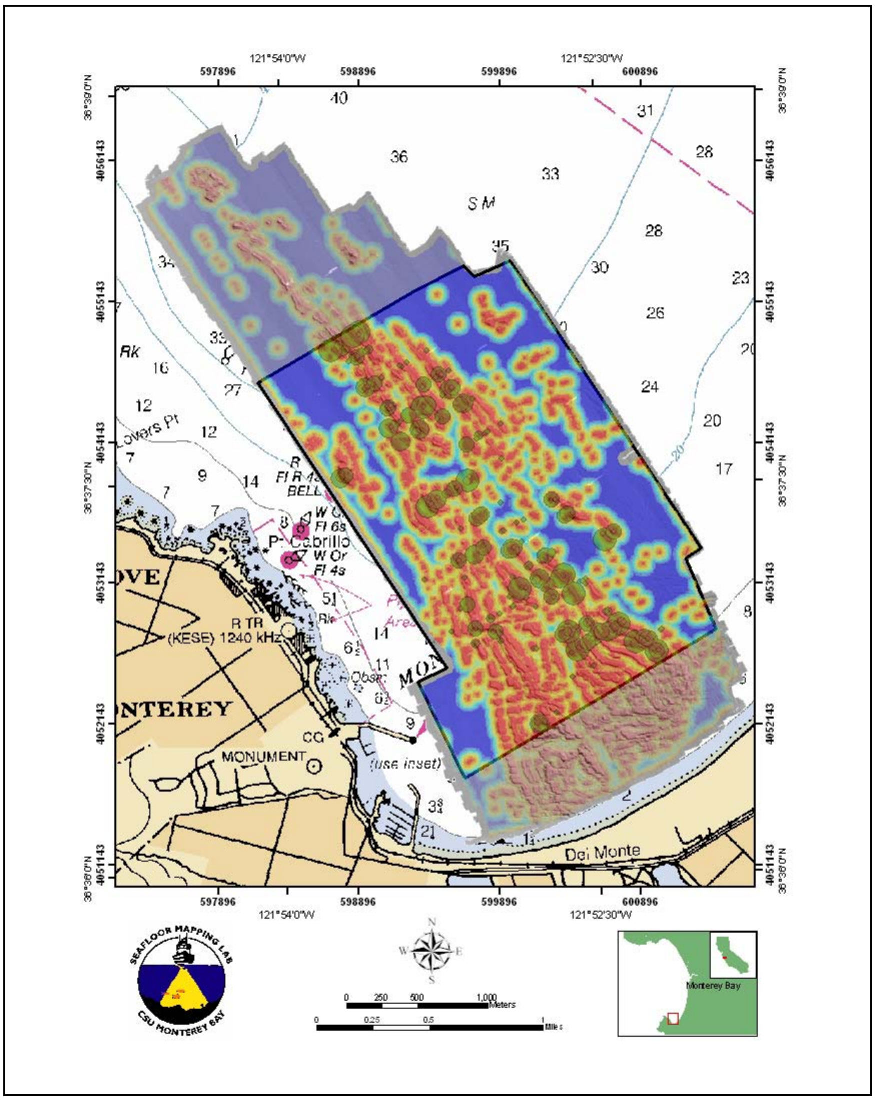
Using GIS landscape analysis tools with high-resolution multibeam bathymetry and ROV mapping to model rockfish distribution and abundance on the Del Monte shale beds, Monterey Bay, California.

A Capstone Project
Presented to the Faculty of the Earth Systems Science Policy
in the
College of Science, Media Arts and Technology
at the
California State University, Monterey Bay
In partial fulfillment of the requirements for the Degree of
Bachelor of Science
By



Erica Summers-Morris

5 May 2004

TABLE OF CONTENTS

TABLE OF FIGURES AND TABLES

ABSTRACT

Accurate and efficient species-based habitat assessment is in great demand for the marine environment. In light of declining rockfish stocks, effective tools capable of providing accurate stock assessments of near-shore, high relief habitat would be invaluable to both state and federal resource managers. Multibeam bathymetry, when analyzed with GIS landscape analysis tools, can create effective models capable of predicting "preferred" habitat based on species-specific parameters. For this study, high-resolution multibeam data of the Del Monte shale beds in Monterey Bay, California were analyzed in GIS for slope, rugosity, and relative topographic position to assess and quantify rockfish (*Sebastes* spp.) habitat preference. Video transects collected by a remotely operated vehicle (ROV) provided habitat ground-truth and fish distribution data for the modeling process. A series of habitat suitability models were created in GIS by combining different suitability factors from multibeam-derived grids: slope, rugosity, topographic position index (TPI) and depth. "Distance to preferred" categories for each of the parameters were determined for 8 rockfish species. Of these, "Distance to Peak" features identified by TPI_{50} proved to be the most effective means of modeling fish distribution, and successfully predicted an average of 80% of the 8 rockfish species. Using fish distribution information collected from the ROV, stock estimates were calculated for the shale beds study area. By combining GIS landscape analysis tools with multibeam bathymetry and ROV video data, we have created a predictive tool that can locate areas of "most suitable" habitat given rockfish-specific parameters.

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 are particularly vulnerable to overfishing. Many species are long-lived, have low fecundity, and slow growth and maturation rates (Yoklavich et al. 2000). 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 as a proxy for habitat mapping requires detailed information about how species interact with their environment. In the marine environment, the primary techniques currently used to analyze abundance, distribution and 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 a more 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 populations 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 are 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). 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 (1m) and deep (1000m+) 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. The 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. Given rockfish preference for high-relief substrates, we tuned the GIS tools to locate areas of high slope, rugosity and 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 multibeam data were transformed into a digital elevation model (DEM) in IVS Fledermaus 5.2, and imported into ArcGIS 8.3 as 2m x,y,z (latitude, longitude, depth) point data. 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 plot 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 refined by using the spring ROV video data as a means of fine-tuning the results, 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 is distinguished by *Metridium senili*, and numerous species of anemones and sea stars. 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 the TSS Position and Orientation System, Marine Vessel (POS-MV) for heave, pitch, roll and yaw corrections (with +/-0.02° accuracy); and Trimble 4700 GPS with differential corrections from the Trimble ProBeacon receiver (with +/- 1-2m 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 ISIS shipboard 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 (latitude, longitude, depth) files with 2m resolution were exported from Caris, reviewed in Fledermaus, and exported as a digital elevation model (DEM) representing a three-dimensional image of the seafloor. The DEM was imported into ArcGIS, and provided the data for all subsequent landscape analysis. Grayscale geotiffs with a 2m 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 plotted 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 500m apart and averaged 1km in length (Figure 2). The ROV was kept approximately 1-2m from the bottom, with a forward viewing angle of approximately 45° off the bottom. Two parallel laser beams were mounted on the frame of the ROV spaced 20cm apart to determine relative size of individual fish, relative distance from the bottom and visibility. The ROV paused for large fish aggregations to more accurately count and identify individuals, and at the base of large ledge features to pan from left to right to record any species-ledge interactions before continuing up and over these features. Video data and transect lines, or parts of transect lines, that did not run perpendicular to the strike of the reef, were flown consistently above 2m from the bottom, or were dragged by the MacGinitie, 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 relative to the ship and depth information was 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 beacon mounted on the ROV received positional data from the transponder mounted onboard the R/V MacGinitie and recorded the ROV position based on calculations made by the ship-board computer. The ROV beacon would periodically lose the signal from the transponder, and would cause a “jump” or an erroneous position to be logged. These positioning errors were corrected by post-processing the trackline data in the lab. A 5m buffer on either side of the corrected tracklines was applied to encompass the viewable area surveyed by the ROV. Area and distance were calculated for the tracklines to determine the amount of area surveyed. Buffered tracklines were used in subsequent landscape analysis of the bathymetric data, and for evaluation of model efficiency.

Video analysis was completed in the lab using a JVC BR-DV600 mini-DV digital VCR with monitor display. Tapes were reviewed and positional data retrieved using the Horita GPS-3 encoder. The precise location of individual fish observations was recorded in a text file, and species identification, abundance, depth, substrate classification and important features were recorded on logsheets. Individuals that were unable to be identified 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 logsheets 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 5 10m 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 3). Thus the suitability models projected 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 (Figure 4).

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 visual representation of the "steepness" of the terrain at a 2m scale, the scale of the resolution of the image.

Rugosity

Rugosity was calculated in ArcView GIS 3.2 using the "Surface Areas and Ratios from Elevation Grid v.1.2," created by Jenness Enterprises (Jenness 2002). Rugosity measures the ratio of surface area to planar area, which creates an estimate of the "roughness" of the terrain. Rugosity values typically range from 1 (completely flat) 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". Rugosity was also calculated at the resolution of the image, or 2m for this project.

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 depth values given a particular neighborhood size. A 10m-thick annulus ring was used to generate mean depth values for each cell, which were subtracted from the depth of the cell to yield a measure of relative elevation. These values were reclassified into 5 groups based on standard deviation classes, and represent relative highs, lows, rises and flat areas, or areas of constant slope (Figure 5). Areas classified as "flat" or with constant slope were further stratified using the slope analysis results to determine low-rise (slope > 5°) and flat (slope ≤ 5°) areas. The 6 TPI classes provide a visual 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 150m were generated using the 2m DEM. Each TPI iteration 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 (Appendix 1).

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 reclassed into habitat suitability categories, from 1 (most suitable) to 10 (least suitable). Spring ROV video data was used to evaluate 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 10,494m over 6 transects during the fall survey, and 48,662m over 21 transects during the spring survey (Figure 2). 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 6). 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 2m in vertical relief. The resolution of the DEM, and thus all derivative grids, was 2m, 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 2m DEM produced values ranging from 0 to 32° (Figure 7), 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. The category for high slope (≥ 8.97°), however, included very little area and very few fish. In order to make this category comparable in area and fish to other categories, the high slope category was merged and defined as slope ≥ 4.86° (Table 1).

