Species-Specific Marine Habitat Maps from High-Resolution, Digital Hydrographic Data

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We used high-resolution multibeam bathymetry, together with precisely geolocated (± 5m) ROV observations of fish distribution, to produce species-specific and genus-specific habitat suitability models for eight rockfish (*Sebastes*) species in the Del Monte shale beds of Monterey Bay, CA., USA. A high-resolution (2 m) 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 (2904 total fish) were then used to create predictive models of habitat suitability and fish distribution, as well as stock estimates for the study area. A second, independent fish observation data set was used to validate the models. Factors evaluated for incorporation in the models included depth, slope, rugosity, and TPI at various scales.

INTRODUCTION

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

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

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

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

Using species-habitat associations to develop accurate habitat maps requires detailed information about how species interact with their environment. In the marine environment, the primary techniques currently used to analyze abundance and distribution of a species and its relationship to physical habitat are 1) video data from submersibles and remotely operated vehicles (ROVs), 2) SCUBA surveys, 3) trawling, and 4) single-beam echosounders. Of these, video data can provide the most accurate picture of habitat features and species interactions. Although submersibles and ROVs can only cover a fraction of the total survey region, an interpolation of discrete data sets can provide a comparatively accurate region-wide estimate. The effects of ROV, subs and SCUBA divers on fish behavior have been documented in several studies, and remain a confounding factor in the estimation of fish populations, however (Adams et al. 1995; Starr et al. 1996; Cailliet et al. 1999; Nasby-Lucas et al. 2002). Trawl surveys can be ineffective for a number of reasons. First, several studies have documented a noted avoidance of nets by target species, thus providing inaccurate (typically lower) numbers (Adams et al. 1995). Second, the trawling equipment tends to damage both the specimens brought to the surface, and the habitat over which the equipment is dragged. Third, not only are the specimens killed during the survey, but a large amount of bycatch is also destroyed (Starr et al. 2002). Single-beam echosounders, on the other hand, do not greatly disturb or destroy fish populations, but require interpolation between data without the benefit of video ground-truth data, thus reducing the accuracy of the estimation.

Given the difficulties of estimating species abundance and distribution, and given the close association marine species have with their habitat (O'Connell et al. 1998; Urbanski and Szymelfenig 2003), surveys of benthic geomorphology are a cost-effective and efficient method of generating habitat maps (Whitmire 2003), which then may be used to produce potential stock estimates. There are several techniques that can be used to map the seafloor, including side-scan sonar, single- and multi-beam bathymetry, sub-bottom profiling, hyper-spectral imagery, and laser line scanning systems. Most of these techniques are not able to provide high-resolution habitat maps on both small- and large-scales, which are necessary in order to evaluate type and extent of habitat (Bult et al. 1998; Kenny et al. 2003). Side-scan sonar records the relative reflectance of the seafloor surface, and although it can provide a very reliable image of the benthic substrate, analysis of landscape features is often difficult. Multibeam bathymetric surveys, however, can provide 100% area coverage at sub-meter resolution, and depending on the particular system used, is capable of high resolution mapping of both shallow (1 m) and deep (1000 m+) environments (Mayer et al. 1997). Multibeam data are used to create digital elevation models (DEMs), or 3D surface models of the seafloor, which can be analyzed with a variety of GIS techniques. For these reasons, multibeam bathymetry is a versatile and effective method of benthic habitat classification.

Although habitat classification and maps are fundamental for delineating areas of EFH, stock estimates are typically the primary indicator of stock size and health. The California Department of Fish and Game (CDFG), PFMC and NMFS all rely on stock assessments to make management decisions regulating groundfish fisheries. Most stock estimates are generated by trawling an area chosen within an area of interest, or from fisheries data. The fish caught are counted, measured and aged. These data are combined with other trawl and fisheries data, then extrapolated over wide geographic areas. High resolution bathymetry or other remotely sensed data are not generally used to inform this estimation process. Also, relying on trawl gear to estimate fish abundance excludes areas where trawl gear may be fouled or lost, thus eliminating many high relief, rocky areas, areas where fishing is restricted or prohibited, and areas near shore (M Dalton pers. comm., Hixon et al. 1991). In order to create a more effective means of estimating stock size and health, a combination of high resolution multibeam bathymetry and ROV or submersible data can provide a more realistic estimate of fish abundance, provide data for previously inaccessible areas, and also include information on species-habitat use and associations.

The goal of this project was to develop GIS modeling tools that can be applied to multibeam bathymetry data to predict the distribution of particular species, given species-specific habitat preference parameters. For this study, we used high-resolution multibeam bathymetry of the Del Monte shale beds in Monterey Bay to assess rockfish habitat (Figure 1). Given rockfish preference for high-relief substrates, we tuned the GIS tools to locate areas of high slope, rugosity and certain classes of relative topographic position. Using different combinations of each of these parameters, we created habitat suitability models that can identify locations of probable high rockfish abundance. Video data collected from a remotely operated vehicle (ROV) were used to determine actual rockfish abundance and distribution along linear transects within the multibeam survey area. These data were used to test the accuracy and efficacy of the suitability models. The video data were also used to produce stock estimates by extrapolating the number of fish found along the transects over the entire survey area, stratified by habitat suitability. The tools used in this project can be applied to most near shore environments with relative ease and speed, areas where resource managers have lacked information capable of providing accurate and reliable stock estimates.

METHODS

General Approach

The general approach of this project was to use GIS landscape analysis tools on high-resolution multibeam bathymetry data to assess the type and extent of habitat on the shale beds in Monterey Bay. The cleaned 2m x,y,z (northing, easting, depth) point data were gridded to produce a digital elevation model (DEM) in IVS Fledermaus 5.2, and imported into ArcGIS 8.3 for further analysis. Slope, rugosity, and relative topographic position grids were generated from the DEM in order to better visualize areas of high relief. Multibeam derived imagery was used to plan ROV transects that ran perpendicular to the strike of the shale reef in order to observe any associations rockfish have with the linear ridge features characteristic of the shale beds. Two sets of ROV surveys were conducted, one in fall 2002 and one in spring 2003. Analysis of the ROV video data determined species, abundance, location, and benthic environment for each observation of adult rockfish along the transects. A database including the position and characteristics of each observation was imported into GIS, and analyzed for spatial patterns relative to the DEM, slope, rugosity and relative togographic position grids. Habitat suitability models were generated by using different combinations of the grid parameters (depth, slope, rugosity and relative topographic position), based on rockfish preference for high relief substrates. All the models were created using the spring ROV fsih distribution and abundance data, and were evaluated using the fall dataset as an independent means of determining each model's ability to predict areas of high rockfish density.

Site description

The Del Monte shale beds cover an area of approximately 9.5km^2, located approximately a kilometer offshore from Monterey Harbor, Cannery Row and Del Monte beach in central California. The shale beds are a relatively low-relief environment, composed of Miocene Monterey Formation, distinguished by laminated semi-siliceous mudstone and sandy siltstone (Eittreim et al 2002). The reef is characterized by long, linear ledges dipping down to the northeast, surrounded by unconsolidated sediment, ranging from 10 to 70m in depth (Greene 1990; Storlazzi and Field 2000). The benthic invertebrate community includes the conspicuous plumose anemone *Metridium senili*, smaller anemones and cup corals (*Corynactis californica*, *Balanophyllia elegans*, *Paracyathus stearnsi*), various encrusting and puffball sponges (e.g. *Hymenamphiastra cyanocrypta*, *Tethya aurantia*) and numerous species of sea stars (e.g. *Asterina miniata*, *Pycnopodia helianthoides*). The reef is home to over 20 species of rockfish (*Sebastes* spp.), several of which have been identified by the National

Marine Fisheries Service (NMFS) as over-fished (PFMC 2004). The area is open to recreational fishing, which for near shore areas such the shale beds, the recreational fishing harvest exceeds commercial harvest (Starr et al. 2002). Overall, the shale beds provide a wonderful opportunity to study the link between species and habitat; they are located near shore and have a diversity of habitats.

Multibeam bathymetry

Multibeam bathymetric data were collected by the Seafloor Mapping Lab at CSUMB, with a Reson 8101 Seabat multibeam sonar, which can map depths of 1 to nearly 300 meters. The 8101 operates at 240 kHz, capable of taking up to 3,000 soundings per second with a swath coverage of up to 7.4 times the water depth, and a swath angle of 150°. Triton Elics Isis Sonar data acquisition system onboard the R/V *MacGinitie* simultaneously logged the multibeam data along with the positional data collected from an Aplannix Position and Orientation System, Marine Vessel (POS-MV) for heave, pitch, roll and yaw corrections (with +/-0.02° accuracy); and Trimble 4700 GPS with differential corrections from a Trimble ProBeacon receiver (with +/- 1-2 m accuracy). An Applied Microsystems Limited (AML) SV+ sound velocity profiler recorded the speed of sound through the water column to account for salinity and temperature changes. Shipboard data were then post-processed in the Seafloor Mapping Lab using Caris Hydrographic Information Processing System (HIPS) 5.2 software. Tide and SVP (sound velocity profile) corrections were applied, and the data were cleaned to remove erroneous soundings.

Multibeam bathymetric data for the shale beds were collected during three survey days in 2000 and 2001. After initial post-processing, the data from 2001 were reprocessed to correct a latency error produced from the shipboard data acquisition computer at the time of the survey. The majority of artifacts were removed during rigorous QA/QC in order to ensure accurate landscape analysis results. Shoal-biased x,y,z (northing, easting, depth) files thinned to 2 m spacing were exported from Caris, reviewed in Fledermaus, and exported as a digital elevation model (DEM) representing a three-dimensional surface of the seafloor. The DEM was imported into ArcGIS, and provided the data for all subsequent landscape analysis. Grayscale geotiffs with a 2 m resolution were also exported from Caris and imported into GIS for visual interpretation of geomorphic features (Figure 1).

ROV Video Analysis

Geomorphology groundtruth and fish census data were collected using a Hyball remotely operated vehicle (ROV) deployed from the R/V *MacGinitie* during two surveys in fall

2002 and spring 2003. Transects were oriented perpendicular to the strike of the reef, running NNE by SSW in order to best view the differentially eroded, under-cut shale ledges. Tracklines were spaced approximately 500 m apart and averaged 1 km in length (Figure 1). The ROV was kept approximately 1-2 m from the bottom, with a forward viewing angle of approximately 45° below horizontal. Two parallel lasers were mounted on the frame of the ROV spaced 20cm apart to provide a scale reference for determining size of individual fish, relative distance from the bottom and visibility. The ROV paused for large fish aggregations to more accurately count and identify individuals, and at the base of large ledge features to pan from left to right to record any species-ledge interactions before continuing up and over these features. Video data and transect lines, or parts of transect lines, that did not run perpendicular to the strike of the reef, were flown consistently above 2 m from the bottom, or were dragged by the support vessel, were excluded from the project. Video from the ROV was recorded with a JVC 470 line resolution, 0.95 lux color CCD with an F 0.8 Pentax lens, and the data were recorded onto mini-DV tapes.

Positional data from the ROV was recorded with a Trackpoint II+ ultra-short baseline acoustic tracking system, with +/- 1-2m accuracy. ROV depth was recorded with a pressure sensor mounted on the vehicle. Position and depth information were recorded onto the videotape using a Horita GPS-3 encoder. ROV data were collected over 3 survey days in October and November 2002, and over 6 days in April and May 2003, and resulted in approximately 9.5 hours of useable ROV footage for the fall survey, and 32.2 hours for the spring survey.

The ROV tracklines were recorded and corrected using Hypack Max v. 2.12 software. The Trackpoint II+ system on the R/V *MacGinitie* calculated the ROV position relative to the vessel, which was integrated with the vessel position in Hypack to determine the real world coordinates of the ROV. The Trackpoint system would occasionally produce bad position fixes for the ROV, or would produce no fixes at all for a short period, causing “jumps” or erroneous positions to be logged. These positioning errors were corrected by post-processing the trackline data in the lab. A 5 m buffer on either side of the corrected tracklines was applied to delineate the viewable area surveyed by the ROV. Area and distance were calculated for the tracklines to determine the amount of area surveyed. Buffered tracklines were used in subsequent landscape analysis of the bathymetric data, and for evaluation of model efficiency.

Video analysis was performed in the lab using a JVC BR-DV600A mini-DV digital VCR with monitor display. Tapes were reviewed and positional data retrieved using the Horita GPS-

3 decoder. The precise location of individual fish observations including species identification, abundance, depth, substrate classification, and important habitat features, were recorded on log sheets and in a digital text file. Individuals that the observer was unable to identify to species and juvenile rockfish were excluded from the study. Substrate classification was based on percent cover of primary and secondary substrates, with the primary substrate covering over 50% of the viewable area. Substrate classes were divided into 6 categories: sand, cobbles (rock fragments < 0.25m), rubble (rock fragments greater than 0.25m, and less than 0.5m in size), boulder (individual rocks greater than 0.5m in size), small ledges (height < 0.5m) and ledges (height > 0.5m). Discrete fish observations were made at a minimum distance of 5m apart. The precise location of single fish observations was determined by recording the position of the ROV at the spot where the fish was initially observed. Observations of groups of individuals and large schools were determined by recording the position of the ROV at the center of the group or school. Individuals were identified to species when in visual range (≤ 5m).

Information from the log sheets and text files were integrated into a database, then imported into GIS, with an attribute table which included the parameters logged during video analysis. Spatial analysis of the video data was done in ArcGIS 8.3. Fish distribution and abundance data were analyzed in relation to geomorphic features derived from the bathymetry data (depth, slope, rugosity, relative topographic position).

GIS Analysis

Analysis of the multibeam data was done in ESRI ArcGIS 8.3 and ArcView 3.2. The use of GIS allows large datasets to be manipulated and analyzed together, and combines the use of various spatial analysis tools for a detailed study of landscape features. Given rockfish preference for high relief substrate, slope, rugosity and relative topographic position grids were generated from the DEM in order to visualize and quantify areas of high relief.

Depth

The transect lines and video data included in the study fell between the depths of 15 and 65 meters. The depth grid was stratified into five 10 m increments to better visualize trends in fish distribution. Although the multibeam survey area covered depths from 2 to 72m, only the depths covered by the ROV survey were included in the creation of the habitat suitability models (Figure 2). Thus, the suitability models interpolated suitability categories for areas between transects, but did not extrapolate these projections over the entire multibeam survey area. In order to do so, a mask was created to exclude the multibeam data that fell outside the ROV survey area from the habitat suitability models. The mask included 1. a 50m buffer area outside each end of the transect lines from the spring survey, and 2. the entire area between the interior transects.

