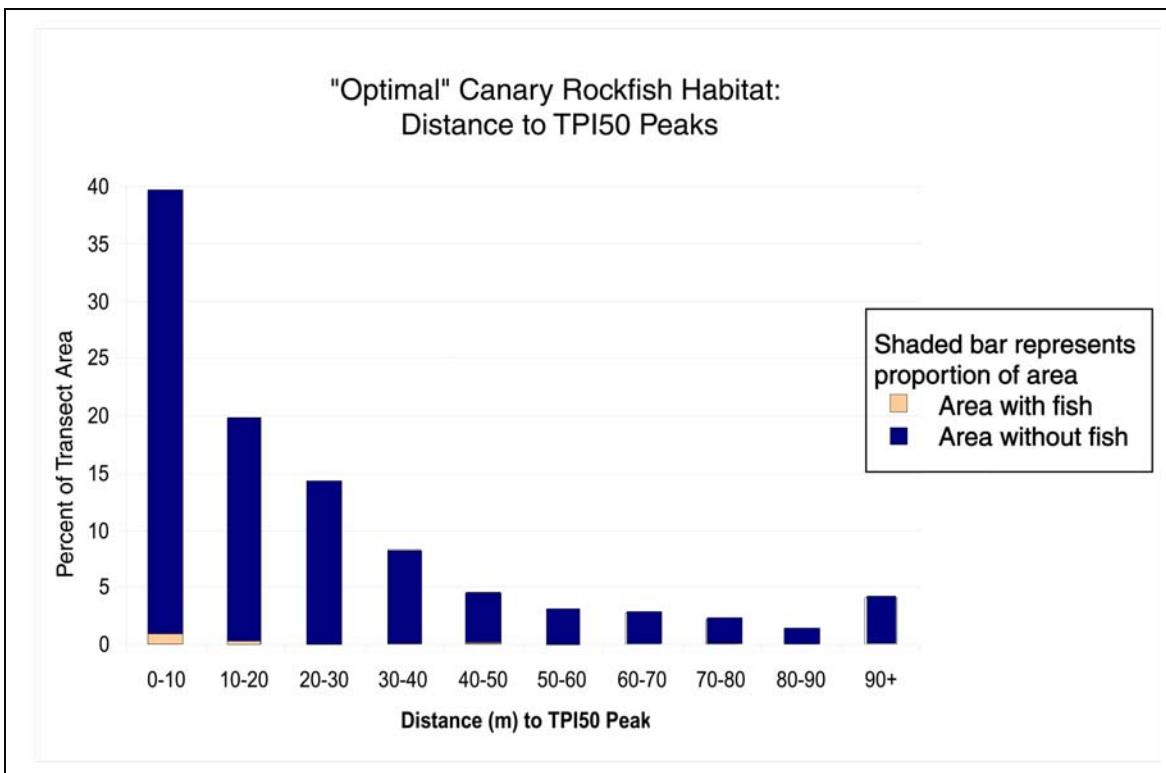
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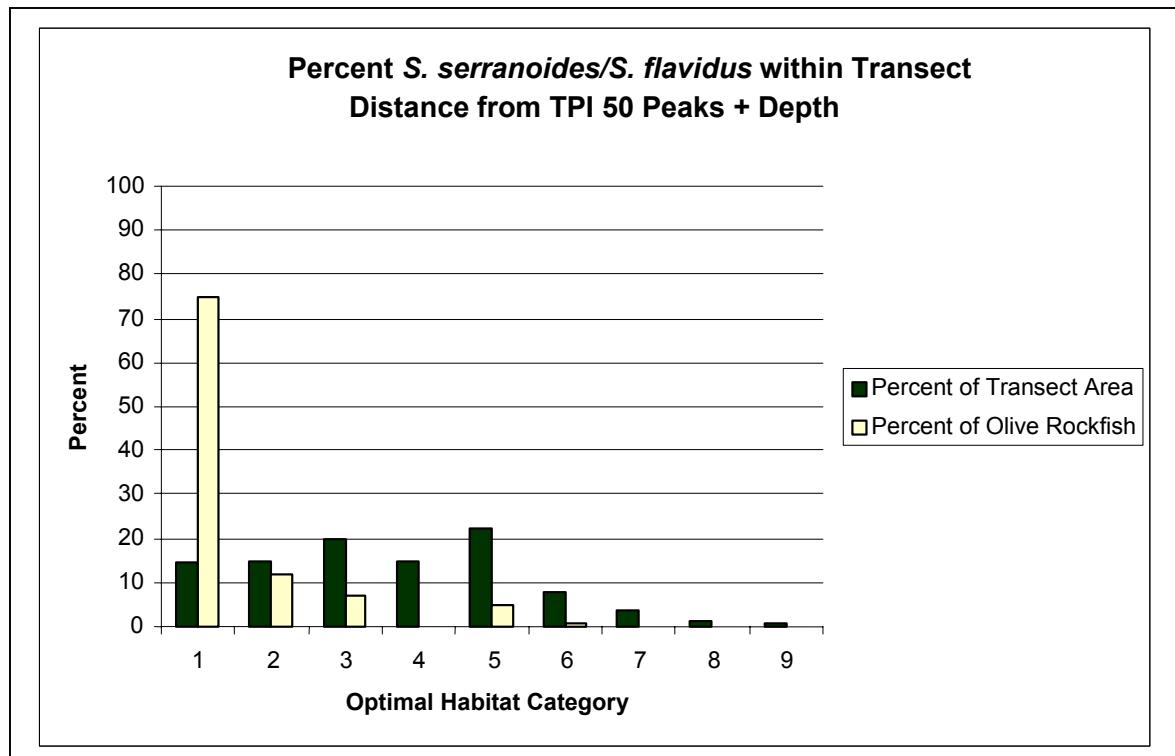