Rugosity

Again, due to the low-relief nature of the shale beds coupled with the 2m resolution of the DEM, the rugosity grid results were lower than expected, ranging from 1 to 1.22 (Figure 8). 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. The category for high rugosity (≥ 1.02), however, included very little area and very few fish. In order to make this category comparable in area and fish to other categories, the high rugosity category was merged and defined as rugosity ≥ 1.003.

Topographic Position Index (TPI)

Multiple TPI grids with neighborhoods ranging from 10 to 150m 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 9).

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 TPI_{50} grid. Data within the 50m buffer were excluded from all subsequent calculations. 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 data coverage. Data collected on the outer edge of the swath tend to be artificially elevated due to signal attenuation through the water column. Thus, swath overlap can sometimes produce artifacts, which appear to be higher in elevation than the surrounding areas. Although the great majority of these artifacts were removed during multibeam data processing, a few residuals 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. Although these may be attractive features, rockfish are not always found clustered directly on top of them. Thus, a 10m "distance to" peaks buffer was calculated, in order to capture the fish found on and around these high-relief features (PFMC 2004).

"Distance to Preferred" slope and rugosity grids (slope ≥ 4.86°, rugosity ≥ 1.003) were also calculated to detect similar trends (Table 2). Each of the three "Distance to Preferred" grids used a buffer distance of 10m increments from preferred areas, 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 5 of the 8 species included in the study (Table 1). The ROV survey area was stratified into 5-10m depth zones (Figure 3). These depth zones were ranked in GIS based on species preference, then incorporated into different habitat suitability models (Table 3).

Four 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 simply added together. 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 in the model (Figure 10). Model 1 appears to predict an average of 80% of rockfish within the "most suitable" category 1 (Table 4). This simple model was based 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 10 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 (55-65m) to 5 for the shallowest zone (15-25m) covered during the ROV surveys (Figure 11). Model 2 – Deep proved to be less effective at capturing both spring and fall species within the “most suitable” category 1 (Table 4).

“Model 2 – Shallow”, added the “distance to TPI_{50} peaks” grid to the reclassified depth grid, classed 1 for the shallowest zone (15-25m) to 5 for the deepest zone (55-65m) covered during the ROV surveys (Figure 12). This model proved to be less effective at capturing the species within these depth ranges in terms of percent fish (Table 4).

Both of these models were limited to the depth zones where the ROV transects were located, between the 15 and 65m 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 65m depth contours. Figures 11 and 12 show Model 2 results limited to the analysis mask area in the foreground, and results projected for the ROV survey area in the background, or the “grayed-out” area.

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 preferred 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 13). 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 13 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 (55-65m) to 5 for the shallowest zone (15-25m) covered during the ROV surveys (Figure 14). Using percent species caught, this model proved better or equally able to capture *S. rosaceus* (spring data), and *S. rubrivinctus* (both spring and fall) within the most suitable category 1 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 (15-25m) to 5 for the deepest zone (55-65m) covered during the ROV surveys (Figure 15). Using percent species caught, this model proved to less effective at capturing *S. mystinus* and *S. miniatus* within the most suitable category 1 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 zones where the ROV transects were located, between the 15 and 65m 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 65m depth contours. Figures 14 and 15 show Model 4 results limited to the analysis mask area in the foreground, and results projected for the ROV survey area in the background, or the “grayed-out” area.

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 16). 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 16, 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 16). 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, category 1 for Model 1 comprised 35.8%. Percent transect area within category 1 was moderately less for fall than for the spring survey. Of the 35.8% 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 16). The ratio of percent area with fish to percent transect area within category 1 showed that Model 2 – Deep returned the greatest amount of area with fish to amount of "suitable habitat," with all models showing greater ratio values than for spring due to the reduced amount of area classified as category 1 (Table 6).

When analyzing raw percent capture of species 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 of the rockfish species depth preferences found in the natural history literature often specify broad depth zones, encompassing the entire depth range of the shale beds study area. Thus depth preference classes chosen for this project was 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, 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 16, 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. In addition to the fact that there were no transect replicates for each season, 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 the fall distribution of 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 the generation. Second, there were three transects in the shallow (10-15m) 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 in the shallowest extent of the reef at 10m, ran along a ledge, and gradually increased in depth to 30m. 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.

CONCLUSION

The models generated for this study have an overall spatial resolution of 2m, and thus are extremely rare in the field of landscape ecology. Many terrestrial studies rely on satellite imagery with resolutions often greater than 1km. Studies of the marine environment have yet 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 research and assessments of stock abundance and distribution 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 (1-2m) 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 necessary 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.

LIST OF REFERENCES

Adams, PB, JL Butler, CH Baxter, TE Laidig, KA Dahlin, WW Wakefield. 1995. Population estimates of Pacific coast groundfishes from video transects and swept-area trawls. Fishery Bulletin 93: 446-455.

Brown, CJ, KM Cooper, WJ Meadows, SD Limpenny, HL Rees. 2002. Small-scale mapping of sea-bed assemblages in the eastern English Channel using sidescan sonar and remote sampling techniques. Estuarine, Coastal and Shelf Science 54: 263-278.

Bult, TP, RL Haedrich, DC Schneider. 1998. New technique describing spatial scaling and habitat selection in riverine habitats. Regul. Rivers: Res. Mgmt. 14: 107-118.

Caillet, GM, AH Andrews, WW Wakefield, G Moreno, KL Rhodes. 1999. Fish faunal and habitat analyses using trawls, camera sleds and submersibles in benthic deep-sea habitats off central California. Oceanologica Acta 22(6): 579-592.

Caselle, JE, MS Love, C Fusaro, D Schroeder. 2002. Trash or habitat? Fish assemblages on offshore oilfield seafloor debris in the Santa Barbara Channel, California. ICES Journal of Marine Science 59: S258-S265.

Eittreim, SL, RJ Anima, AJ Stevenson. 2002. Seafloor geology of the Monterey Bay area continental shelf. Marine Geology 181: 3-34.

Freemen, SM, SI Rogers. 2003. A new analytical approach to the characterization of macro-epibenthic habitats: linking species to the environment. Estuarine, Coastal and Shelf Science 56: 749-764.

García-Charton, JA, Á Pérez-Ruzafa. 2001. Spatial pattern and the habitat structure of a Mediterranean rocky reef fish local assemblage. Marine Biology 138: 917-934.

Greene, HG, MM Yoklavich, RM Starr, VM O'Connell, WW Wakefield, DE Sullivan, JE McRea, GM Caillet. 1999. A classification scheme for deep seafloor habitats. Oceanologica Acta 22(6): 663-678.

Greene, HG. 1990. Regional tectonics and structural evolution of the Monterey Bay region, central California, in Garrison, R.E., Greene, H.G., Hicks, K.R., Weber, G.E., and Wright, T.L. (eds.), Geology and Tectonics of the Central California Coastal Region, San Francisco to Monterey: Pacific Section, American Association of Petroleum Geologists Volume and Guidebook GB 67, p. 31-56.

Helvey, M. 2002. Are southern California oil and gas platforms essential fish habitat? ICES Journal of Marine Science 59: S266-S271.

Hixon, MA, BN Tissot, WG Pearcy. 1991. Fish assemblages of rocky banks of the Pacific Northwest: Final Report. Minerals Management Service, Outer Continental Shelf Study 91-0052. Pacific OCS Region: Camarillo, CA.

Humann, P. 1996. Coastal fish identification: California to Alaska. New World Publications, Inc: Jacksonville, FL.

Jenness, J. 2002. Surface areas and ratios from elevation grid, v. 1.2 for Arc View 3.2. Jenness Enterprises, Flagstaff, AZ. www.jennessent.com

Kenny, AJ, I Cato, M Desprez, G Fader, RTE Schüttenhelm, J Side. 2003. An overview of seabed-mapping technologies in the context of marine habitat classification. ICES Journal of Marine Science 60: 411-418.

Love, MS. 1996. Probably more than you wanted to know about the fishes of the Pacific coast. Really Big Press: Santa Barbara, CA.

Love, MS, M Yoklavich, L Thorsteinson. 2002. The rockfishes of the northeast pacific. University of California Press: Berkeley, CA.

Mason, J. 1999. Declines in rockfish: Declining rockfish lengths in the Monterey Bay, California Recreational Fishery, 1959-94. Marine Fisheries Review 60:3.

Mayer, L, J Hughes-Clarke, S Dijkstra. 1997. Multibeam sonar: potential applications for fisheries research. *In* Changing Oceans and Changing Fisheries: Environmental Data for Fisheries Research and Management. (GW Boehlert, JD Schumacher, eds.), pp. 79-92. U.S. Dep. Commer, NOAA Tech. Memo. NMFS-SWFSC-239, 146 pp.

Nasby-Lucas, NM, SG Merle, BW Embley, BN Tissot, MA Hixon, DJ Wright. 2002. Integration of submersible transect data and high-resolution multibeam sonar imagery for a habitat-based groundfish assessment of Haceta Bank, Oregon. Fishery Bulletin 100: 739-751.

O'Connell, V, WW Wakefield, HG Greene. 1998. The use of no-take marine reserve in the eastern Gulf of Alaska to protect essential fish habitat. *In* Marine harvest refugia for west coast rockfish: a workshop (M. Yoklavich, ed.), pp. 125-132. U.S. Dep. Commer, NOAA Tech. Memo. NMFS-SWFC-255, 159 pp.

[PFMC] Pacific Fisheries Management Council. 2004. PFMC home page. www.pcouncil.org. Accessed April 2004.

Pacific Fishery Management Council. 2004 Acceptable biological catch and optimum yield specification and management measures for the 2004 Pacific Coast groundfish fishery. Final environmental impact statement and regulatory analyses. Pacific Fishery Management Council, Portland, OR. December 2003.