Slope

Slope was calculated using the Spatial Analyst extension in ArcGIS 8.3. Slope is calculated by taking the steepest slope between each cell in the DEM and its 8 nearest neighbors. This tool provides a quantitative representation of the "steepness" of the terrain at a 2 m scale, the scale of the resolution of the DEM.

Rugosity

Rugosity was calculated in ArcView GIS 3.3 using the "Surface Areas and Ratios from Elevation Grid v.1.2" extension, created by Jenness Enterprises (Jenness 2002). Rugosity is a measure of the ratio of surface area to planar area, which is an estimate of the "roughness" of the terrain. Rugosity values derived from high-resolution seafloor DEMs typically range from 1 (completely flat and smooth) to approximately 4 (rugged terrain), and higher values indicate there is more surface area relative to flat area – thus the area is considered "rough" or "rocky". For this study, rugosity was also calculated at the 2 m resolution of the DEM.

Topographic Position Index (TPI)

Topographic Position Index (TPI) was calculated in ArcGIS 8.3. TPI was calculated using the following formula:

tpi<*scalefactor*> = int((dem - focalmean(dem, annulus, *irad*, *orad*)) + .5)

where:

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

The generation of TPI is a multi-step process that involves calculating the focal mean for each cell in the DEM to generate average neighborhood elevation (depth) values given a particular neighborhood size. The shape of the neighborhood used in the focal mean calculation is arbitrary, but an annulus ring ("doughnut") is often used so that the immediately neighboring cells are not included. For this study, a five cell (10 m) thick annulus ring neighborhood was used. Each cell's average neighborhood depth was then subtracted from the depth of the cell to yield a measure of relative elevation; highly positive numbers denote areas with relative elevations much higher than their surroundings, while highly negative numbers show areas much lower than their surroundings (within the neighborhood size). Relative elevation values near zero can result from flat areas, where the elevation of the cell is the same as its neighbors, or from constantly sloping areas, where there are just as many neighboring cells that are higher as there are cells that are lower (Figure 3). The relative elevation values were reclassified into five standard deviation classes that represent relative highs, lows, rises and flat areas, or areas of constant slope. The middle class, which contained both flat and constant slope areas, was split into two classes using the results of the DEM slope analysis; areas with slope ≤ 5° were classified as "flat", while those with slope > 5° were designated as slopes. The resulting 6 TPI classes provide a quantitative representation of regional highs, lows, slopes and flat areas given neighborhood size (Weiss 2001). TPI is a powerful tool that can represent areas where there are abrupt changes in relief, such as ledges next to sand channels.

TPI with neighborhood sizes of 10, 20, 30, 40, 50, 60, 80, 100, 120 and 150 m were generated using the 2 m DEM. Each TPI scale result was visually compared to the grayscale geotiff in GIS to assess accuracy of geomorphic feature definition. Substrate data collected during ROV video analysis was also compared to each TPI for further accuracy assessment.

Habitat Suitability Models

Habitat suitability models were designed to predict areas of high rockfish density. Models were created with the raster calculator function in Spatial Analyst by adding different combinations of slope, rugosity, TPI and depth values. Each additive model was reclassified into habitat suitability categories, from 1 (most suitable) to 10 (least suitable). Spring ROV video data were used to create and refine each habitat suitability model. Fall ROV video data was used to evaluate predictive ability of the suitability models.

Stock Estimates

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

RESULTS

ROV Video Analysis

The ROV Video data were collected in fall 2002 and spring 2003. ROV survey trackline distance totaled 10.5 km over 6 transects during the fall survey, and 48.7 km over 21 transects during the spring survey (Figure 1). The database generated from the fall survey included a total of 730 individual rockfish identified to species; the spring survey included 2904 individuals. Eight species were included in the study: *Sebastes mystinus* (blue rockfish), *S. serranoides/S. flavidus* (olive/yellowtail rockfish), *S. miniatus* (vermilion rockfish), *S. auriculatus* (brown rockfish), *S. carnatus* (gopher rockfish), *S. pinniger* (canary rockfish), *S. rosaceus* (rosy rockfish), and *S. rubrivinctus* (flag rockfish). There were 4 other rockfish species identified during the analysis, but their abundance was each less than 0.5% of the total number of fish, so these species were excluded from the study.

GIS Analysis

Visual analysis of the ROV data in relation to the geomorphology of the reef showed there was a strong relationship between fish distribution and abundance, and local higher-relief structures along the shale beds (Figure 4). Indeed, the life history data of rockfish show that many *Sebastes* species tend to inhabit rocky outcrops and reefs, and prefer high relief habitat (Haldorson and Love 1991; Love et al 1991, 1996, 2002; Humann 1996; Casselle et al. 2002; Helvey 2002). Fish abundance was summarized by grid category (Table 1), and used to inform the construction of the habitat suitability models.

The shale beds are a relatively low relief environment, containing features generally less than 2 m in vertical relief. The resolution of the DEM, and thus all derivative grids, was 2 m, and this proved to be a confounding factor in the landscape analysis of this area. With a resolution on the same order as the maximum vertical relief, many features were obscured, and derived slope and rugosity values reflected this limitation, with smaller ranges and lower maximum values than originally expected from visual analysis.

Slope

Slope derived from the 2 m DEM produced values ranging from 0 to 32° (Figure 5), which were lower than estimated from the ROV videos, in which very steep, near 90° angles at the face of ledge features were observed. In order to produce summary statistics and use the grid as part of an additive habitat suitability model, the grid was classified into 3, 4, and 5 equal interval and natural breaks classes to quantify species-slope interactions. Visual analysis of the multibeam derived imagery showed that 5 natural breaks classes appeared to best symbolize the data, but for the purposes of analysis, the natural-breaks category for high slope (≥ 8.97°) was merged with the next lower class and defined as slope ≥ 4.86° (Table 1).

Rugosity

Again, due to the low-relief nature of the shale beds coupled with the 2 m resolution of the DEM, the rugosity grid results were lower than expected, ranging from 1 to 1.22 (Figure 6). Video analysis recorded relatively rugged areas covering a substantial portion of the reef area, which were not reflected in the rugosity calculation of the DEM. The rugosity grid was classified using a similar process to that used for the slope grid. Three natural breaks classes appeared to best represent the low rugosity values of the shale beds. As with the slope reclassification, the highest natural-breaks rugosity class (≥ 1.02) was merged with the next lowest class and defined as rugosity ≥ 1.003.

Topographic Position Index (TPI)

Multiple TPI grids with neighborhoods ranging from 10 to 150 m were generated and compared to the geotiff image, substrate and fish data collected during the ROV surveys (Appendix 1, Table 1). After careful analysis, TPI_{50} was determined to be the optimal neighborhood size, best matching both the observational data and geomorphic features (Figure 7).

Although the TPI algorithm was very effective at classifying relative topographic position, it was susceptible to edge effects and artifacts in the DEM. For example, the near-shore edge of the DEM tended to be classified as a "peak," or a high area relative to its neighbors. The lack of neighbors to the shoreward side caused this misclassification. As this area was not actually a relative high, but was found on the upslope edge of the dataset, a 50m buffer was created around the edges of the original DEM grid and used as a mask when creating the TPI_{50} grid. Residual artifacts in the DEM from overlap in the multibeam data were also classified as "peaks." Multibeam surveys are designed as a series of parallel swaths covering the seafloor, which incorporate some degree of overlap in the coverage of adjacent swaths. Elevation data (soundings) on the outer edge of the swath tend to be "noisier" and sometimes exhibit shallower depths due to incomplete sound-velocity correction and signal attenuation through the water column. Thus, swath overlap can sometimes produce artifacts, which appear as "ridges" parallel to the survey swaths having higher elevation than the surrounding areas. Although the great majority of these artifacts were removed during multibeam data processing, some were impossible to address and remained a confounding factor in the calculation of the habitat suitability models.

Habitat Suitability Models

Spring ROV observation data were used to guide the generation of all habitat suitability models. Summary statistics were generated for slope, rugosity and TPI grids, including number and percent of rockfish per grid category (Table 1). Analysis of these data showed that TPI_{50} peaks seemed to be the most attractive feature to rockfish. However, fish that were very likely *associated with* a peak feature, were not always found clustered directly on top of it. Thus, in order to account for the fact that a given fish may have been observed on a "flat" area, but very near a "peak", a "distance to TPI_{50} peaks" grid was calculated, and this was reclassified into 10 m incremental categories for use in creating the habitat suitability models (PFMC 2004).

"Distance to Preferred" slope and rugosity grids were created to classify the study area according to apparent proclivity of rockfish for areas of higher slope (≥ 4.86°), and rugosity (≥ 1.003,Table 2). Each of these "Distance to Preferred" grids was classified in 10 m increments, with categories ranging from 1 to 10, or from 0 to 100m away from, preferred areas. Category 1 included the preferred area, and the area within 10m of the feature (Table 3).

Summary statistics of the ROV observation data also revealed depth preferences for five of the 8 species included in the study (Table 1). The ROV survey area was stratified into five 10 m depth zones (Figure 2). These depth zones were ranked in GIS based on species preference, then incorporated into different habitat suitability models (Table 3).

Four initial sets of habitat suitability models were generated in order to predict rockfish distribution and abundance in the shale beds ROV survey site. The factors included in the models were "Distance to Preferred" categories, which were either analyzed alone or added together. The models were created in GIS using the raster calculator function in Spatial Analyst. Models incorporating more than one factor (e.g. distance to TPI_{50} peaks + depth) were simple, additive, unweighted models. As the grids were classified based on a common scale from 1 (most suitable) to 10 (least suitable), the additive model resulted in values ranging from 2 to 20. These raw models were reclassified into 10 equal interval categories from 1 (most suitable) to 10 (least suitable).

Model Evaluation

Summary statistics were generated for each set of models with respect to number and percent of rockfish by species found in each category for both the fall and spring surveys (Table 4). The fall dataset was not included in the generation of the models, and therefore can be considered an independent dataset for use in validation of the models. Model performance was evaluated by comparing the results of the "most suitable" category 1 for both the fall and spring surveys. The model with the most rockfish predicted by category 1 was determined to be the most successful. Density tables were also generated for each of the 4 models to standardize the number of fish found per category within a 100m^2 area (Table 5).

Model 1: Distance to TPI_{50} Peaks

Model 1 included only distance to TPI_{50} peaks as a single factor (Figure 8). Model 1 appears to predict an average of 80% of rockfish within the “most suitable” category 1 (Table 4). This simple model was based solely on the relationship rockfish have with high-relief features.

This model did not require the use of stratified depth zones, so the results from this model could be extrapolated over the entire multibeam study area. Figure 8 shows Model 1 results limited to the analysis mask area in the foreground, where the ROV video data provided feedback on the model performance, and results projected for the entire survey area in the background, or the “grayed-out” area.

Model 2: Distance to TPI_{50} Peaks + Depth

Model 2 included two factors in the analysis: distance to TPI_{50} peaks and species-specific depth stratification categories. Three species were more abundant in deeper water, increasing in abundance with increasing depth: *S. serranoides/S. flavidus*, *S. rosaceus,* and *S. rubrivinctus*. Two species showed the opposite trend, more abundant in shallower water, decreasing in abundance with increasing depth: *S. mystinus* and *S. miniatus* (Table 3). The depth distribution of these species covers very broad depth zones, and can vary in the natural history literature (Humann 1996; Love 1996, 2002; PFMC 2004), so the stratification of these species was based solely on ROV observation data.

Two sets of Model 2 were generated, one for each of the two different depth preferences. “Model 2 – Deep”, added the “distance to TPI_{50} peaks” grid to the reclassified depth grid, classed 1 for the deepest zone (55-65 m) to 5 for the shallowest zone (15-25 m) covered during the ROV surveys . Model 2 – Deep proved to be less effective at capturing both spring and fall species within the “most suitable” category 1 (Table 4 - due to file size limitations, figures showing all models are not included; please contact author for further information).

“Model 2 – Shallow”, added the “distance to TPI_{50} peaks” grid to the reclassified depth grid, classed 1 for the shallowest zone (15-25 m) to 5 for the deepest zone (55-65 m) covered during the ROV surveys. This model proved to be less effective at predicting the occurrence of fish within these depth ranges (Table 4).

Both of these models were limited to the depth zones where the ROV transects were located, between the 15 and 65 m contour lines. Because species depth preferences were noted during analysis of the ROV data, and were not determined by life-history data, the models were not extended beyond the 15 and 65 m depth contours.

Model 3: Distance to Preferred: TPI_{50} Peaks + Slope + Rugosity

In order to ascertain whether distance to TPI_{50} peaks alone was an effective predictor, Model 3 was generated to combine distance to TPI_{50} peaks with "distance to preferred" slope (slope≥ 4.86°) and rugosity (rugosity ≥ 1.003). These three "distance to preferred" grids were added together in raster calculator to generate the raw Model 3 values ranging from 3 to 30. These values were reclassed into 10 equal interval classes and referred to as Model 3 (Figure 9). Summary statistics were compiled for each of the 8 species included in the study, and show increased predictive ability for *S. rosaceus* in the spring survey data, and increased or equal predictive ability for *S. rosaceus,* and *S. rubrivinctus* in the fall survey data when compared to Model 1, distance to TPI_{50} peaks, alone (Table 4).

Similar to Model 1, this model did not involve the use of stratified depth zones. Therefore, the results from this model could be extrapolated over the entire multibeam study area. Figure 9 shows Model 3 results limited to the analysis mask area in the foreground, and results projected for the entire survey area in the background, or the "grayed-out" area.

Model 4: Distance to Preferred: TPI_{50} Peaks + Slope + Rugosity + Depth

To further refine the models, species-specific depth preferences were added to the three "distance to preferred" factors included in Model 3. The same depth stratifications that were used to generate Model 2 were employed to generate Model 4.

Again, two sets of Model 4 were generated, one for each of the two depth stratifications. "Model 4 – Deep" added distance to TPI_{50} peaks + distance to preferred slope (≥ 4.86°) + distance to preferred rugosity (≥ 1.003) + the reclassified depth grid, classed 1 for the deepest zone (55-65 m) to 5 for the shallowest zone (15-25 m) covered during the ROV surveys. The percentage of fish observed within the most suitable category (1) suggested this model was better or equally able to predict the distribution of *S. rosaceus* (spring data), and *S. rubrivinctus* (both spring and fall) when compared to Model 1, but less effective than Model 3 (Table 4).