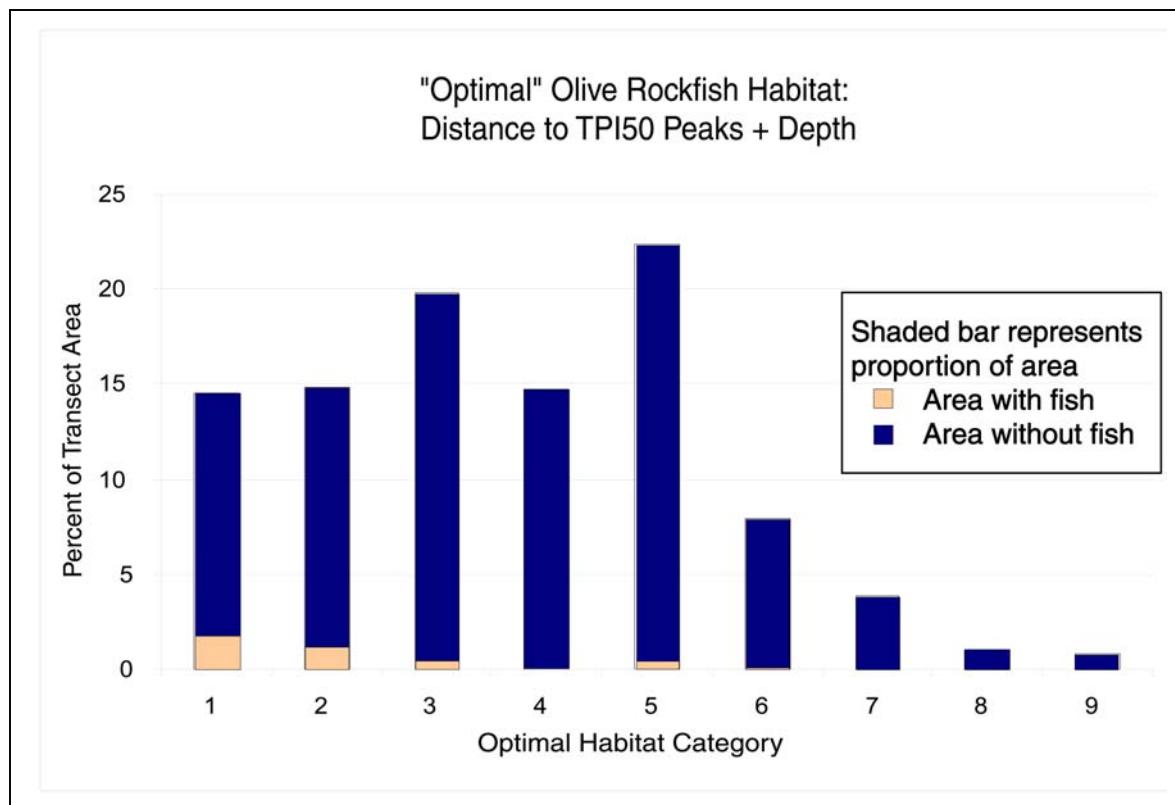


Appendix B (continued)

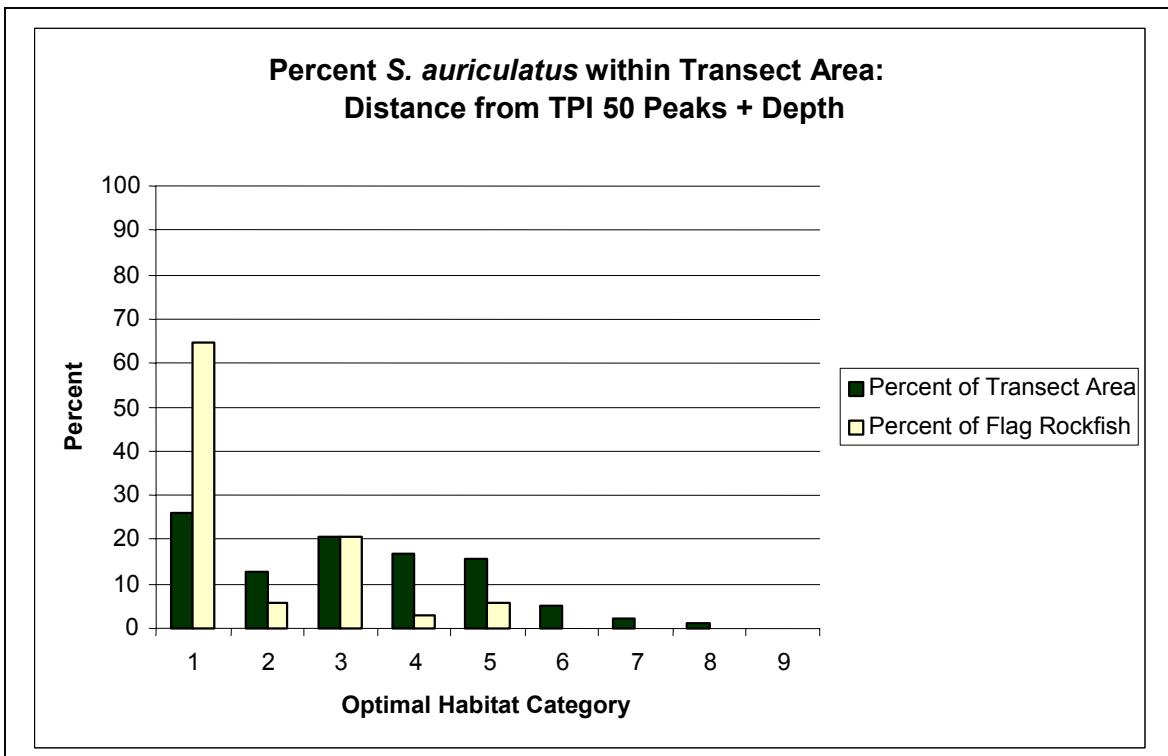