Ralston, S. 1998. The status of federally managed rockfish on the US West Coast. *In* Marine harvest refugia for west coast rockfish: a workshop (M. Yoklavich, ed.), pp. 6-16. U.S. Dep. Commerl, NOAA Tech. Memo. NMFS-SWFC-255, 159 pp.

Seafloor Mapping Lab. California State University, Monterey Bay. 2000. SFML webpage: http://seafloor.csumb.edu. 2003 August.

Starr, RM, JM Cope, LA Kerr. 2002. Trends in Fisheries and Fishery Resources Associated with the National Marine Sanctuary Monterey Bay From 1981-2000. California Sea Grant College Program: University of California, La Jolla, CA, Publication No. T-046.

Starr, RM. 1998. Design principles for rockfish reserves on the U.S. west coast. *In* Marine harvest refugia for west coast rockfish: a workshop (M. Yoklavich, ed.), pp. 50-63. U.S. Dep. Commerl, NOAA Tech. Memo. NMFS-SWFC-255, 159 pp.

Starr, RM, DS Fox, MA Hixon, BN Tissot, GE Johnson, WH Barss. 1996. Comparison of submersible-survey and hydroacoustic-survey estimates of fish density on a rocky bank. Fishery Bulletin 94: 113-123.

Storlazzi, CD, ME Field. 2000. Sediment distribution and transport along a rocky, embayed coast: Monterey Peninsula and Carmel Bay, California. Marine Geology 170: 289-316.

Urbanski, JA, M Szymelfenig. 2003. GIS-based mapping of benthic habitats. Estuarine, Coastal and Shelf Science 56: 99-109.

Weiss, A. 2001. Topographic Position and Landforms Analysis. Poster presentation, ESRI User Conference, San Diego, CA.

Whitmire, CE. 2003. Integration of high-resolution multibeam sonar imagery with observational data from submersibles to classify and map benthic habitats at Haceta Bank, Oregon [MSc thesis draft]. Corvallis (OR): Oregon State University. 55pp.

Yoklavich, MM, HG Greene, GM Caillet, DE Sullivan, RN Lea, MS Love. 2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fishery bulletin 98(3): 625.

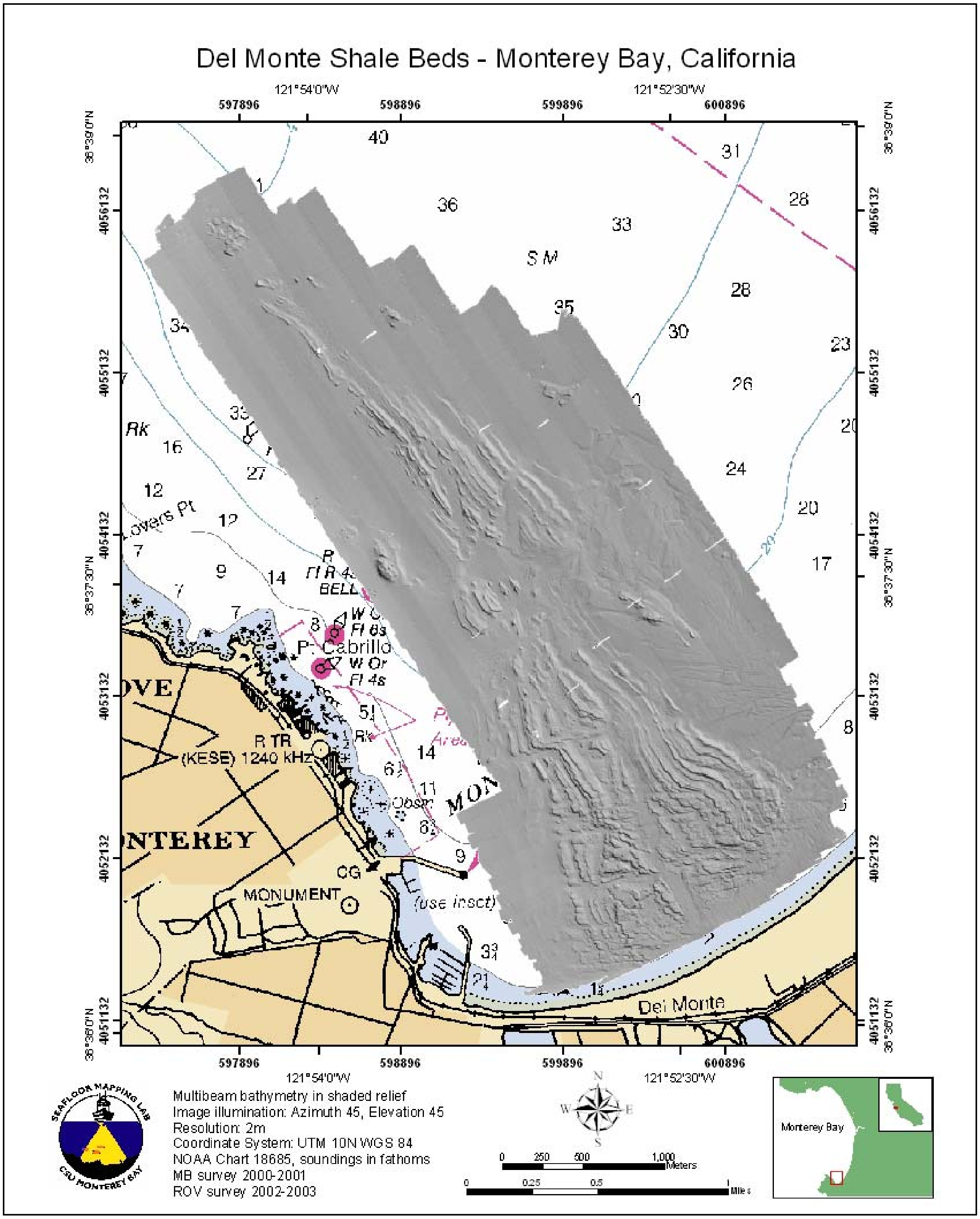


FIGURE 1. Shaded-relief grayscale image of multibeam bathymetry for the Del Monte shale beds study site, Monterey Bay, CA.

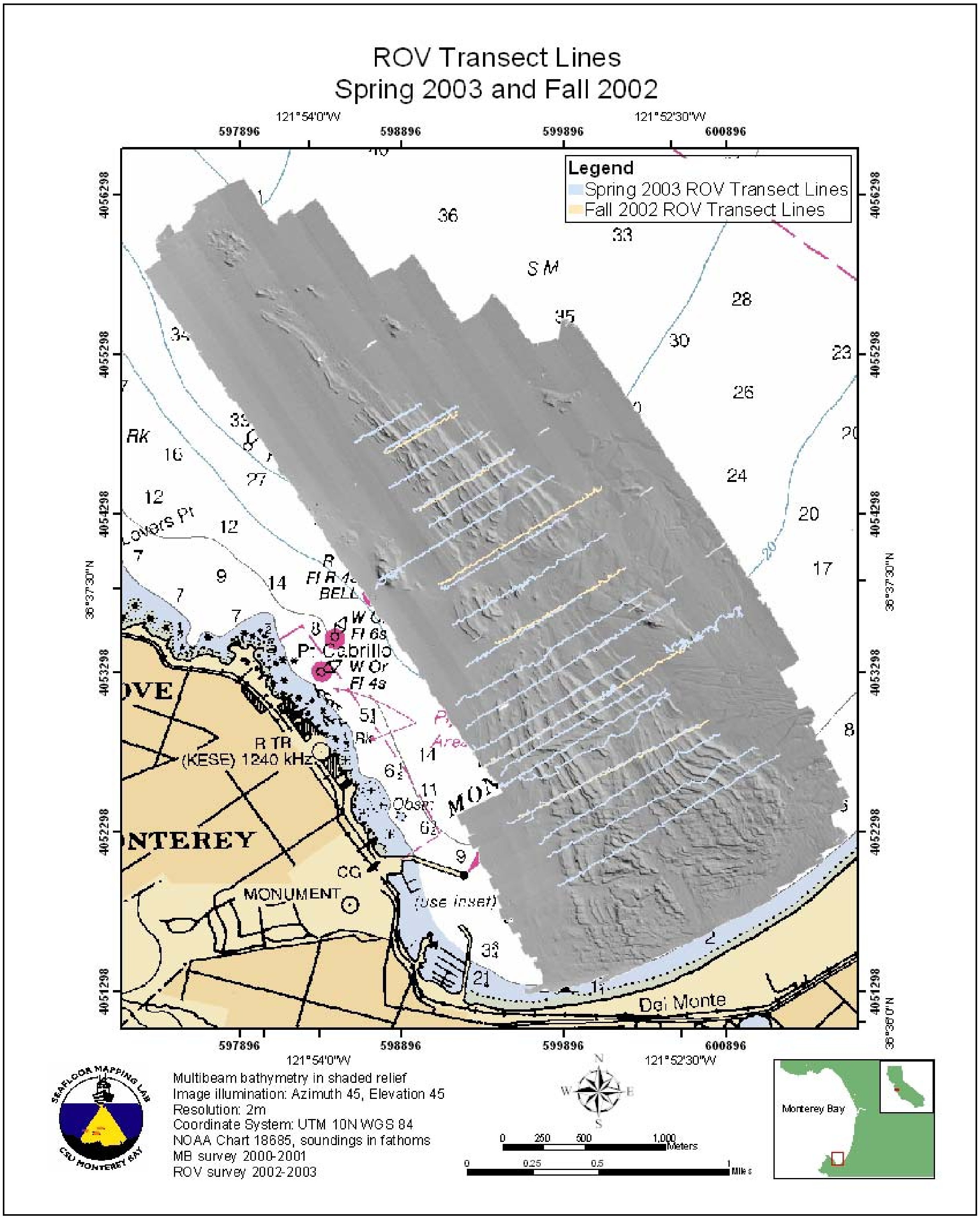


FIGURE 2. ROV tracklines for Fall 2002 and Spring 2003 surveys. Tracklines have been buffered by 2.5m on either side to create a 5m corridor representing the visual area covered by the ROV during the surveys. Buffered transect areas were used in the evaluation of all habitat suitability models.