"Model 4 – Shallow", added distance to TPI_{50} peaks + distance to preferred slope (≥ 4.86°) + distance to preferred rugosity (≥ 1.003) + the reclassified depth grid, classed 1 for the shallowest zone (15-25 m) to 5 for the deepest zone (55-65 m) covered during the ROV surveys. The percentage of fish observed within the most suitable category (1) suggested this model was less effective at predicting *S. mystinus* and *S. miniatus* when compared to Models 1 and 2, but more effective than Model 3 (Table 4).

Similar to Model 2, both of these models were limited to the depth range of the ROV transects, between the 15 and 65 m contour lines. Again, because species-depth preferences were noted during analysis of the ROV data, and were not determined by life history data, the models were not extended beyond the 15 and 65 m depth contours.

Stock Estimates

Stock estimates were calculated by taking the number of fish found on a particular substrate, stratified by suitability category, and extrapolating the total amount of fish that would be found in the study site based on the amount of substrate found in the area. Adjusted stock estimates were also calculated to take into account the fact that fish were not found everywhere there was available habitat within the study area. Proportion values were computed based on the amount of area rockfish were found on within the transect, divided by the area found within the transect for each habitat suitability category (Appendix 2). These proportions were multiplied with the original stock values to produce adjusted, more accurate estimates (Appendix 3). On average, the adjusted stock values were 5% of the original estimate.

DISCUSSION

The goal of this project was to develop a set of semi-automated tools using GIS landscape analysis of high-resolution multibeam bathymetry data to create a set of models capable of predicting the distribution and abundance of particular species, based on habitat preference. For this paper, habitat suitability models were generated using rockfish preference for high relief habitat to determine which factors to include in the models. ROV footage provided habitat ground-truth and fish census data, which were used to both assess and inform the model generation process.

After reviewing the results of each of the four models, Model 1, distance to TPI_{50} peaks, most successfully predicts the distribution of the majority of rockfish within the “most suitable” category 1 for both the spring and fall datasets. When using raw percentage of fish as the basis of comparison, Model 1 predicted an average of 84.5% for 5 of 8 the species for the spring dataset, and an average of 76.6% for 4 of 8 species for the fall dataset. Model 3, distance to TPI_{50} peaks + distance to preferred slope (≥ 4.86°) + distance to preferred rugosity (≥ 1.003), most effectively predicted the distribution of the remaining three species (*S.*

carnatus, S. rosaceus, and *S. rubrivinctus*) in category 1 for the spring survey, with an average of 79.9%. For the fall dataset, Model 3 most effectively predicted the distribution of three species (*S. carnatus, S. pinniger,* and *S. rubrivinctus*) within category 1 with an average of 43.0%, and *S. rosaceus* by Model 4 at 66.7%. Model 3 percent capture for the fall dataset was low due to increased numbers predicted within category 2. When percentages from categories 1 and 2 were combined, Model 3 predicts 91.7% of these three species.

In order to quantify efficiency, a comparison of transect area with fish to area without fish between models was calculated (Figure 10). Only transect area within category 1 was considered for comparison. "Area with fish" was calculated by creating 10m buffers around each fish observation point and confining these buffers within the transect area. The remainder of the transect was then considered as "area without fish." Calculations for both area with fish and area without fish were compiled for each model (Figure 10, Table 6).

Of the transect area surveyed in spring, category 1 for Model 1 comprised 40.0%. Of this area, observations of fish were located in only 9.8% of category 1 transect area, although approximately 80% of rockfish were found within this category. Thus, there were no fish observations in 32.1% of the area classified as "most suitable" habitat (category 1). Models 1 and 3 had the greatest proportion of area with fish to no fish, but both models also had a greater percentage of transect area within category 1 (Figure 10). The ratio of percent area with fish to percent transect area within category 1 showed that for the spring dataset, Model 4 – Shallow was slightly more efficient, and returned the greatest amount of area with fish to amount of "suitable habitat" (Table 6).

Of the transect area surveyed in fall, percent transect area within category 1 was moderately less than for the spring survey, totaling 35.8%. Of the transect area within category 1, fish observations were located in 10.22% of this area, although approximately 61% of rockfish were found in this category. Thus, there were no fish observations in 25.5% of the area classified as "most suitable" habitat (Figure 10). The ratio of percent area with fish to percent transect area within category 1 showed that Model 2 – Deep returned the greatest ratio of area with fish to amount of "suitable habitat," with all models showing greater ratio values for fall than for spring due to the reduced amount of area classified as category 1 (Table 6).

When analyzing raw percent predictive success alone, including depth in the generation of the habitat suitability models did not prove to be an effective variable in predicting species distribution and abundance. There are several reasons which may explain this trend. First, many published species-specific depth preferences for rockfish define broad depth zones, encompassing the entire depth range of the shale beds study area. Thus, depth preference classes used in this study were not based on natural history preferences, but rather on ROV observation data. Second, because many of the species depth ranges were greater than the extent of the survey area, there may have been multiple factors more important in determining their distribution along the reef, including diel cycles, seasonal migrations, recruitment, reproductive cycles, resource availability and other physical factors such as wave height, tide, current, and temperature. Third, the fall survey which was used as an independent dataset to evaluate the accuracy of the models, only covered a fraction of the transects included in the spring dataset. The lack of data from the fall survey may have obscured any clear depth preferences among the rockfish species in that season.

Considering the efficiency estimates of the models (Figure 10, Table 6), depth did seem to be an important factor, however. Increased efficiency of depth-inclusive Models 2 and 4 was due to decreased area classified as “preferred” habitat inputs. Including stratified depth zones in the Models 2 and 4 reduced the area ranked as “most suitable” habitat to 10m zones (Table 3), as opposed to the entire extent of the multibeam survey used in Models 1 and 3. Although these findings suggest that depth may be an important factor in modeling species distribution, data for this project did not produce a clear trend. Efficiency ratio values were very similar between Model 1, Model 2 – Deep and Model 4 – Shallow (Table 6).

There were a couple trends found during the analysis of the fish data that were not included in the generation of the models. First, the two ROV surveys occurred during two distinctly different seasons: fall and spring. Because there were no transect replicates for each season, a statistical comparison could not be made, but there may have been seasonal differences in the distribution of the fish. Visual analysis of the data showed that the spring distribution of fish tended to favor the northern edge of the shale reef, whereas in fall the fish showed a tendency to cluster toward the middle of the reef. These observations were not borne out through quantitative analysis, however, and were thus not included in model generation. Second, there were three transects in the shallow (10-15 m) end of the shale beds that did not follow the methodology used for the rest of the ROV survey. Two partial transects were aborted due to high currents and winds which caused the ROV to be dragged several meters from the bottom. No fish were seen or identified, so these areas were eliminated from the study. One complete transect during the fall survey ran parallel to the shale ledges. The transect began at the shallowest extent of the reef at 10m, ran along a ledge, and gradually increased in depth to 30 m. No fish were found in the shallow end of the transect, and only few fish were found in the deeper end. Because this transect did not run perpendicular to the shale ledges, it was also excluded from the study. Although all the ROV data indicated that there were few to no fish in shallower water, this trend was not incorporated in the creation of the models.

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

CONCLUSIONS

The models generated for this study utilized high-resolution (2 m) DEM data, and were created at a fine scale extremely rare in the field of landscape ecology. Many terrestrial studies rely on satellite imagery with resolutions often greater than 1 km. Studies of the marine environment are just beginning to incorporate the use of high-resolution multibeam bathymetry in an easy-to-use, automated, scaleable habitat analysis tool capable of mapping both small- and large-scale areas.

The most effective model generated for this project was also the most simple – distance to TPI_{50} peaks. Peaks are attractive features to rockfish, but most individuals are not found on top of the peak features, but rather are distributed in the space closely surrounding them. By using the TPI algorithm, we were able to identify topographic highs relative to their surroundings, which for the shale beds, often occurred next to sand channels, or near transition zones from one substrate to another. This predictive model is a relatively simple process to duplicate, and involves little subjective reasoning in the calculation of the algorithm.

One of the most important aspects of this project is the ability to provide habitat classification and stock estimates for near-shore, high-relief environments. The current methods of stock abundance and distribution assessment rely on trawling and fisheries data. Trawling is not permitted on the shale beds, and the recreational fishery does not yet have consistent, reliable catch data. Therefore, the stock estimates created for this project provide invaluable data for resource managers in the California Department of Fish and Game, Pacific Fisheries Management Council, and the National Marine Fisheries Service. The ability to assess species-habitat associations at very high-resolution (1-2 m) allowed us to extrapolate the fish distribution recorded along the transects over the entire survey area. More accurate, adjusted stock estimates were calculated using the proportion of area actually occupied by fish within the transect area to limit the original stock projection. Such a method has great potential for generating more precise stock assessments for rockfish fisheries management, and should be carefully examined and evaluated using any relevant fisheries data.

The models for this project were based on the assumption that habitat is a proxy for fish distribution. Although habitat often provides a good indication of where rockfish may be, habitat itself merely suggests patterns of rockfish abundance and distribution. The high percentage of “area without fish” within the “most suitable” Category 1 highlights the fact that the models can’t predict the distribution of rockfish with absolute certainty on the shale beds. Distance to TPI_{50} peaks is potentially a useful factor for locating preferred, suitable rockfish habitat, but it is not the only one affecting rockfish distribution and abundance. Perhaps with more research, even clearer patterns of distribution and abundance may be found. Further model validation also needs to be performed in order to assess the transportability of the model results. Although there are many variables affecting species distribution and abundance within a particular ecosystem, the results from this project seem promising, and should be investigated further.

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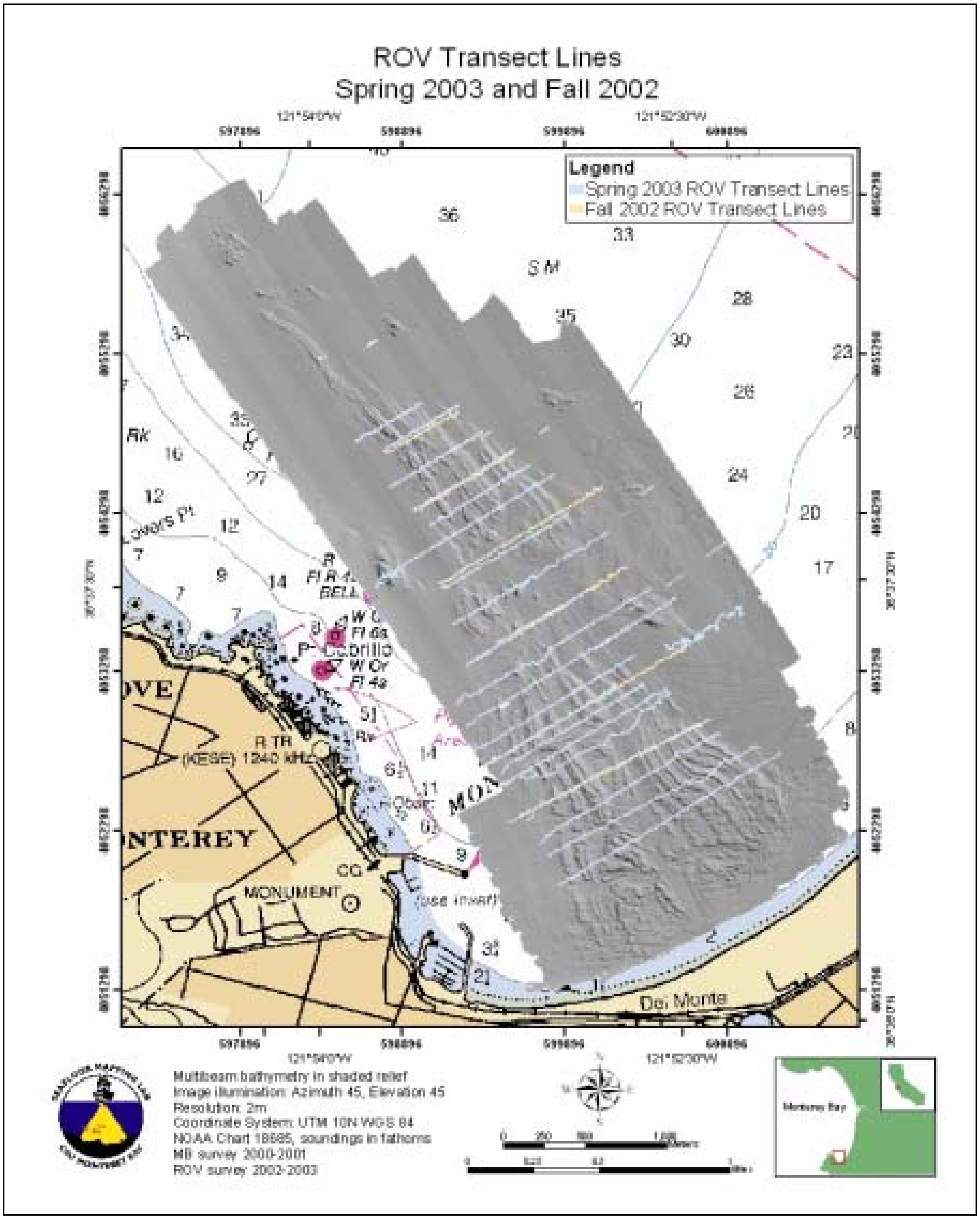

FIGURE 1. Multibeam shaded relief DEM and ROV tracklines for Fall 2002 and Spring 2003 surveys. Tracklines have been buffered by 2.5m on either side to create a 5m corridor representing the visual area covered by the ROV during the surveys. Buffered transect areas were used in the evaluation of all habitat suitability models.