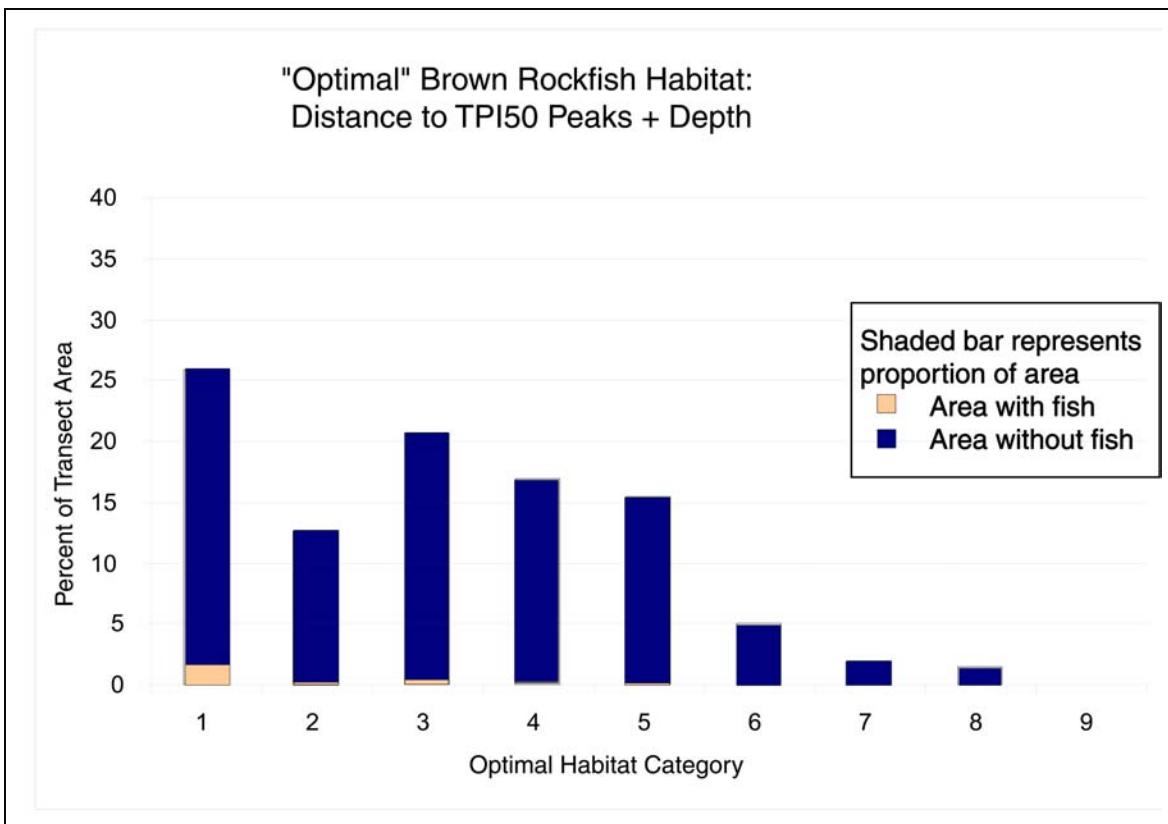
Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

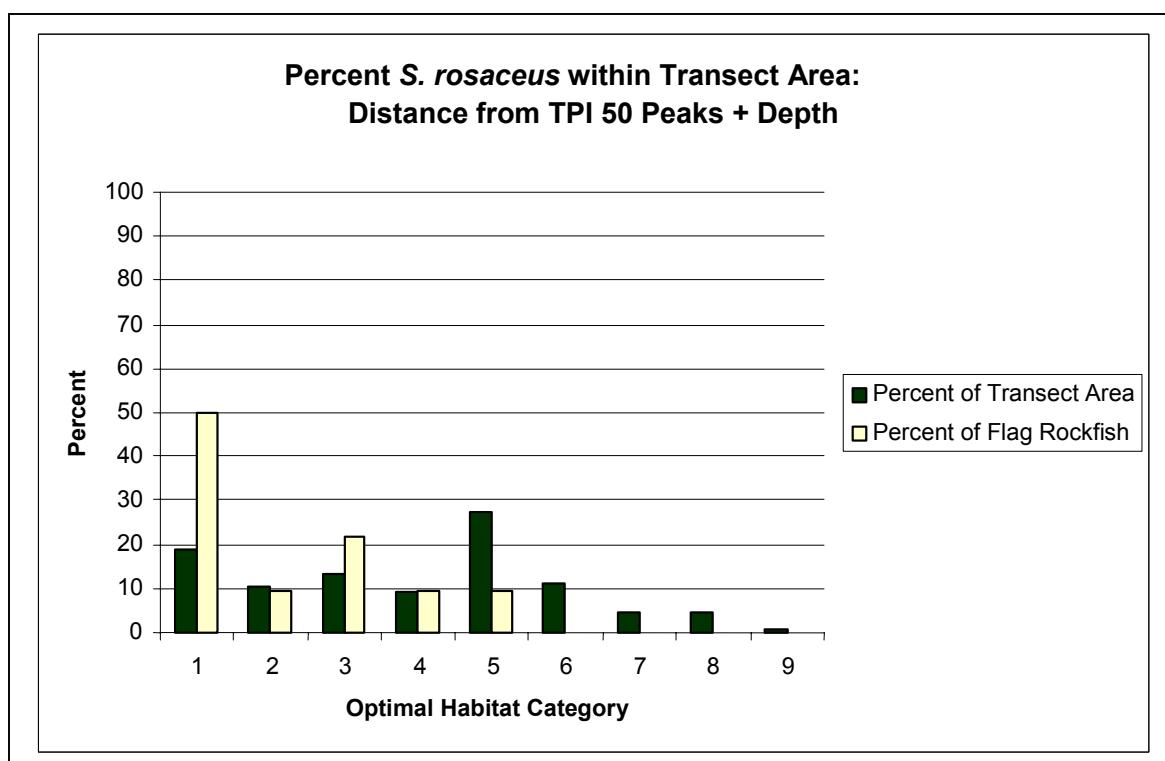