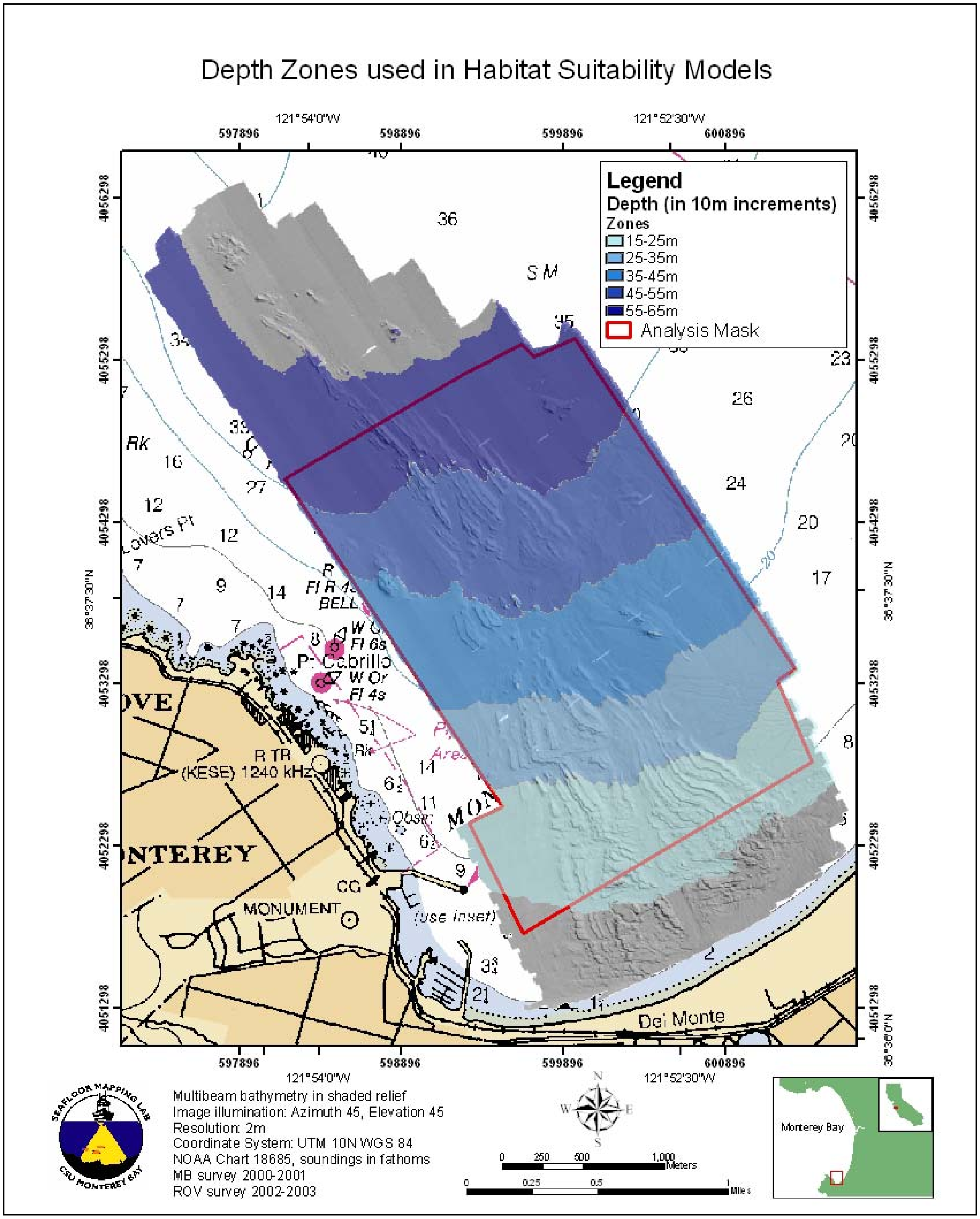


FIGURE 3. Depth zones in 10m increments used in the generation of habitat suitability models. Depth classes derived from bathymetry DEM. Depth zones were restricted to the boundaries of the analysis mask in the modeling process.

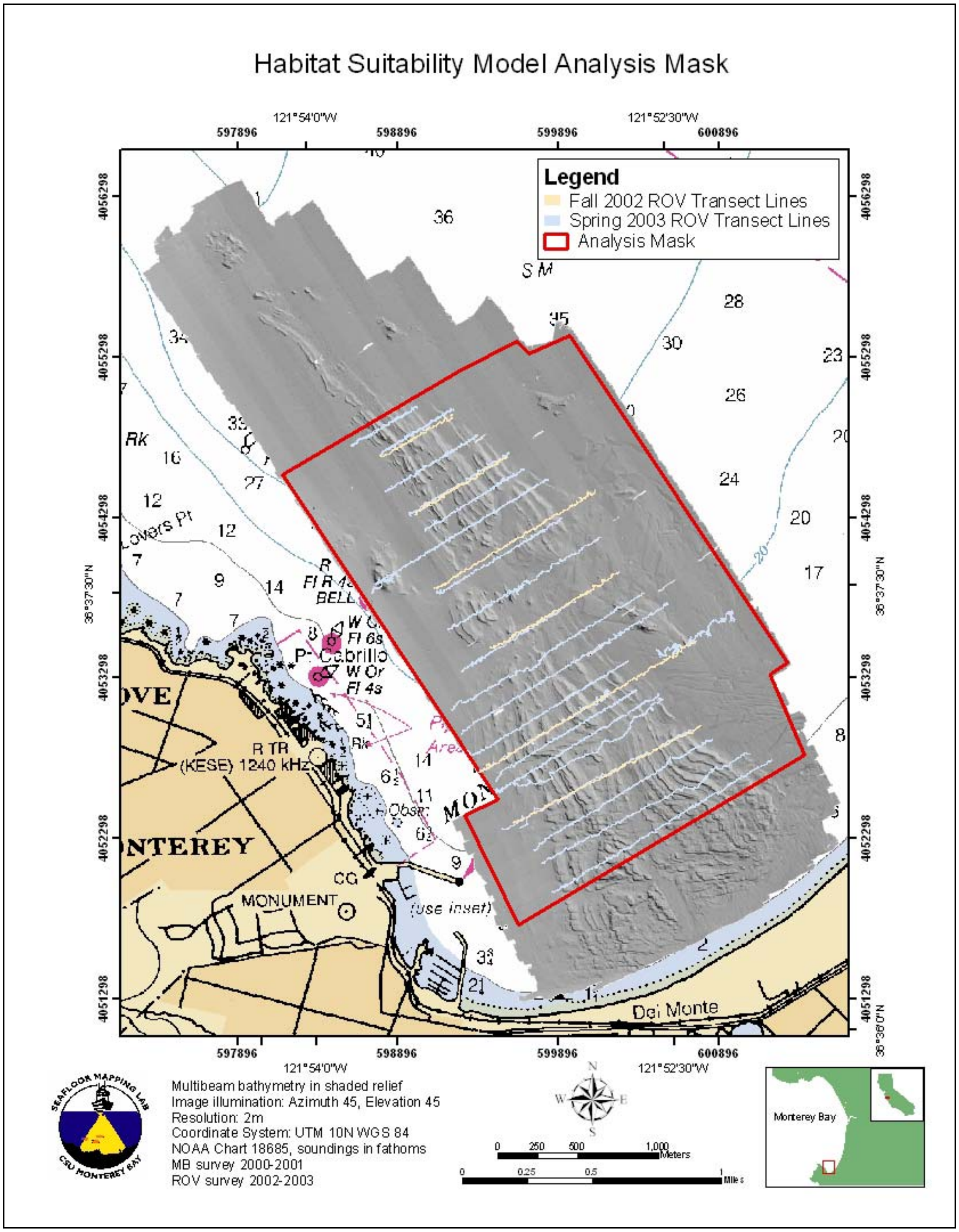


Figure 4. Habitat suitability model analysis mask. Mask was created by buffering the end transect lines by 50 meters, and tracing the extent of the multibeam survey area between these points. Mask was created to limit the results of the model to the extent of the ROV ground-truth data.