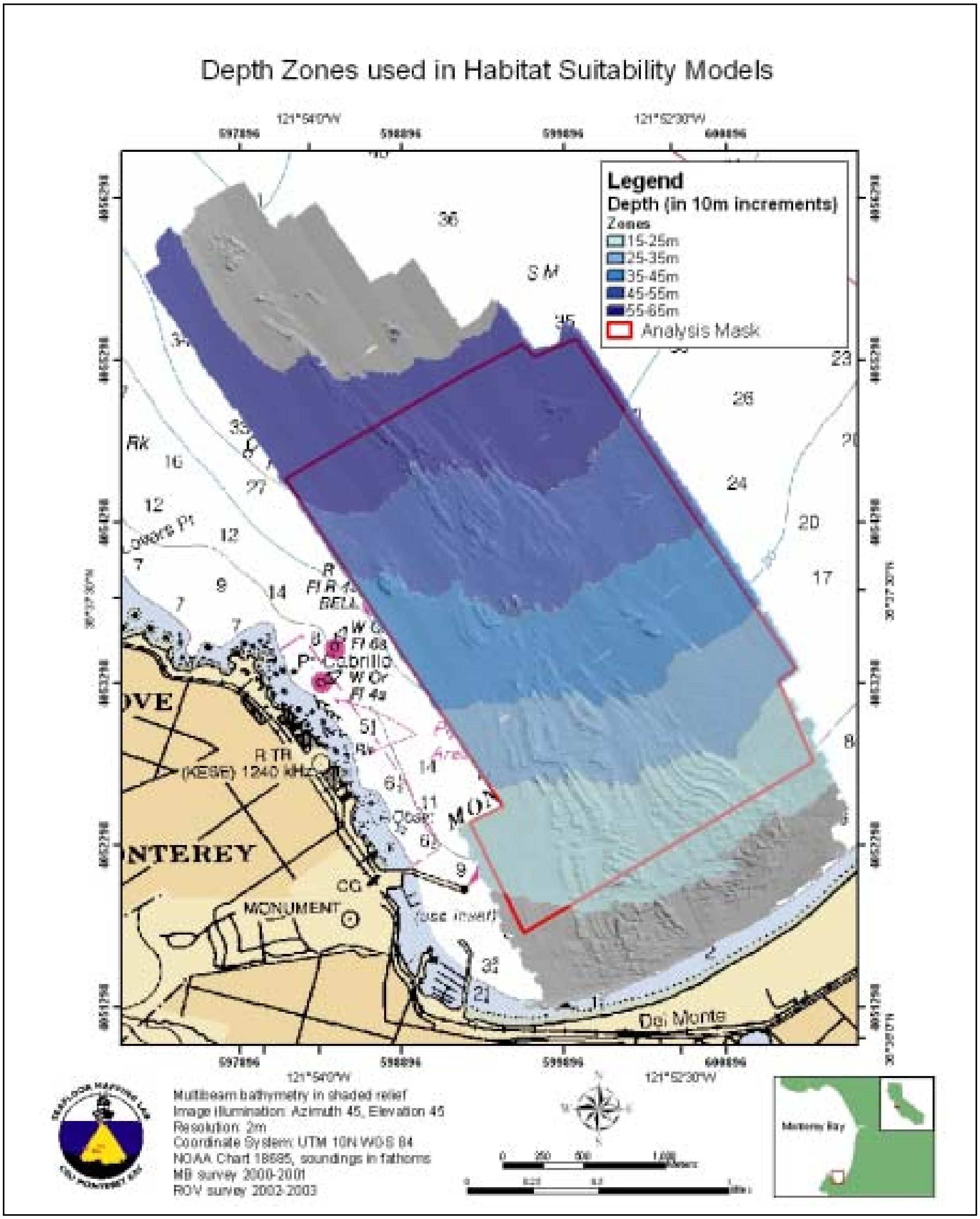

FIGURE 2. Depth zones in 10m increments used in the generation of habitat suitability models. Depth classes derived from bathymetry DEM. Depth zones were restricted to the boundaries of the analysis mask in the modeling process.

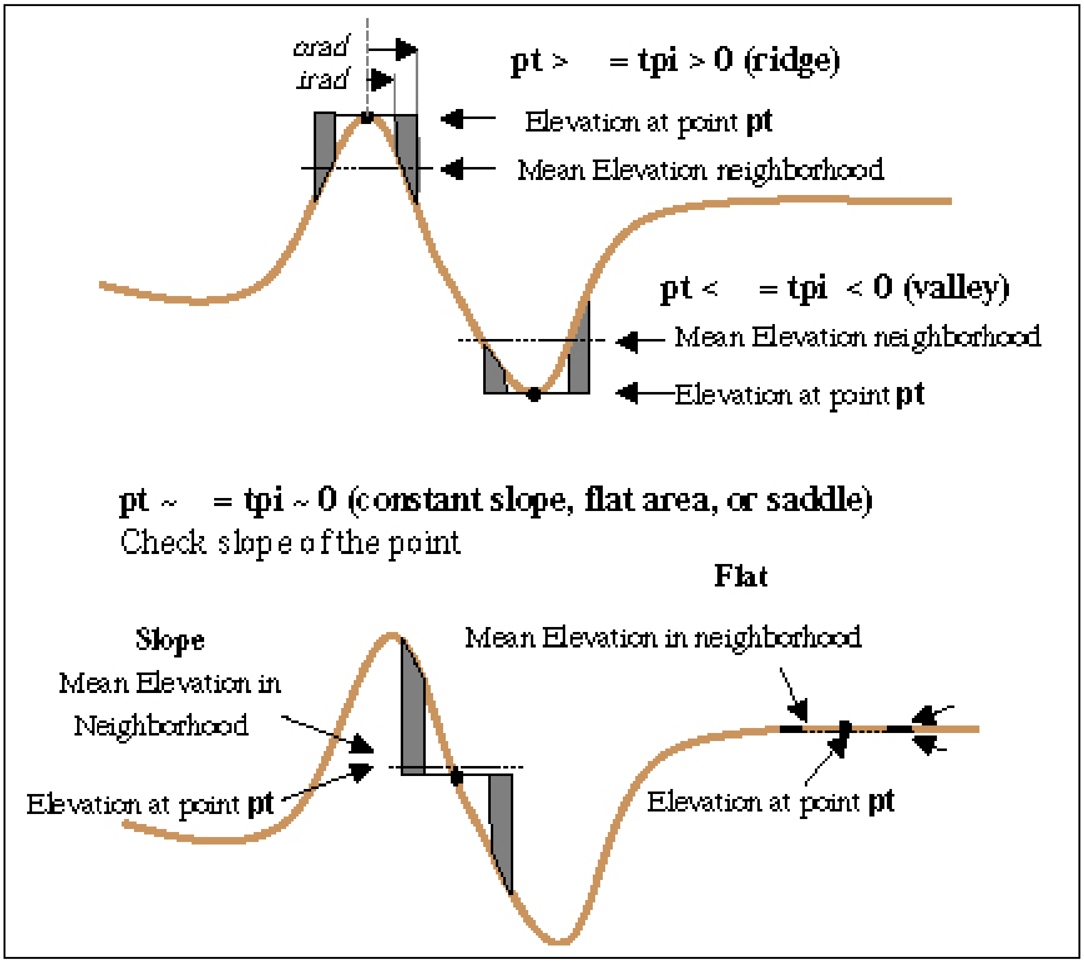

FIGURE 3. Schematic depiction of TPI calculation. Brown line represents a hypothetical cross-section view of a DEM, with cases illustrated showing TPI calculation of various feature types (peak, valley, etc.). Positive TPI values represent locations that are higher than the average of their surroundings, 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)

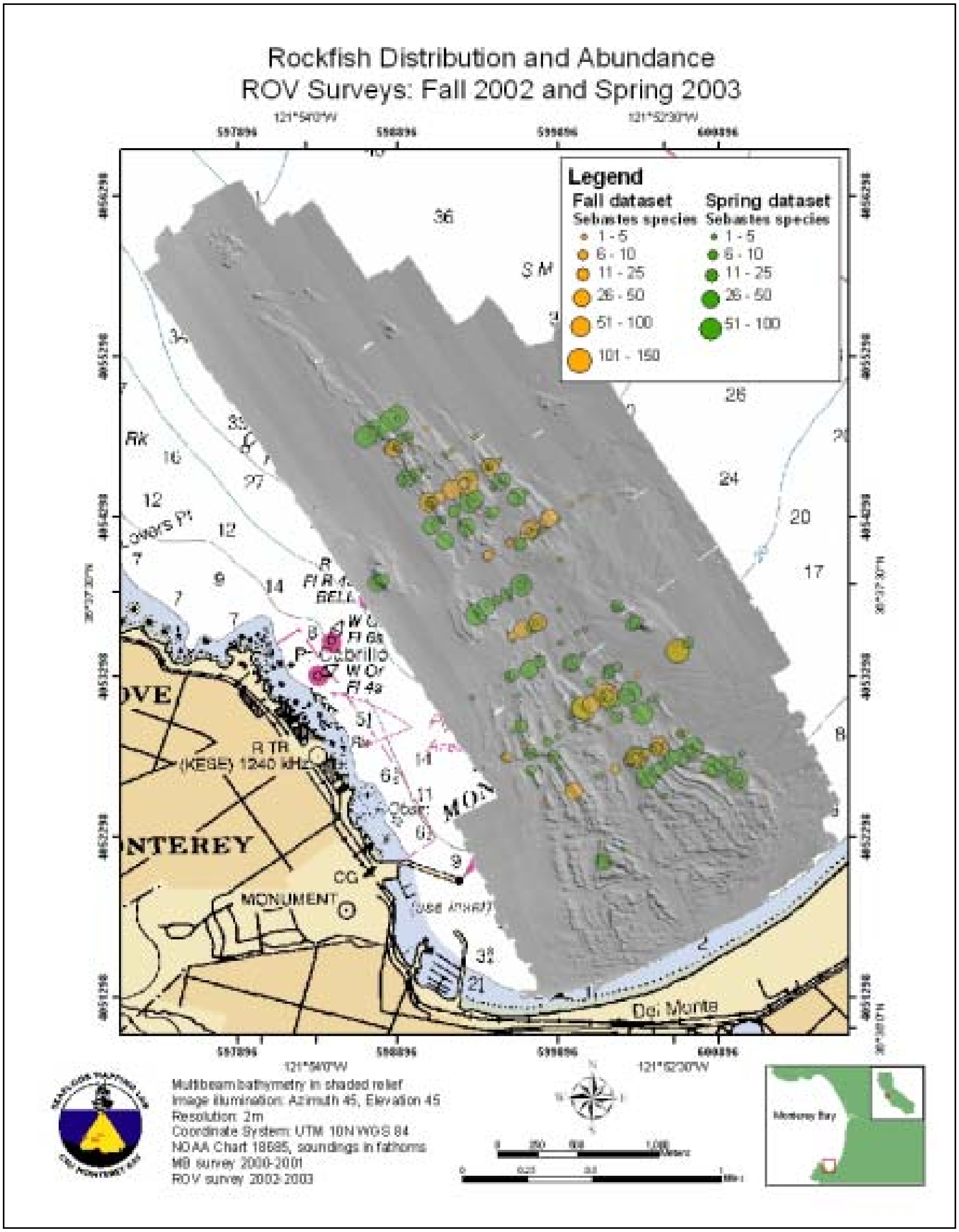

FIGURE 4. Rockfish distribution and abundance calculated from analysis of ROV video data. Visual analysis of these data revealed a strong association between rockfish and high relief habitat.

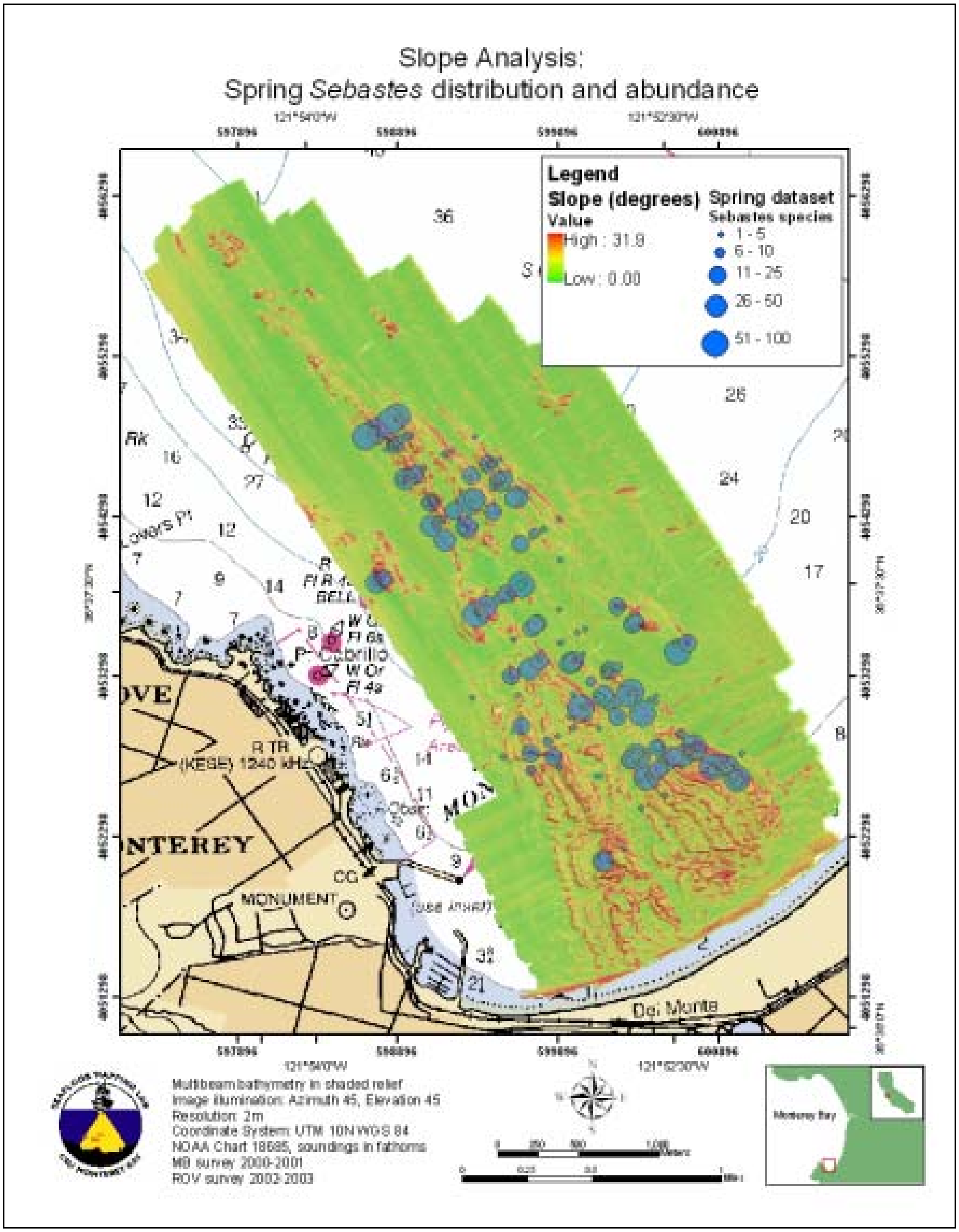

FIGURE 5. Slope analysis of multibeam survey area with distribution and abundance of rockfish observed during Spring 2003 ROV survey. Slope grid derived from bathymetry DEM. Symbol size for fish data is proportional to number of rockfish observed, and grid color indicates slope value.