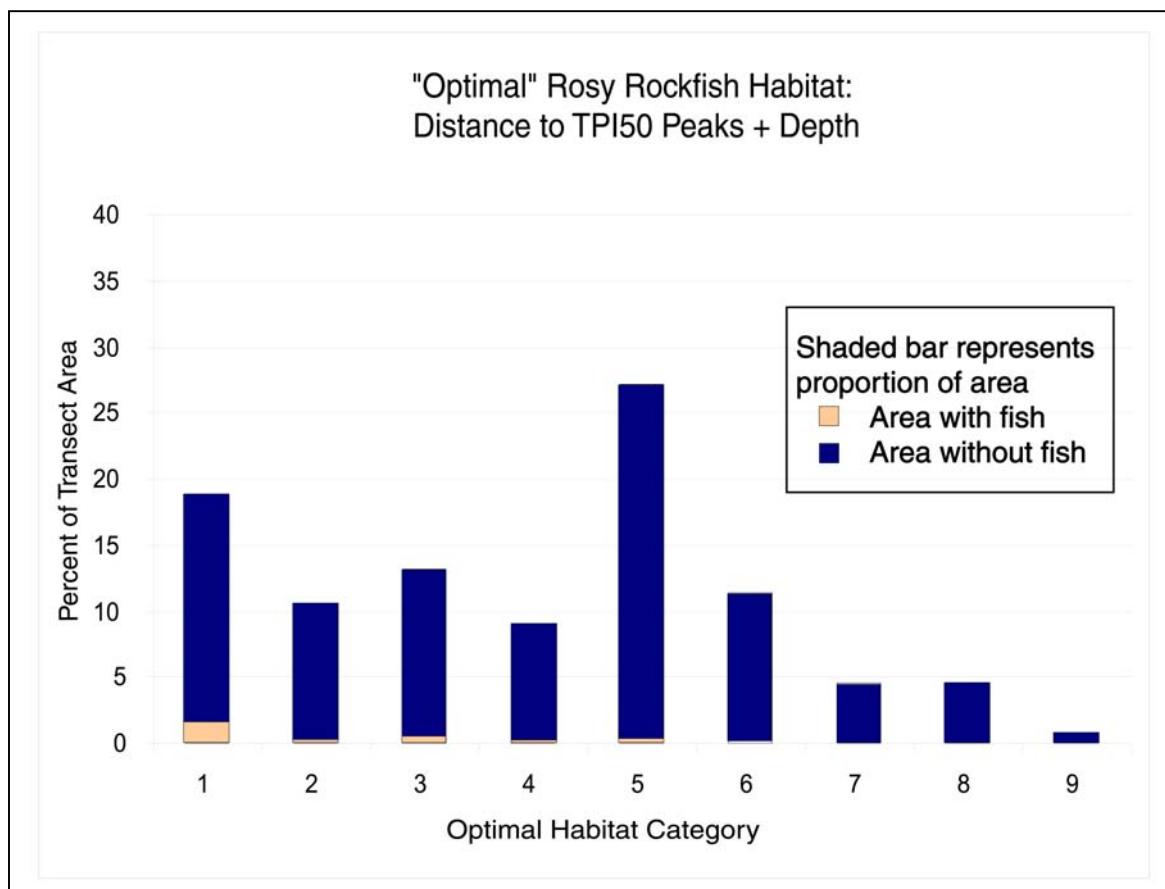
Appendix B (continued)



Appendix B (continued)

Appendix B (continued)



Appendix B (continued)

Integrated Spatial Data Modeling Tools for auto-classification and delineation of species-specific habitat maps

Appendix B (continued)