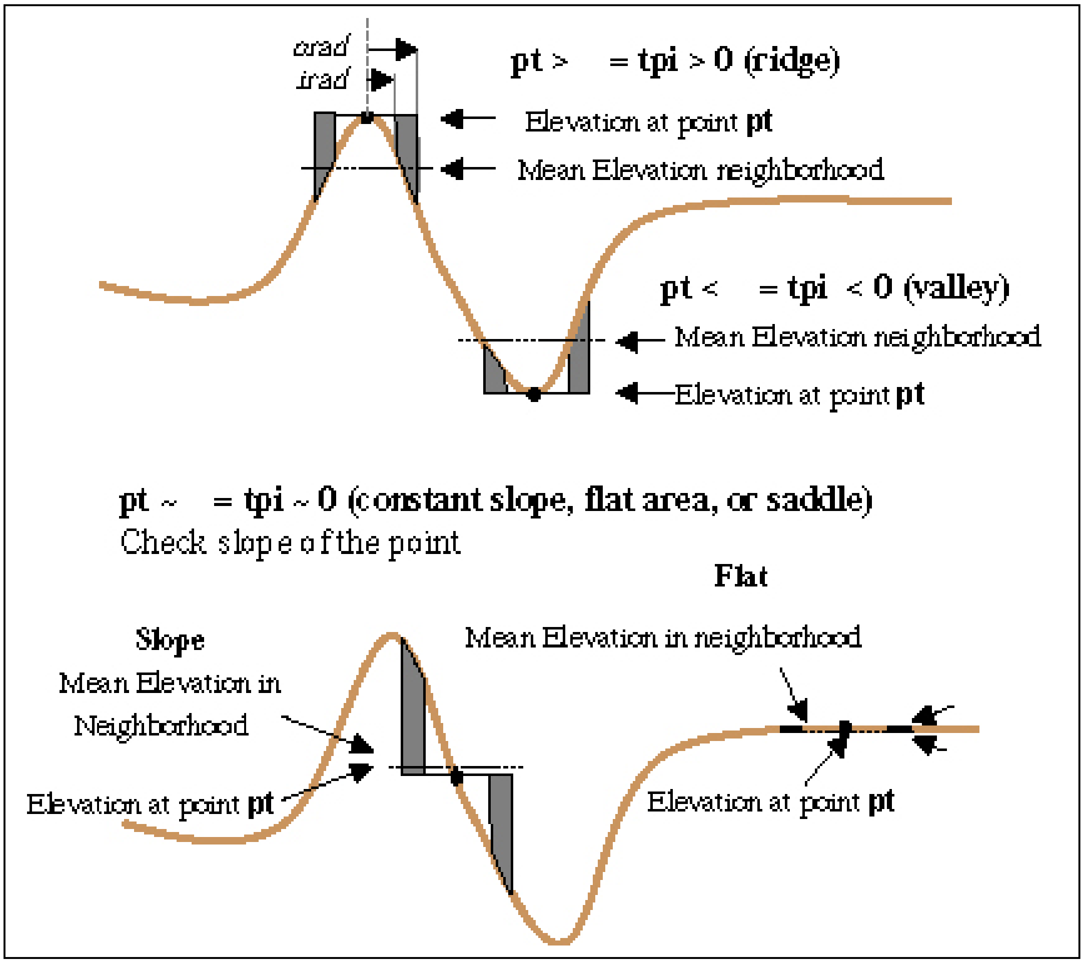


FIGURE 5. Schematic depiction of TPI calculation. Brown line represents a hypothetical cross-section view of a DEM, with cases illustrated showing TPI calculation of various feature types (peak, valley, etc.). Positive TPI values represent locations that are higher than the average of their surroundings, 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)

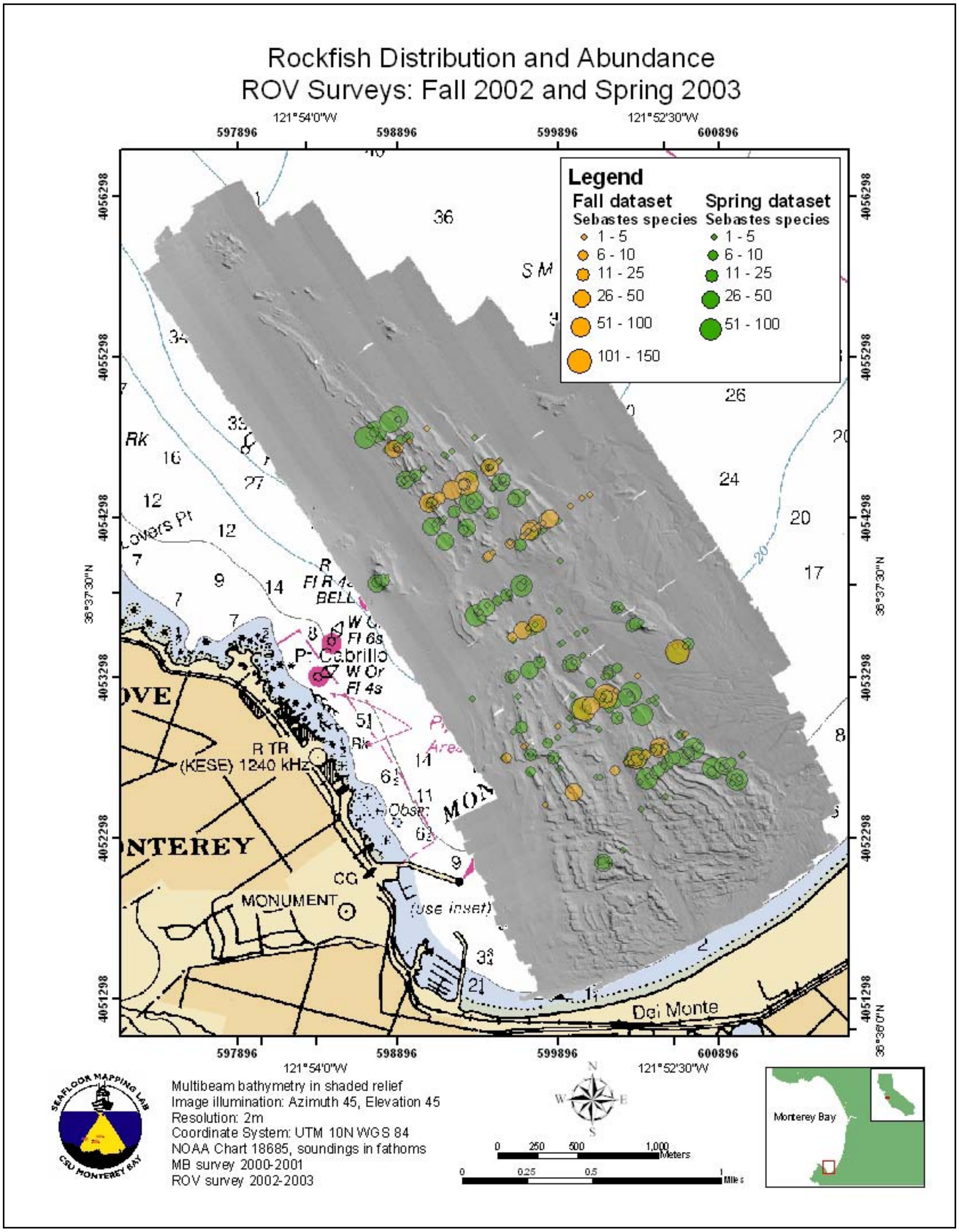


FIGURE 6. Rockfish distribution and abundance calculated from analysis of ROV video data. Visual analysis of these data revealed a strong association between rockfish and high relief habitat.

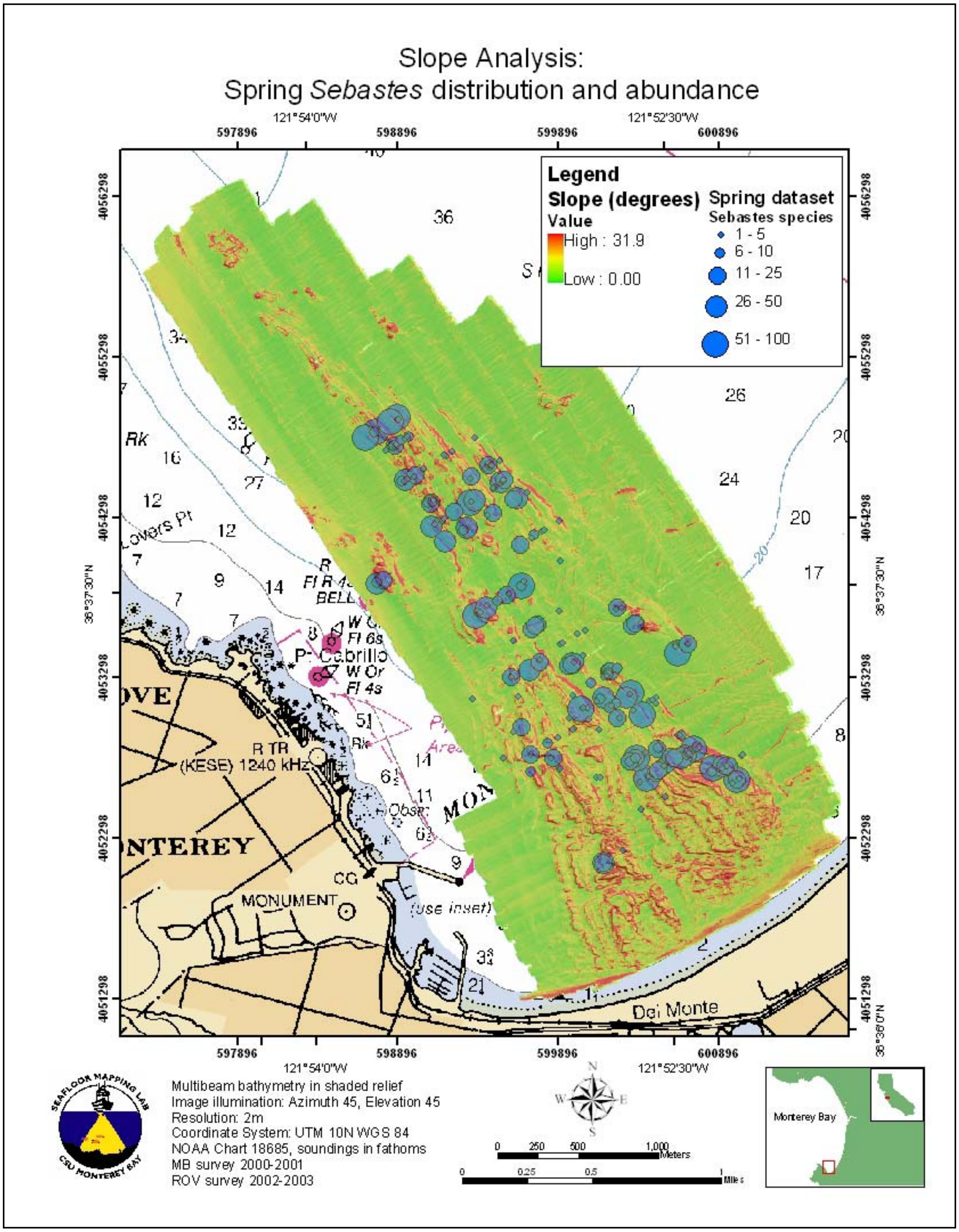


FIGURE 7. Slope analysis of multibeam survey area with distribution and abundance of rockfish observed during Spring 2003 ROV survey. Slope grid derived from bathymetry DEM. Symbol size for fish data is proportional to number of rockfish observed, and grid color indicates slope value.