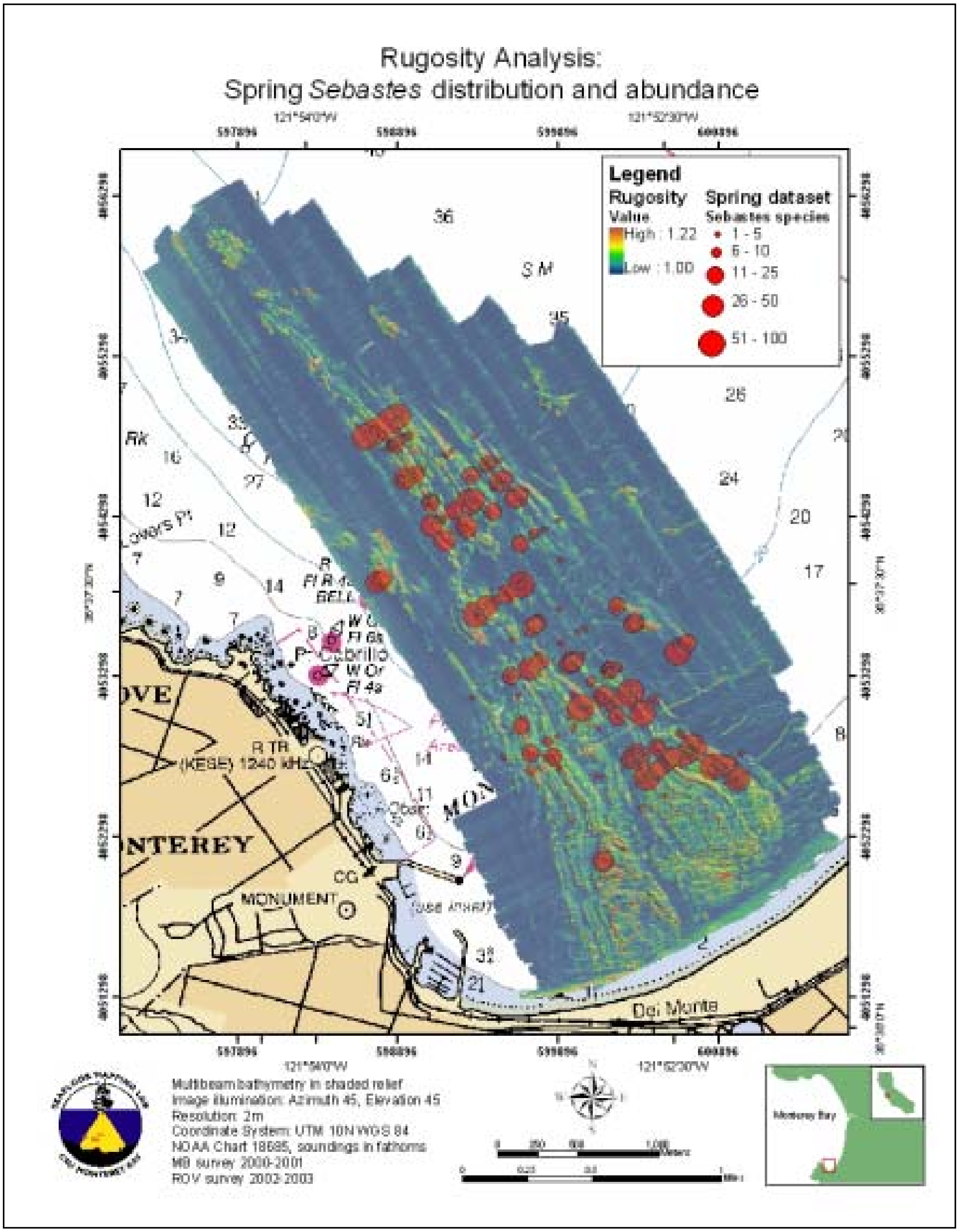

FIGURE 6. Rugosity analysis of multibeam survey area with distribution and abundance of rockfish observed during Spring 2003 ROV survey. Rugosity grid derived from bathymetry DEM. Symbol size for fish data is proportional to number of rockfish observed, and grid color indicates rugosity value.

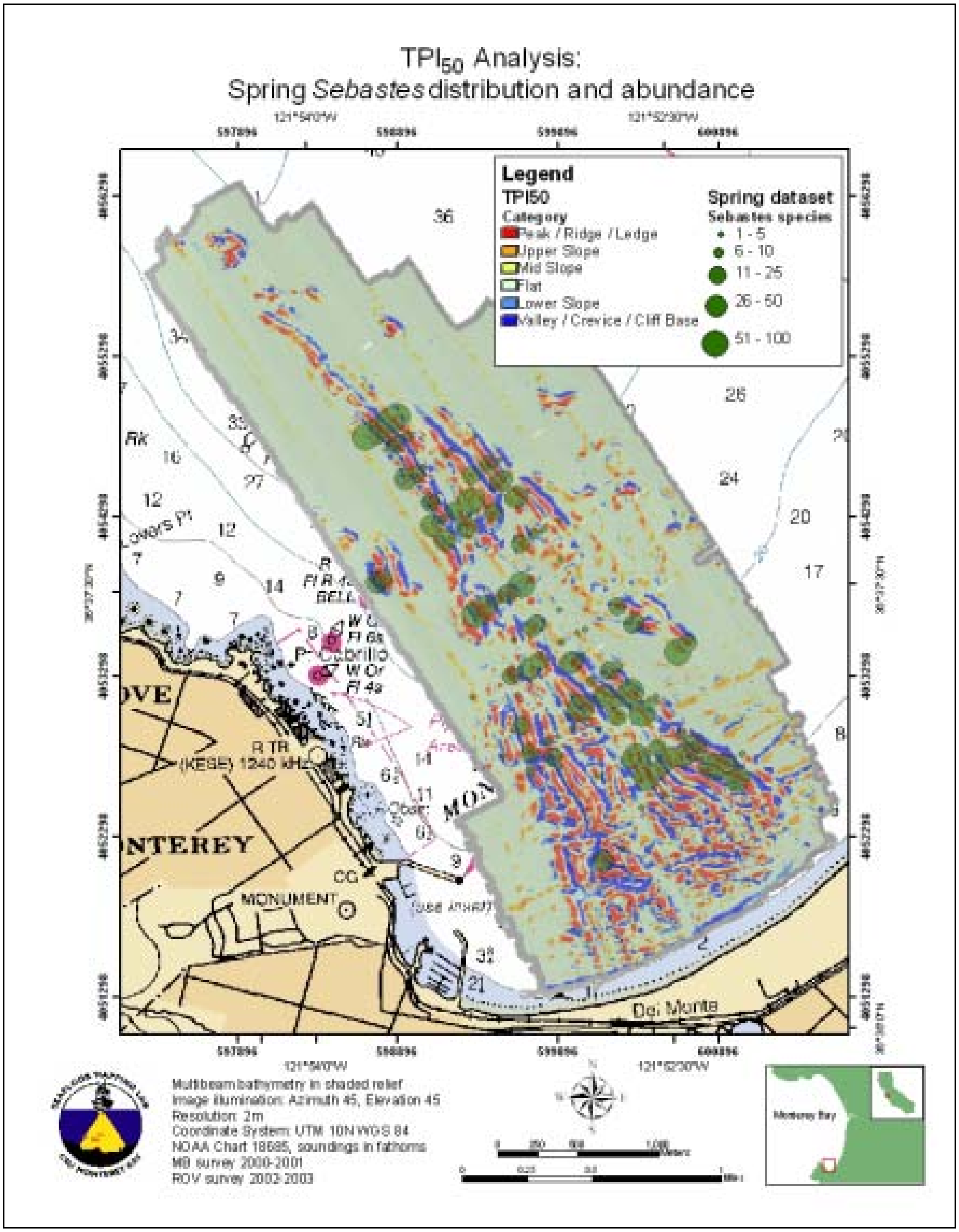

FIGURE 7. TPI$_{50}$ analysis of multibeam survey area with distribution and abundance of rockfish observed during Spring 2003 ROV survey. TPI$_{50}$ classes derived from bathymetry DEM. Symbol size for fish data is proportional to number of rockfish observed, and grid color indicates TPI$_{50}$ class. Note 50 meter buffered area around extent of multibeam survey area has been eliminated from TPI analysis due to edge and artifact noise.

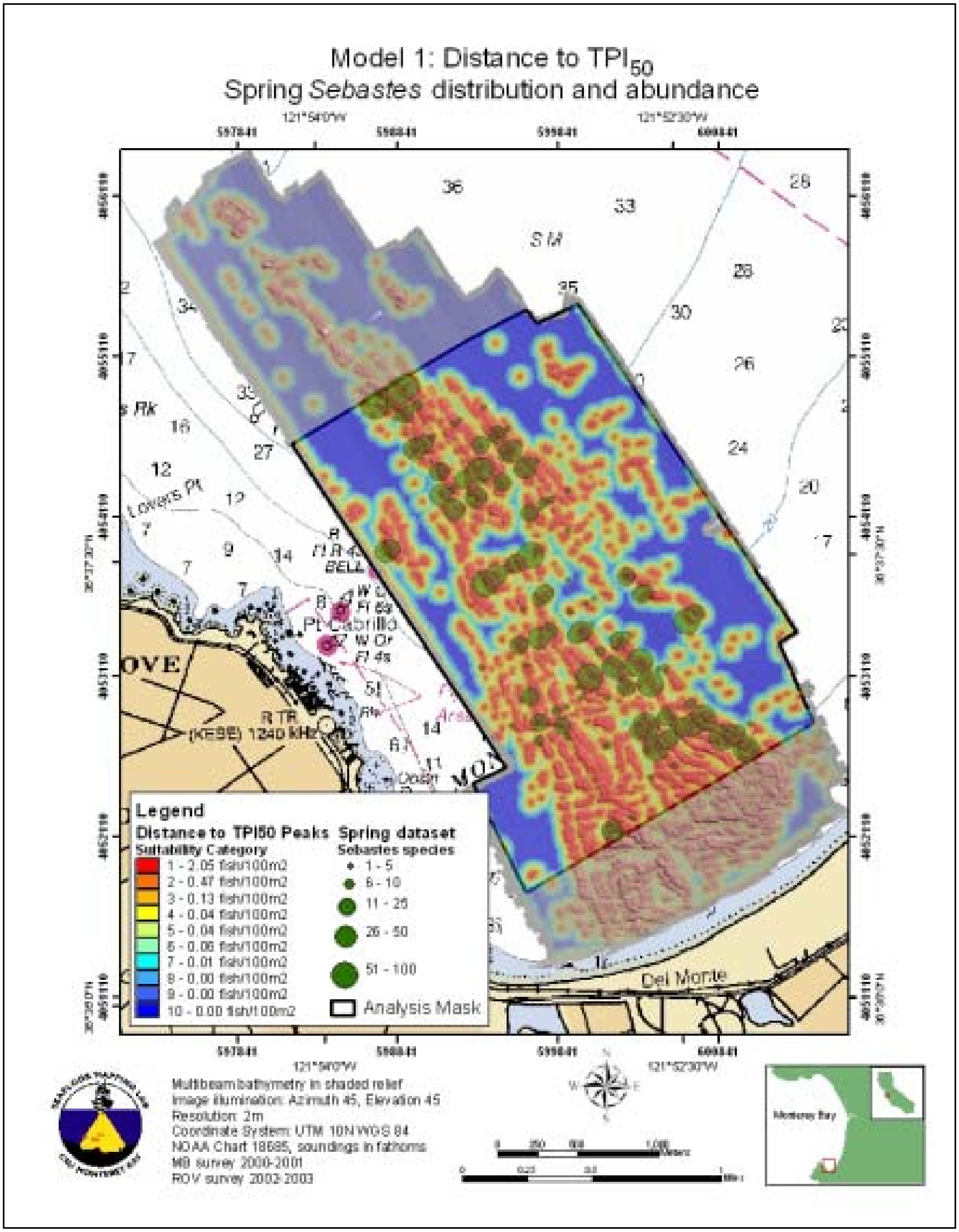

FIGURE 8. Model 1: Distance to TPI_{50} Peaks. Displays distribution and abundance of rockfish for the spring dataset. Size of symbol is proportional to number of rockfish observed, and grid color indicates Model 1 habitat suitabilty. Note habitat suitability categories also display density of rockfish for the spring dataset found within each category. Analysis mask indicates area where ROV video data has been collected. Results limited to the analysis mask area in the foreground, and results projected for the entire survey area in the background, or the "grayed-out" area.