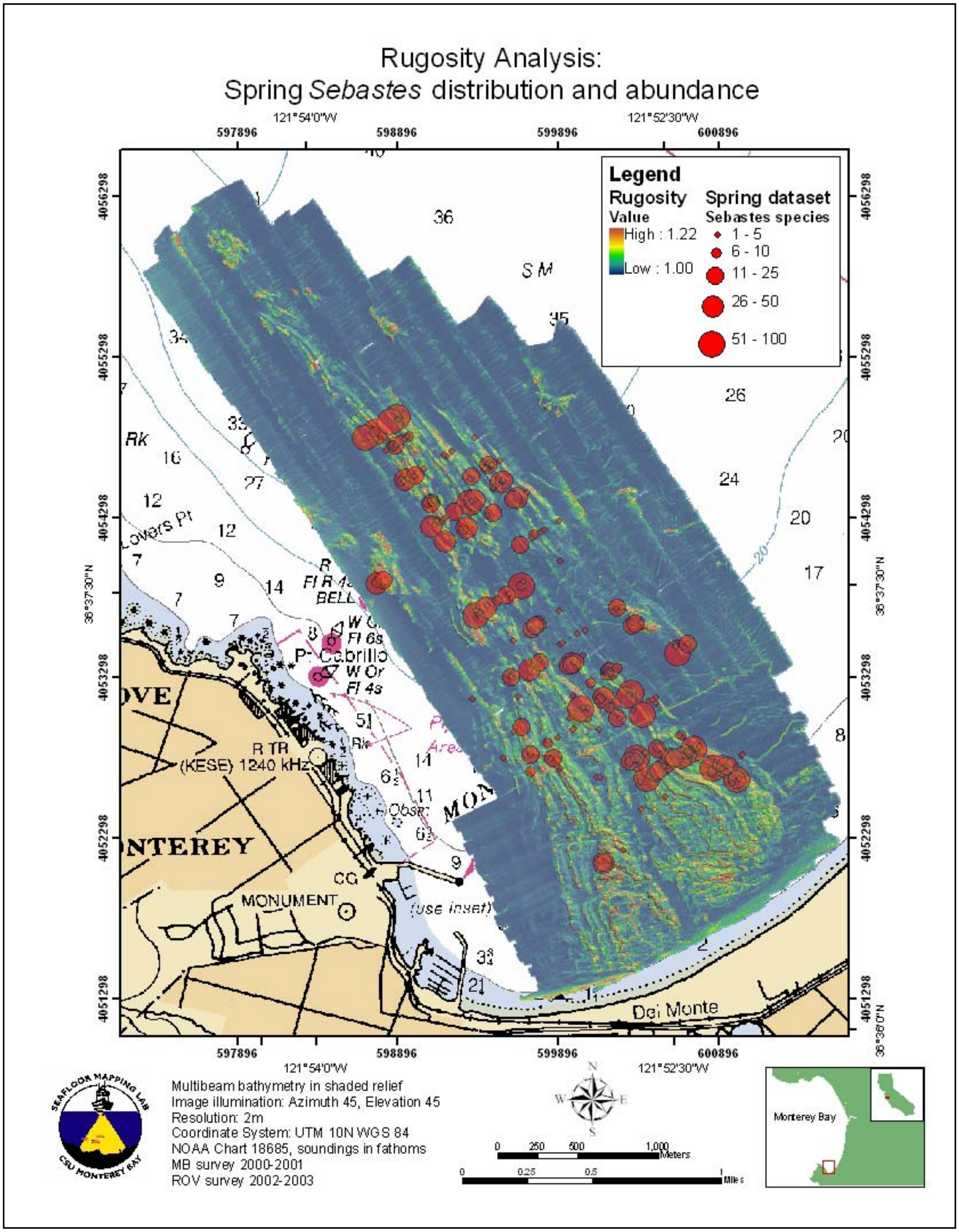


FIGURE 8. Rugosity analysis of multibeam survey area with distribution and abundance of rockfish observed during Spring 2003 ROV survey. Rugosity grid derived from bathymetry DEM. Symbol size for fish data is proportional to number of rockfish observed, and grid color indicates rugosity value.

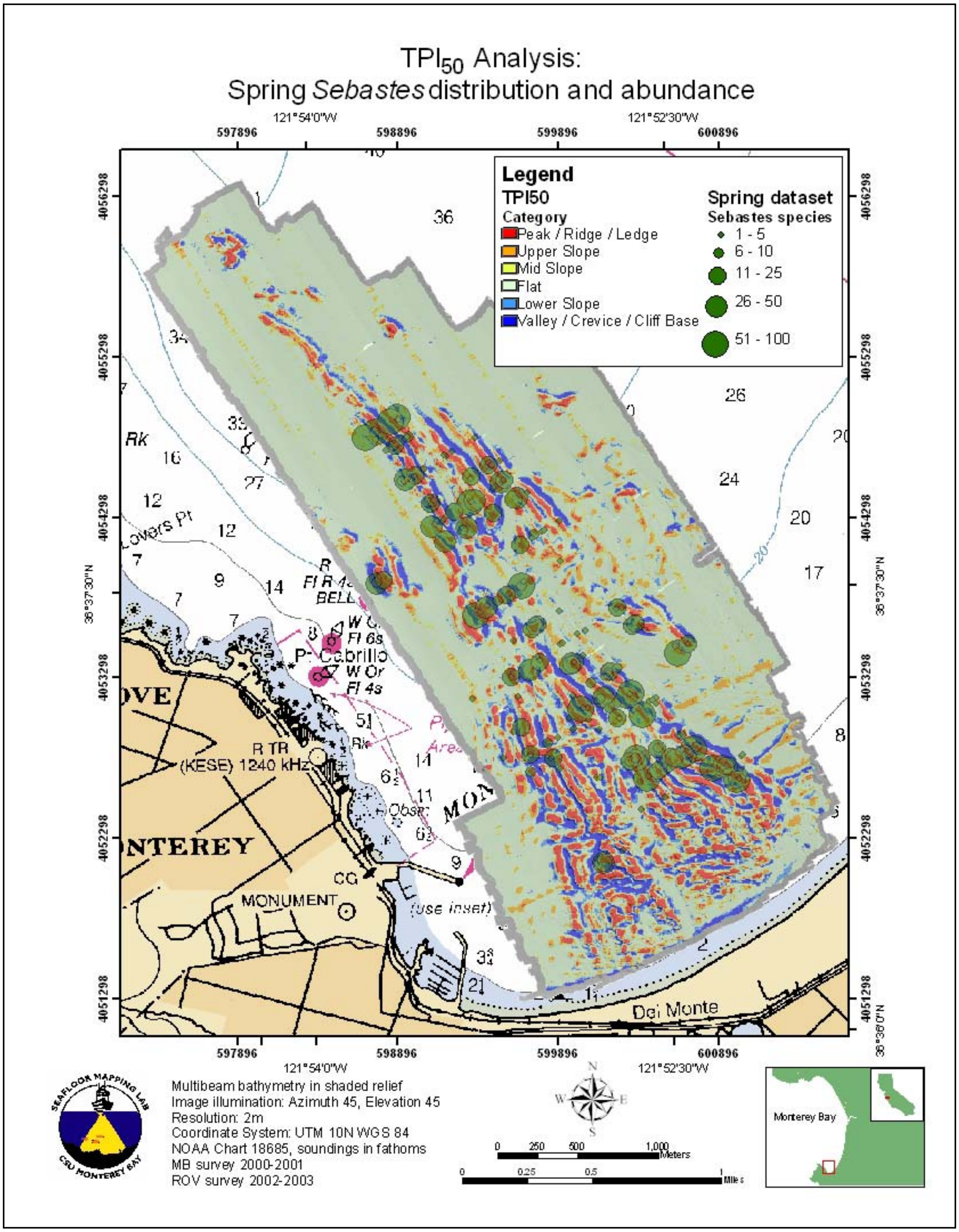


FIGURE 9. TPI_{50} analysis of multibeam survey area with distribution and abundance of rockfish observed during Spring 2003 ROV survey. TPI_{50} classes derived from bathymetry DEM. Symbol size for fish data is proportional to number of rockfish observed, and grid color indicates TPI_{50} class. Note 50 meter buffered area around extent of multibeam survey area has been eliminated from TPI analysis due to edge and artifact noise.