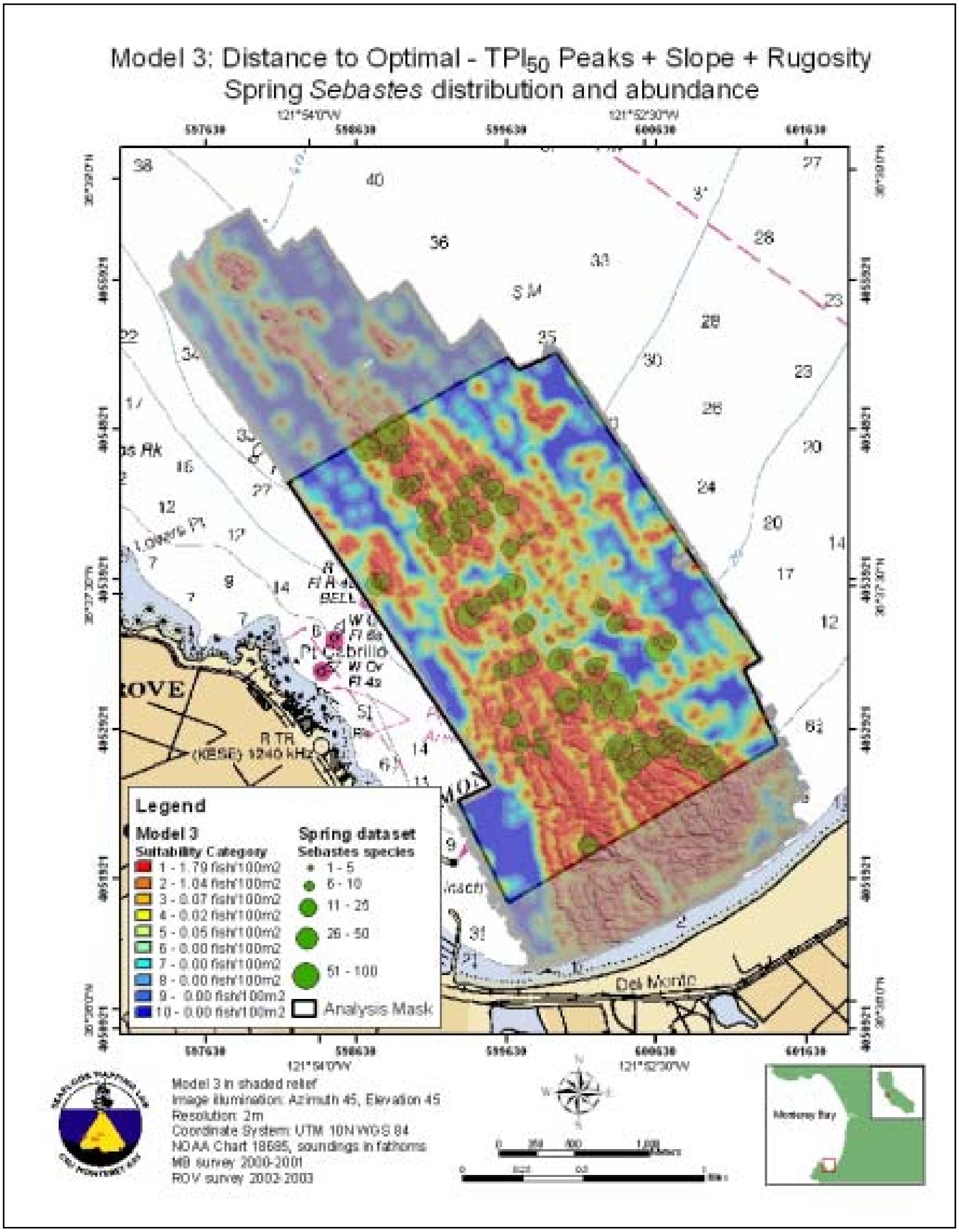

FIGURE 9. Model 3: Distance to Optimal – TPI$_{50}$ Peaks + Slope + Rugosity. Displays distribution and abundance of rockfish for the spring dataset. Size of symbol is proportional to number of rockfish observed, and grid color indicates Model 3 habitat suitabilty. Note habitat suitability categories also display density of rockfish for the spring dataset found within each category. Analysis mask indicates area where ROV video data has been collected. Results limited to the analysis mask area in the foreground, and results projected for the entire survey area in the background, or the "grayed-out" area.

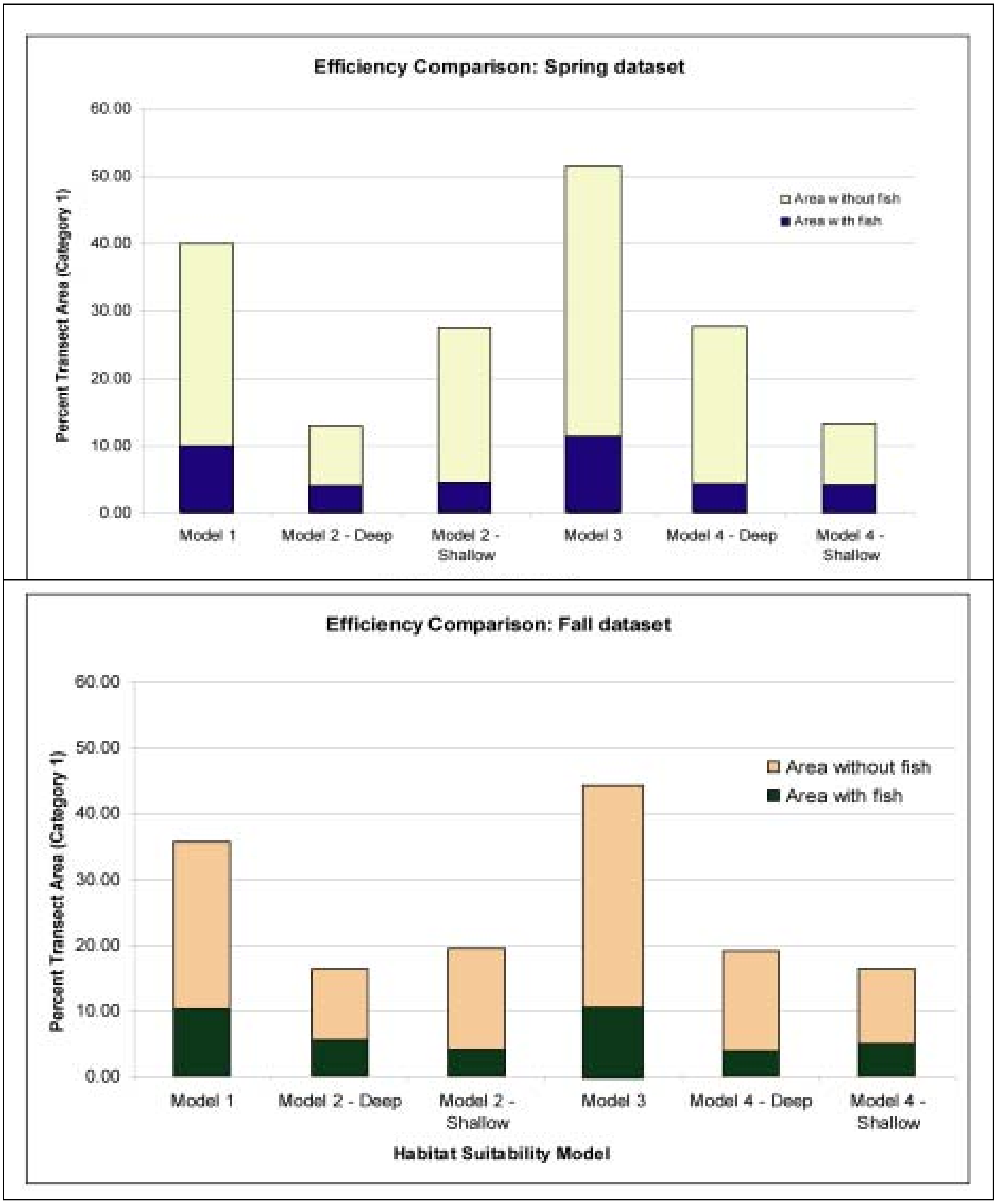

FIGURE 10. Efficiency comparison. Computes the amount of area with fish versus area without fish for transect area within category 1 for each model. Note the area with fish versus area without fish is proportional within the amount of transect area for category 1 for each model. Y-axes represent percent transect area within category 1 for each model, and does not measure percent area with fish or area without fish.

TABLE 1. Counts and percentages of rockfish observed in Spring 2003 ROV surveys for derivative grids: slope, rugosity, TPI_{50} and depth. Analysis of these results informed the generation of the habitat suitability models. Note that the last two categories of the slope grid were combined to create the "most suitable" slope category ≥ 4.86° due to insufficient area found in slope category ≥ 8.97°. Note also that the same reasoning was used to combine the two highest rugosity categories, to create a "most suitable" rugosity category ≥ 1.003.

	Transect Area	*Sebastes* spp.		*Sebastes mystinus*		*Sebastes serranoides/ Sebastes*		*Sebastes miniatus*		*Sebastes auriculatus*		*Sebastes carnatus*		*Sebastes pinniger*
SLOPE														
category	**m^2**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**
0-1.12°	97836	565	19.54	472	21.05	43	13.44	23	15.13	4	11.76	14	31.11	3
1.12-2.61°	128676	1384	47.86	1014	45.23	224	70.00	76	50.00	20	58.82	12	26.67	20
2.61-4.86°	57052	592	20.47	489	21.81	28	8.75	28	18.42	3	8.82	13	28.89	14
4.86-8.97°	22396	337	11.65	256	11.42	24	7.50	24	15.79	7	20.59	5	11.11	11
8.97-31.9°	3812	14	0.48	11	0.49	1	0.31	1	0.66	0	0.00	1	2.22	0
total	309772	2892	100.00	2242	100	320	100	152	100	34	100	45	100	48
RUGOSITY														
category	**m^2**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**
1.00-1.003	270440	2398	82.92	1865	83.18	275	85.94	124	81.58	26	76.47	37	82.22	34
1.003-1.02	36996	482	16.67	366	16.32	44	13.75	28	18.42	8	23.53	8	17.78	14
1.02-1.22	1872	12	0.41	11	0.49	1	0.31	0	0.00	0	0.00	0	0.00	0
total	309308	2892	100.00	2242	100.00	320	100.00	152	100.00	34	100.00	45	100.00	48
TPI_{50}														
category	**m^2**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**
peak	55740	1138	39.35	874	38.98	154	48.13	37	24.34	17	50.00	12	26.67	19
upper slope	39096	475	16.42	344	15.34	64	20.00	41	26.97	4	11.76	9	20.00	6
mid slope	5964	130	4.50	96	4.28	9	2.81	11	7.24	2	5.88	0	0.00	11
flat	138576	872	30.15	729	32.52	57	17.81	43	28.29	10	29.41	11	24.44	8
lower slope	21828	128	4.43	103	4.59	15	4.69	2	1.32	1	2.94	3	6.67	3
valley	48568	149	5.15	96	4.28	21	6.56	18	11.84	0	0.00	10	22.22	1
total	309772	2892	100	2242	100	320	100	152	100	34	100	45	100	48
DEPTH (m)														
category	**m^2**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**
15-25	72192	687	23.76	616	27.48	19	5.94	43	28.29	0	0.00	8	17.78	1
25-35	81472	556	19.23	460	20.52	18	5.63	46	30.26	6	17.65	19	42.22	4
35-45	69072	575	19.88	472	21.05	23	7.19	20	13.16	15	44.12	10	22.22	24
45-55	56612	712	24.62	521	23.24	112	35.00	23	15.13	11	32.35	8	17.78	18
55-65	30424	362	12.52	173	7.72	148	46.25	20	13.16	2	5.88	0	0.00	1
total	309772	2892	100	2242	100	320	100	152	100	34	100	45	100	48

TABLE 2. Counts and percentages of rockfish observed in Spring 2003 ROV surveys for "Distance to Preferred" grids: slope, rugosity, and TPI_{50}. Habitat suitability models were created by taking different combinations of "Distance to Preferred" category 1 for each grid. Category 1 includes the "most suitable area" plus the area within 10m of that feature. All subsequent categories are in 10m increments, with category 10 being 100m from the "most suitable" feature.

	Sebastes spp.		*Sebastes mystinus*		*Sebastes serranoides/ Sebastes flavidus*		*Sebastes miniatus*		*Sebastes auriculatus*		*Sebastes carnatus*		*Seba*
DISTANCE TO OPTIMAL: SLOPE>4.865													
category	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**
1	2091	72.30	1626	72.52	227	70.94	106	69.74	21	61.76	32	71.11	
2	687	23.76	540	24.09	79	24.69	35	23.03	11	32.35	6	13.33	
3	59	2.04	39	1.74	11	3.44	7	4.61	0	0.00	2	4.44	
4	35	1.21	30	1.34	0	0.00	3	1.97	0	0.00	1	2.22	
5	11	0.38	6	0.27	0	0.00	0	0.00	2	5.88	0	0.00	
6	6	0.21	1	0.04	0	0.00	1	0.66	0	0.00	4	8.89	
7-10	3	0.10	0	0.00	3	0.94	0	0.00	0	0.00	0	0.00	
total	2892	100	2242	100	320	100	152	100	34	100	45	100	
DISTANCE TO OPTIMAL: RUGOSITY>1.003													
category	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**
1	2278	78.77	1773	79.08	228	71.25	128	84.21	27	79.41	36	80.00	
2	589	20.37	459	20.47	89	27.81	19	12.50	5	14.71	5	11.11	
3	16	0.55	9	0.40	0	0.00	3	1.97	0	0.00	4	8.89	
4	9	0.31	1	0.04	3	0.94	2	1.32	2	5.88	0	0.00	
5	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	
6	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	
7-10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	
total	2892	100	2242	100	320	100	152	100	34	100	45	100	
DISTANCE TO OPTIMAL: TPI_{50} PEAKS													
category	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**
1	2524	87.28	1979	88.27	285	89.06	125	82.24	27	79.41	28	62.22	
2	288	9.96	222	9.90	17	5.31	18	11.84	5	14.71	12	26.67	
3	57	1.97	33	1.47	14	4.38	5	3.29	0	0.00	2	4.44	
4	11	0.38	6	0.27	4	1.25	1	0.66	0	0.00	0	0.00	
5	5	0.17	1	0.04	0	0.00	1	0.66	0	0.00	2	4.44	
6	6	0.21	1	0.04	0	0.00	2	1.32	2	5.88	0	0.00	
7-10	1	0.03	0	0.00	0	0.00	0	0.00	0	0.00	1	2.22	
total	2892	100	2242	100	320	100	152	100	34	100	45	100	

TABLE 3. Reclassification tables used to rank "Distance to Preferred" grids and depth.

Reclass Distance to Preferred

Distance to Preferred (m)	reclass value
0-10 (includes "most suitable" feature)	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: Deep

Species with preference for deeper depths:
S. serranoides/S. flavidus
S. rosaceus
S. rubrivinctus

depth (m)	reclass value
55-65	1
45-55	2
35-45	3
25-35	4
15-25	5

Reclass Depth: Shallow

Species with preference for deeper depths:
S. mystinus
S. miniatus

depth (m)	reclass value
15-25	1
25-35	2
35-45	3
45-55	4
55-65	5

TABLE 4. Model evaluation tables. Models were considered "successful" if a high percentage of fish were captured in the "most suitable" category 1. Values for Category 1 *in italics* indicate greatest value of the 4 models.

SPRING

Model 1: Distance to TPI50 Peaks - % fish

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	***88.27***	9.90	1.47	0.27	0.04	0.04	0.00
S. serranoides/ S. flavidus	***89.06***	5.31	4.38	1.25	0.00	0.00	0.00
S. miniatus	***82.24***	11.84	3.29	0.66	0.66	1.32	0.00
S. auriculatus	***79.41***	14.71	0.00	0.00	0.00	5.88	0.00
S. carnatus	62.22	14.71	4.44	0.00	4.44	0.00	2.22
S. pinniger	***83.33***	14.71	4.17	0.00	0.00	2.08	0.00
S. rosaceus	78.13	14.71	0.00	0.00	0.00	0.00	0.00
S. rubrivinctus	78.95	14.71	5.26	0.00	5.26	0.00	0.00

Model 2: Distance to Optimal TPI50 Peaks + Depth - % fish

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
Deep							
S. serranoides/ S. flavidus	43.75	35.31	9.38	5.63	4.69	0.31	0.94
S. rosaceus	25.00	34.38	31.25	9.38	0.00	0.00	0.00
S. rubrivinctus	47.37	36.84	15.79	0.00	0.00	0.00	0.00
Shallow							
S. mystinus	26.36	21.36	20.96	23.46	7.63	0.18	0.04
S. miniatus	27.63	28.29	13.82	15.79	13.16	0.00	1.32

Model 3: Distance to Optimal TPI50 Peaks + Slope + Rugosity - % fish

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	76.85	22.57	0.49	0.04	0.04	0.00	0.00
S. serranoides/ S. flavidus	71.25	25.63	2.19	0.00	0.94	0.00	0.00
S. miniatus	81.58	13.16	3.95	1.32	0.00	0.00	0.00
S. auriculatus	73.53	20.59	0.00	0.00	5.88	0.00	0.00
S. carnatus	***68.89***	17.78	11.11	2.22	0.00	0.00	0.00
S. pinniger	81.25	12.50	4.17	0.00	2.08	0.00	0.00
S. rosaceus	***81.25***	18.75	0.00	0.00	0.00	0.00	0.00
S. rubrivinctus	***89.47***	5.26	0.00	5.26	0.00	0.00	0.00

Model 4: Distance to Optimal TPI50 Peaks + Slope + Rugosity + Depth - % fish

category

FALL

Model 1: Distance to TPI50 Peaks - % fish

	1	**2**	**3**
S. mystinus	***89.11***	6.60	4.
S. serranoides/ S. flavidus	***100.00***	0.00	0.0
S. miniatus	***39.47***	39.47	13.
S. auriculatus	***77.78***	22.22	0.0
S. carnatus	50.00	0.00	50.0
S. pinniger	7.69	46.15	0.0
S. rosaceus	66.67	16.67	0.0
S. rubrivinctus	57.14	42.86	0.0

Model 2: Distance to Optimal TPI50 Peaks + Depth -

	1	**2**	**3**
Deep			
S. serranoides/ S. flavidus	0.00	91.49	0.0
S. rosaceus	16.67	66.67	16.6
S. rubrivinctus	57.14	42.86	0.0
Shallow			
S. mystinus	3.30	48.84	8.0
S. miniatus	5.26	18.42	7.

Model 3: Distance to Optimal TPI50 Peaks + Slope +

	1	**2**	**3**
S. mystinus	76.40	23.60	0.0
S. serranoides/ S. flavidus	97.87	2.13	0.0
S. miniatus	31.58	34.21	28.
S. auriculatus	55.56	22.22	22.
S. carnatus	***50.00***	25.00	25.0
S. pinniger	***7.69***	92.31	0.0
S. rosaceus	66.67	0.00	33.
S. rubrivinctus	***71.43***	28.57	0.0

Model 4: Distance to Optimal TPI50 Peaks + Slope +

TABLE 5. Density calculations for habitat suitability models. Density was calculated for each category by taking (number fish by species/transect area)*100.

SPRING

Model 1: Distance to TPI50 Peaks - #fish/100m^2

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	1.6031	0.3637	0.0754	0.0233	0.0071	0.0107	0.0000
S. serranoides/ S. flavidus	0.2309	0.0279	0.0320	0.0156	0.0000	0.0000	0.0000
S. miniatus	0.1013	0.0295	0.0114	0.0039	0.0071	0.0213	0.0000
S. auriculatus	0.0227	0.0082	0.0000	0.0000	0.0000	0.0213	0.0000
S. carnatus	0.0227	0.0197	0.0046	0.0000	0.0143	0.0000	0.0118
S. pinniger	0.0324	0.0082	0.0046	0.0000	0.0000	0.0107	0.0000
S. rosaceus	0.0203	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000
S. rubrivinctus	0.0122	0.0033	0.0023	0.0000	0.0071	0.0000	0.0000

Model 2: Distance to Optimal TPI50 Peaks + Depth - #fish/100m^2

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
Deep							
S. serranoides/ S. flavidus	0.8226	0.2684	0.0630	0.0252	0.0230	0.0045	0.0121
S. rosaceus	0.0470	0.0261	0.0210	0.0042	0.0000	0.0000	0.0000
S. rubrivinctus	0.0529	0.0166	0.0063	0.0000	0.0000	0.0000	0.0000
Shallow							
S. mystinus	1.1719	0.7129	0.9228	0.9773	0.4788	0.0296	0.0053
S. miniatus	0.0833	0.0640	0.0412	0.0446	0.0560	0.0000	0.0107

Model 3: Distance to Optimal TPI50 Peaks + Slope + Rugosity - #fish/100m^2

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	1.3957	0.8291	0.0251	0.0039	0.0071	0.0000	0.0000
S. serranoides/ S. flavidus	0.1847	0.1344	0.0160	0.0000	0.0214	0.0000	0.0000
S. miniatus	0.1004	0.0328	0.0137	0.0078	0.0000	0.0000	0.0000
S. auriculatus	0.0203	0.0115	0.0000	0.0000	0.0143	0.0000	0.0000
S. carnatus	0.0251	0.0131	0.0114	0.0039	0.0000	0.0000	0.0000
S. pinniger	0.0316	0.0098	0.0046	0.0000	0.0071	0.0000	0.0000
S. rosaceus	0.0211	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000
S. rubrivinctus	0.0138	0.0016	0.0000	0.0039	0.0000	0.0000	0.0000

Model 4: Distance to Optimal TPI50 Peaks + Slope + Rugosity + Depth - #fish/100m^2

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
Deep							
S. serranoides/ S. flavidus	0.5508	0.0790	0.0257	0.0147	0.0000	0.0000	0.0000
S. rosaceus	0.0397	0.0167	0.0013	0.0000	0.0000	0.0000	0.0000
S. rubrivinctus	0.0397	0.0022	0.0013	0.0000	0.0000	0.0000	0.0000
Shallow							
S. mystinus	1.1598	0.9031	0.8617	0.0751	0.0050	0.0000	0.0000
S. miniatus	0.0884	0.0520	0.0517	0.0157	0.0000	0.0000	0.0000

FALL

Model 1: Distance to TPI50 Peaks - #fish/100m^2

	c		
	1	**2**	**3**
S. mystinus	1.8942	0.2492	0.2182
S. serranoides/ S. flavidus	0.1649	0.0000	0.0000
S. miniatus	0.0526	0.0934	0.0420
S. auriculatus	0.0246	0.0125	0.0000
S. carnatus	0.0070	0.0000	0.0168
S. pinniger	0.0035	0.0374	0.0000
S. rosaceus	0.0140	0.0062	0.0000
S. rubrivinctus	0.0140	0.0187	0.0000

Model 2: Distance to Optimal TPI50 Peaks + Dept

	c		
	1	**2**	**3**
Deep			
S. serranoides/ S. flavidus	0.0000	0.3081	0.0000
S. rosaceus	0.0177	0.0287	0.0079
S. rubrivinctus	0.0710	0.0215	0.0000
Shallow			
S. mystinus	0.3805	1.7379	0.4119
S. miniatus	0.0381	0.0411	0.0252

Model 3: Distance to Optimal TPI50 Peaks + Slop

	c		
	1	**2**	**3**
S. mystinus	1.6003	0.7904	0.0000
S. serranoides/ S. flavidus	0.1590	0.0055	0.0000
S. miniatus	0.0415	0.0719	0.0920
S. auriculatus	0.0173	0.0111	0.0167
S. carnatus	0.0069	0.0055	0.0084
S. pinniger	0.0035	0.0663	0.0000
S. rosaceus	0.0138	0.0000	0.0167
S. rubrivinctus	0.0173	0.0111	0.0000

Model 4: Distance to Optimal TPI50 Peaks + Slop

	c		
	1	**2**	**3**
Deep			
S. serranoides/ S. flavidus	0.3288	0.0204	0.0000
S. rosaceus	0.0313	0.0041	0.0061
S. rubrivinctus	0.0391	0.0082	0.0000
Shallow			
S. mystinus	1.3499	1.7123	0.3822
S. miniatus	0.0331	0.0456	0.0896

TABLE 6. Efficiency table calculations. These values were used to generate Figure 10. Note all comparisons are made based on only category 1 values for each model. Ratio numbers in bold indicate greatest value for all models.

	Spring		**Fall**	
	Area with fish	**Area without fish**	**Area with fish**	**Area without fish**
Model 1	9.83	30.21	10.22	25.54
Model 2 - Deep	3.96	9.08	5.51	10.74
Model 2 - Shallow	4.40	23.08	4.10	15.53
Model 3	11.30	40.15	10.69	33.63
Model 4 - Deep	4.14	23.51	3.88	15.35
Model 4 - Shallow	4.06	9.07	4.92	11.34

Transect area within category 1

	Spring	**Fall**
Model 1	40.04	35.76
Model 2 - Deep	13.04	16.25
Model 2 - Shallow	27.47	19.63
Model 3	51.45	44.32
Model 4 - Deep	27.64	19.23
Model 4 - Shallow	13.13	16.25

Ratio: % fish/% transect area

	Spring	**Fall**
Model 1	0.25	0.29
Model 2 - Deep	0.30	**0.34**
Model 2 - Shallow	0.16	0.21
Model 3	0.22	0.24
Model 4 - Deep	0.15	0.20
Model 4 - Shallow	**0.31**	0.30

APPENDIX 1. 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.

NUMBER OF FISH OBSERVATIONS

Video Analysis: Substrate Category	TPI Category						
	valley	lower slope	flat	mid slope	upper slope	peak	totals
TPI_{10}: NUMBER OF FISH OBSERVATIONS							
boulders	1	N/A	2	0	N/A	2	5
ledges	11	N/A	36	6	N/A	16	69
outcrop		N/A	1	0	N/A	12	13
rubble	3	N/A	43	0	N/A	14	60
sand		N/A	8	0	N/A	5	13
small ledges	7	N/A	52	4	N/A	30	93
no relief	0	N/A	1	0	N/A	2	3
low relief	9	N/A	100	4	N/A	58	171
high relief	13	N/A	41	6	N/A	19	79
TPI_{20}: NUMBER OF FISH OBSERVATIONS							
boulders	1	1	0	1	1	1	5
ledges	14	11	17	4	7	16	69
outcrop	0	0	1	0	1	11	13
rubble	3	9	27	0	6	15	60
sand	0	0	5	0	3	5	13
small ledges	4	5	33	2	14	35	93
no relief	0	0	0	0	0	3	3
low relief	7	12	63	2	24	63	171
high relief	15	14	20	5	8	17	79
TPI_{30}: NUMBER OF FISH OBSERVATIONS							
boulders	1	1	0	1	0	2	5
ledges	14	9	19	4	4	19	69
outcrop	0	0	1	0	2	10	13
rubble	11	6	19	1	7	16	60
sand	0	0	5	0	4	4	13
small ledges	8	8	26	4	7	40	93
no relief	0	0	1	0	1	1	3
low relief	18	14	48	5	17	69	171
high relief	16	10	21	5	4	21	77

PERCEN

Video Analysis: Substrate Category	TP	
	valley	lower slop
TPI_{10}: PERCENT C		
boulders	20.0	N/A
ledges	15.9	N/A
outcrop	0.0	N/A
rubble	5.0	N/A
sand	0.0	N/A
small ledges	7.5	N/A
no relief	0.0	N/A
low relief	5.3	N/A
high relief	16.5	N/A
TPI_{20}: PERCENT C		
boulders	20.0	20.0
ledges	20.3	15.9
outcrop	0.0	0.0
rubble	5.0	15.0
sand	0.0	0.0
small ledges	4.3	5.4
no relief	0.0	0.0
low relief	4.1	7.0
high relief	19.0	17.7
TPI_{30}: PERCENT C		
boulders	20.0	20.0
ledges	20.3	13.0
outcrop	0.0	0.0
rubble	18.3	10.0
sand	0.0	0.0
small ledges	8.6	8.6
no relief	0.0	0.0
low relief	10.5	8.2
high relief	20.8	13.0

APPENDIX 1 (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.

	TPI Category						
Video Analysis: Substrate Category	valley	lower slope	flat	mid slope	upper slope	peak	totals
	TPI_{40}: NUMBER OF FISH OBSERVATIONS						
boulders	2	0	0	1	0	2	5
ledges	10	9	16	4	7	23	69
outcrop	0	0	1	0	0	12	13
rubble	11	3	21	0	4	21	60
sand	0	0	5	0	2	6	13
small ledges	3	15	16	4	10	45	93
no relief	0	0	1	0	1	1	3
low relief	13	18	39	4	16	81	171
high relief	13	9	19	5	6	27	79
	TPI_{50}: NUMBER OF FISH OBSERVATIONS						
boulders	2	0	0	0	0	3	5
ledges	8	5	21	3	7	25	69
outcrop	0	0	1	0	1	11	13
rubble	10	2	18	0	13	17	60
sand	0	0	5	0	5	3	13
small ledges	5	5	25	4	12	42	93
no relief	0	0	0	0	3	0	3
low relief	14	7	47	4	27	72	171
high relief	11	5	23	3	8	29	79
	TPI_{60}: NUMBER OF FISH OBSERVATIONS						
boulders	2	0	0	0	1	2	5
ledges	9	4	22	3	6	25	69
outcrop	0	0	2	0	0	11	13
rubble	10	0	24	2	8	16	60
sand	0	1	7	0	2	3	13
small ledges	7	5	29	4	6	42	93
no relief	0	0	3	0	0	0	3
low relief	16	6	56	6	16	71	171
high relief	12	4	25	3	7	28	79

	TPI (	
Video Analysis: Substrate Category	valley	lower slope
	TPI_{40}: PERCENT OI	
boulders	40.0	0.0
ledges	14.5	13.0
outcrop	0.0	0.0
rubble	18.3	5.0
sand	0.0	0.0
small ledges	3.2	16.1
no relief	0.0	0.0
low relief	7.6	10.5
high relief	16.5	11.4
	TPI_{50}: PERCENT OI	
boulders	40.0	0.0
ledges	11.6	7.2
outcrop	0.0	0.0
rubble	16.7	3.3
sand	0.0	0.0
small ledges	5.4	5.4
no relief	0.0	0.0
low relief	8.2	4.1
high relief	13.9	6.3
	TPI_{60}: PERCENT OI	
boulders	40.0	0.0
ledges	13.0	5.8
outcrop	0.0	0.0
rubble	16.7	0.0
sand	0.0	7.7
small ledges	7.5	5.4
no relief	0.0	0.0
low relief	9.4	3.5
high relief	15.2	5.1

APPENDIX 1 (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.