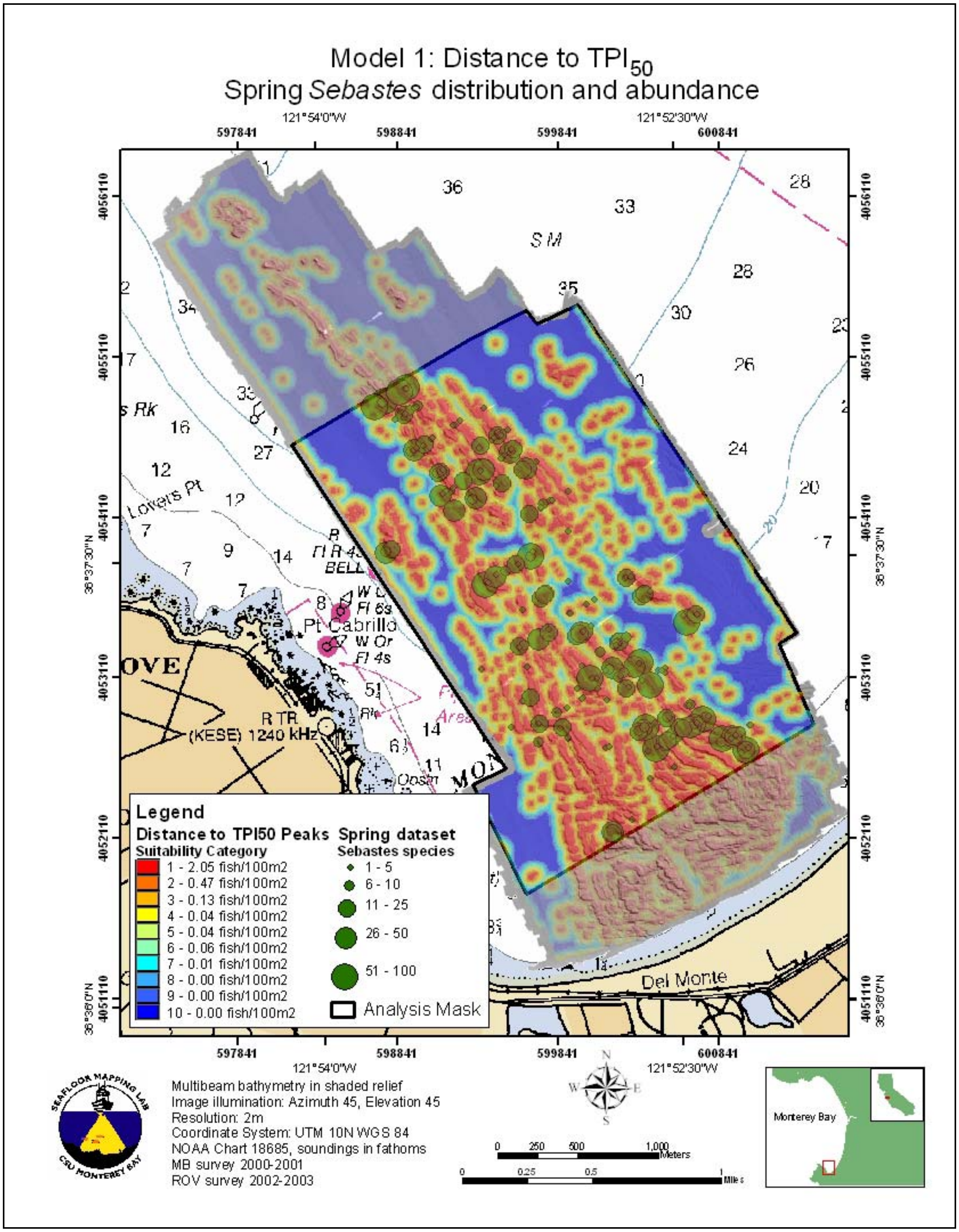


FIGURE 10. Model 1: Distance to TPI$_{50}$ Peaks. Displays distribution and abundance of rockfish for the spring dataset. Size of symbol is proportional to number of rockfish observed, and grid color indicates Model 1 habitat suitabilty. Note habitat suitability categories also display density of rockfish 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.

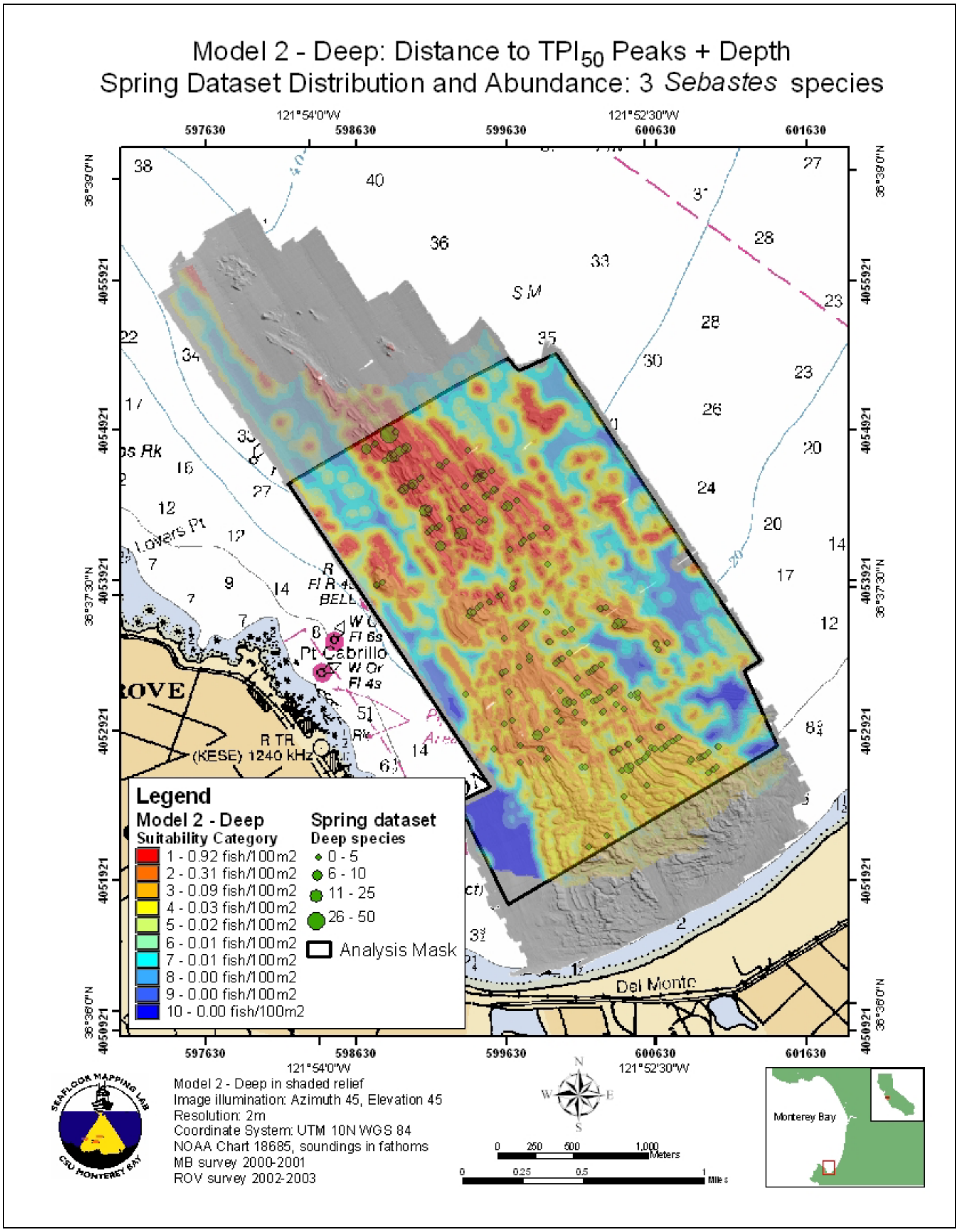


FIGURE 11. Model 2 – Deep: Distance to Preferred – TPI$_{50}$ Peaks + Depth. Displays distribution and abundance of three species in the spring dataset with preference for shallower water: *S. serranoides/ S. flavidus, S. rosaceus* and *S. rubrivinctus*. Size of symbol is proportional to number of rockfish observed, and grid color indicates Model 2 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.