NUMBER OF FISH OBSERVATIONS

	TPI Category						
Video Analysis: Substrate Category	valley	lower slope	flat	mid slope	upper slope	peak	totals
	TPI_{40}: NUMBER OF FISH OBSERVATIONS						
boulders	2	0	0	1	0	2	5
ledges	10	9	16	4	7	23	69
outcrop	0	0	1	0	0	12	13
rubble	11	3	21	0	4	21	60
sand	0	0	5	0	2	6	13
small ledges	3	15	16	4	10	45	93
no relief	0	0	1	0	1	1	3
low relief	13	18	39	4	16	81	171
high relief	13	9	19	5	6	27	79
	TPI_{50}: NUMBER OF FISH OBSERVATIONS						
boulders	2	0	0	0	0	3	5
ledges	8	5	21	3	7	25	69
outcrop	0	0	1	0	1	11	13
rubble	10	2	18	0	13	17	60
sand	0	0	5	0	5	3	13
small ledges	5	5	25	4	12	42	93
no relief	0	0	0	0	3	0	3
low relief	14	7	47	4	27	72	171
high relief	11	5	23	3	8	29	79
	TPI_{60}: NUMBER OF FISH OBSERVATIONS						
boulders	2	0	0	0	1	2	5
ledges	9	4	22	3	6	25	69
outcrop	0	0	2	0	0	11	13
rubble	10	0	24	2	8	16	60
sand	0	1	7	0	2	3	13
small ledges	7	5	29	4	6	42	93
no relief	0	0	3	0	0	0	3
low relief	16	6	56	6	16	71	171
high relief	12	4	25	3	7	28	79

PERCENT

	TPI (	
Video Analysis: Substrate Category	valley	lower slope
	TPI_{40}: PERCENT OI	
boulders	40.0	0.0
ledges	14.5	13.0
outcrop	0.0	0.0
rubble	18.3	5.0
sand	0.0	0.0
small ledges	3.2	16.1
no relief	0.0	0.0
low relief	7.6	10.5
high relief	16.5	11.4
	TPI_{50}: PERCENT OI	
boulders	40.0	0.0
ledges	11.6	7.2
outcrop	0.0	0.0
rubble	16.7	3.3
sand	0.0	0.0
small ledges	5.4	5.4
no relief	0.0	0.0
low relief	8.2	4.1
high relief	13.9	6.3
	TPI_{60}: PERCENT OI	
boulders	40.0	0.0
ledges	13.0	5.8
outcrop	0.0	0.0
rubble	16.7	0.0
sand	0.0	7.7
small ledges	7.5	5.4
no relief	0.0	0.0
low relief	9.4	3.5
high relief	15.2	5.1

APPENDIX 1 (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.

NUMBER OF FISH OBSERVATIONS

	TPI Category						
Video Analysis: Substrate Category	valley	lower slope	flat	mid slope	upper slope	peak	totals
TPI_{80}: NUMBER OF FISH OBSERVATIONS							
boulders	1	1	0	0	0	3	5
ledges	7	5	12	3	13	29	69
outcrop	0	1	0	0	1	11	13
rubble	9	4	18	3	9	17	60
sand	1	2	4	0	3	3	13
small ledges	5	7	21	2	12	46	93
no relief	0	0	0	0	2	0	2
low relief	14	14	41	5	22	76	172
high relief	9	6	14	3	14	33	79
TPI_{100}: NUMBER OF FISH OBSERVATIONS							
boulders	0	1	0	1	0	3	5
ledges	8	3	13	3	14	28	69
outcrop	0	1	1	0	1	10	13
rubble	6	7	21	2	9	15	60
sand	1	3	4	0	1	4	13
small ledges	3	10	22	2	10	46	93
no relief	0	1	1	0	0	1	3
low relief	9	20	45	4	21	72	171
high relief	9	4	15	4	14	33	79
TPI_{120}: NUMBER OF FISH OBSERVATIONS							
boulders	1	0	1	0	0	3	5
ledges	6	5	14	4	17	23	69
outcrop	0	0	2	0	1	10	13
rubble	6	2	22	2	11	17	60
sand	1	0	7	0	1	4	13
small ledges	3	7	27	1	14	41	93
no relief	0	0	2	0	0	1	3
low relief	9	9	54	3	27	69	171
high relief	8	5	17	4	17	28	79

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	T	
Video Analysis: Substrate Category	valley	lower slope
TPI_{80}: PERCENT		
boulders	20.0	20.0
ledges	10.1	7.2
outcrop	0.0	7.7
rubble	15.0	6.7
sand	7.7	15.4
small ledges	5.4	7.5
no relief	0.0	0.0
low relief	8.1	8.1
high relief	11.4	7.6
TPI_{100}: PERCENT		
boulders	0.0	20.0
ledges	11.6	4.3
outcrop	0.0	7.7
rubble	10.0	11.7
sand	7.7	23.1
small ledges	3.2	10.8
no relief	0.0	33.3
low relief	5.3	11.7
high relief	11.4	5.1
TPI_{120}: PERCENT		
boulders	20.0	0.0
ledges	8.7	7.2
outcrop	0.0	0.0
rubble	10.0	3.3
sand	7.7	0.0
small ledges	3.2	7.5
no relief	0.0	0.0
low relief	5.3	5.3
high relief	10.1	6.3

APPENDIX 1 (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.

NUMBER OF FISH OBSERVATIONS

TPI Category

TPI$_{150}$: NUMBER OF FISH OBSERVATIONS

Video Analysis: Substrate Category	valley	lower slope	flat	mid slope	upper slope	peak	totals
boulders	1	0	0	0	0	4	5
ledges	3	7	23	4	7	25	69
outcrop	0	0	2	1	0	10	13
rubble	5	6	25	2	6	16	60
sand	1	2	6	0	1	3	13
small ledges	4	7	33	1	13	35	93
no relief	0	0	1	0	0	1	2
low relief	9	15	62	4	20	62	172
high relief	5	7	26	4	7	30	79

PERC

TPI$_{150}$: PERCEN

Video Analysis: Substrate Category	valley	lower slop
boulders	20.0	0.0
ledges	4.3	10.1
outcrop	0.0	0.0
rubble	8.3	10.0
sand	7.7	15.4
small ledges	4.3	7.5
no relief	0.0	0.0
low relief	5.2	8.7
high relief	6.3	8.9

APPENDIX 2. Proportion table for adjusted stock estimates. Calculation of proportion value used the formula for each category
Proportion values were used for calculating adjusted stock estimates by multiplying the original stock assessment by the proportion

	SPRING				**FALL**		
MODEL 1	Area with fish	Area without fish	transect area	proportion values	Area with fish	Area without fish	tra
Category 1	30232	92892	123124	0.10	8052	20112	
Category 2	8800	52296	61096	0.03	1620	14260	
Category 3	3196	40172	43368	0.01	944	10824	
Category 4	648	24932	25580	0.00	300	7292	
Category 5	792	13248	14040	0.00	136	4096	
Category 6	380	9028	9408	0.00	0	3208	
Category 7	72	8368	8440	0.00	0	2596	
Category 8	148	6416	6564	0.00	0	1448	
Category 9	0	3976	3976	0.00	16	948	

Category 10	0	11908	11908	0.00	224	2684
MODEL 2 - DEEP						
Category 1	12184	27916	40100	0.04	4340	8460
Category 2	9824	26824	36648	0.03	1444	8116
Category 3	9080	46012	55092	0.03	3600	13500
Category 4	8936	59900	68836	0.03	1016	12224
Category 5	2196	35316	37512	0.01	500	8720
Category 6	1064	22564	23628	0.00	148	5708
Category 7	836	21108	21944	0.00	4	5764
Category 8	148	6008	6156	0.00	0	1248
Category 9	0	14376	14376	0.00	240	2888
Category 10	0	3152	3152	0.00	0	836
MODEL 2 - SHALLOW						
Category 1	13524	70944	84468	0.04	3228	12232
Category 2	9992	38964	48956	0.03	1244	8724
Category 3	10160	40004	50164	0.03	3532	10348
Category 4	6172	29620	35792	0.02	2088	10704
Category 5	2688	23172	25860	0.01	676	7292
Category 6	928	16548	17476	0.00	152	4720
Category 7	652	19808	20460	0.00	132	7160
Category 8	152	13448	13600	0.00	16	4248
Category 9	0	10668	10668	0.00	224	2036
Category 10	0	0	0	0.00	0.00	0

APPENDIX 2 (Continued). Proportion table for adjusted stock estimates. Calculation of proportion value used the formula fish/transect area). Proportion values were used for calculating adjusted stock estimates by multiplying the original stock assessme

	SPRING				FALL		
MODEL 3	Area with fish	Area without fish	transect area	proportion values	Area with fish	Area without fish	tra
Category 1	34740	123472	158212	0.11	8420	26488	
Category 2	6144	53244	59388	0.02	1720	13620	
Category 3	2420	29752	32172	0.01	816	9988	
Category 4	512	12584	13096	0.00	96	4840	
Category 5	452	11252	11704	0.00	0	4536	
Category 6	0	8808	8808	0.00	0	2948	
Category 7	0	3964	3964	0.00	0	1020	
Category 8	0	7780	7780	0.00	128	1364	
Category 9	0	7564	7564	0.00	112	984	
Category 10	0	4816	4816	0.00	0	1680	
MODEL 4 - DEEP							
Category 1	12724	72284	85008	0.04	3052	12092	
Category 2	20300	72284	92584	0.07	4092	15764	
Category 3	7884	38644	46528	0.03	3100	13552	
Category 4	2624	29432	32056	0.01	808	11044	
Category 5	728	19172	19900	0.00	0	7140	
Category 6	8	10152	10160	0.00	0	3404	
Category 7	0	9784	9784	0.00	128	2520	
Category 8	0	7916	7916	0.00	112	480	

Category 9	0	3388	3388	0.00	0	1472
Category 10	0	180	180	0.00	0.00	0
MODEL 4 - SHALLOW						
Category 1	12484	27876	40360	0.04	3872	8928
Category 2	17712	72432	90144	0.06	5172	19356
Category 3	9336	68868	78204	0.03	1452	14904
Category 4	3912	43768	47680	0.01	460	11212
Category 5	824	19240	20064	0.00	96	6408
Category 6	0	7816	7816	0.00	0	2072
Category 7	0	7280	7280	0.00	128	684
Category 8	0	8824	8824	0.00	112	1344
Category 9	0	5072	5072	0.00	0	2520
Category 10	0	2060	2060	0.00	0	40

APPENDIX 3. Stock estimates for habitat suitability models. Stock estimates were calculated for each category by taking (# fish by species/transect area)*total survey area. Adjusted stock estimates accounted for the fact that suitability categories contained only a proportion of fish relative to no fish area within the transect. Adjusted values represent the first accurate stock estimate for near-shore, high relief area.

SPRING - ORIGINAL

Model 1 - Stock Estimate (# species/transect area)*total transect area

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	30374	4250	743	178	44	56	0
S. serranoides /S. flavidus	4374	325	315	119	0	0	0
S. miniatus	1919	345	113	30	44	111	0
S. auriculatus	414	96	0	0	0	111	0
S. carnatus	430	230	45	0	87	0	55
S. pinniger	614	96	45	0	0	56	0
S. rosaceus	384	134	0	0	0	0	0
S. rubrivinctus	230	38	23	0	44	0	0

Model 2 - Stock Estimate (# species/transect area)*total transect area

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
Deep							
S. serranoides /S. flavidus	2287	1796	392	288	314	26	115
S. rosaceus	131	175	131	48	0	0	0
S. rubrivinctus	147	111	39	0	0	0	0
Shallow							
S. mystinus	7338	5691	6847	10506	3775	112	39
S. miniatus	522	511	306	479	442	0	78

Model 3 - Stock Estimate (# species/transect area)*total transect area

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	27710	9833	284	39	58	0	0
S. serranoides /S. flavidus	3667	1594	181	0	175	0	0
S. miniatus	1994	389	155	77	0	0	0
S. auriculatus	402	136	0	0	117	0	0
S. carnatus	499	155	129	39	0	0	0
S. pinniger	627	117	52	0	58	0	0
S. rosaceus	418	117	0	0	0	0	0
S. rubrivinctus	273	19	0	39	0	0	0

Model 4 - Stock Estimate (# species/transect area)*total transect area

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
Deep							
S. serranoides /S. flavidus	2104	228	0	0	0	0	0
S. rosaceus	200	46	78	0	0	0	0
S. rubrivinctus	250	91	0	0	0	0	0
Shallow							
S. mystinus	14772	19260	3127	0	0	0	0
S. miniatus	362	513	733	481	0	0	410

SPRING - ADJUSTED

Model 1 - Stock Estimate [(# species/transe

	1	**2**	**3**
S. mystinus	3622	96	10
S. serranoides /S. flavidus	522	7	4
S. miniatus	229	8	1
S. auriculatus	49	2	0
S. carnatus	51	5	1
S. pinniger	73	2	1
S. rosaceus	46	3	0
S. rubrivinctus	27	1	0

Model 2 - Stock Estimate [(# species/transe

	1	**2**	**3**
Deep			
S. serranoides /S. flavidus	0	53	0
S. rosaceus	5	5	4
S. rubrivinctus	18	4	0
Shallow			
S. mystinus	124	194	13
S. miniatus	12	5	8

Model 3 - Stock Estimate [(# species/transe

	1	**2**	**3**
S. mystinus	3298	233	3
S. serranoides /S. flavidus	436	38	2
S. miniatus	237	9	2
S. auriculatus	48	3	0
S. carnatus	59	4	1
S. pinniger	75	3	1
S. rosaceus	5	1	0
S. rubrivinctus	33	0	0

Model 4 - Stock Estimate [(# species/transe

	1	**2**	**3**
Deep			
S. serranoides /S. flavidus	82	12	0
S. rosaceus	8	2	3
S. rubrivinctus	10	5	0
Shallow			
S. mystinus	726	1265	58
S. miniatus	18	34	14

APPENDIX 3 (Continued). Stock estimates for habitat suitability models. Stock estimates were calculated for each category by taking (# fish by species/transect area)*total survey area. Adjusted stock estimates accounted for the fact that suitability categories contained only a proportion of fish relative to no fish area within the transect. Adjusted values represent the first accurate stock estimate for near-shore, high relief area.