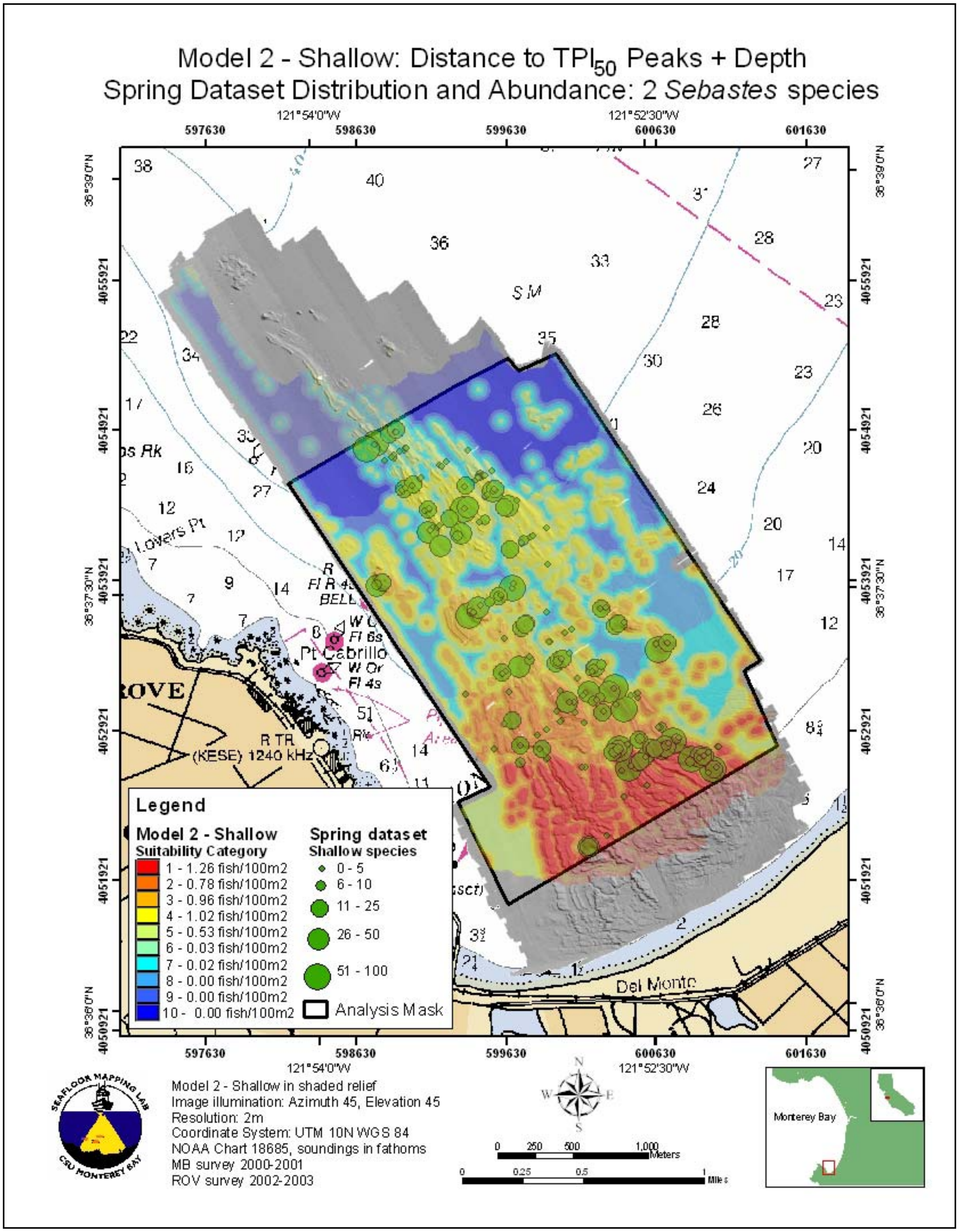


FIGURE 12. Model 2 – Shallow: Distance to Optimal – TPI_{50} Peaks + Depth. Displays distribution and abundance of two species in the spring dataset with preference for shallower water: *S. mystinus* and *S. miniatus*. Size of symbol is proportional to number of rockfish observed, and grid color indicates Model 2 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.

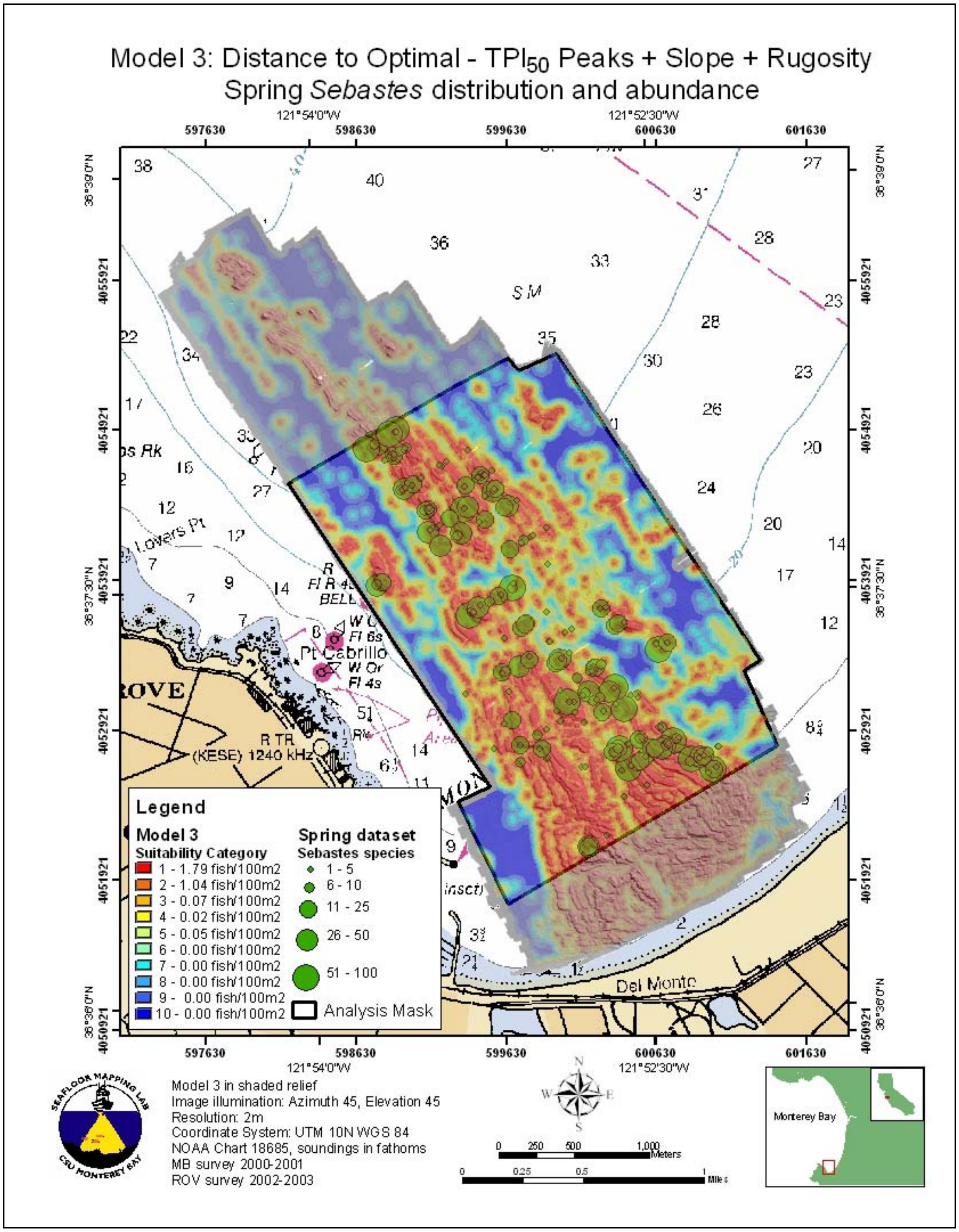


FIGURE 13. Model 3: Distance to Optimal – TPI$_{50}$ Peaks + Slope + Rugosity. Displays distribution and abundance of rockfish for the spring dataset. Size of symbol is proportional to number of rockfish observed, and grid color indicates Model 3 habitat suitabilty. Note habitat suitability categories 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.

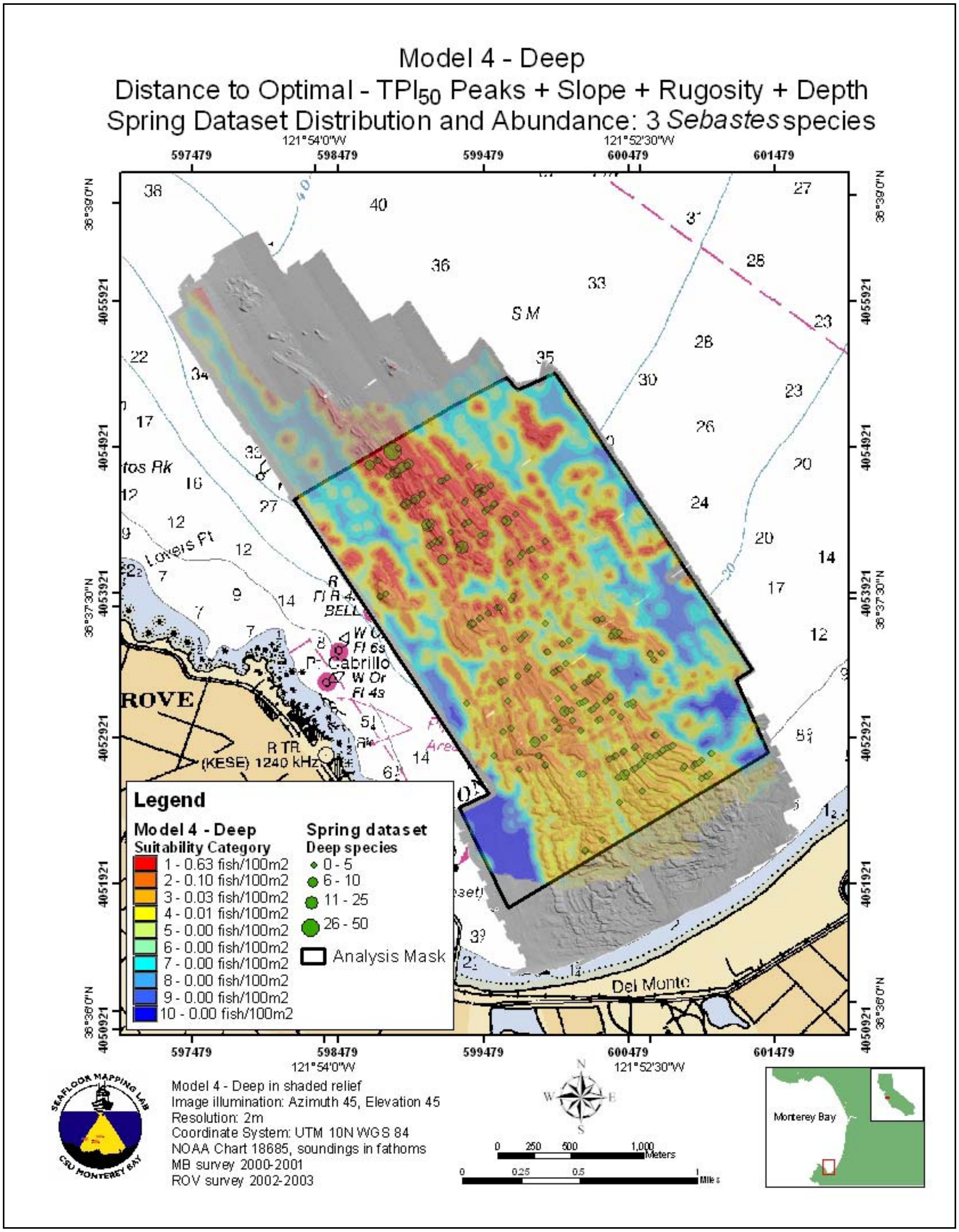


FIGURE 14. Model 4 – Deep: Distance to Optimal – TPI$_{50}$ Peaks + Slope + Rugosity + Depth. Displays distribution and abundance of three species in the spring dataset with preference for deeper water: *S. serranoides/S. flavidus, S. rosaceus,* and *S. rubrivinctus*. Size of symbol is proportional to number of rockfish observed, and grid color indicates Model 4 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.

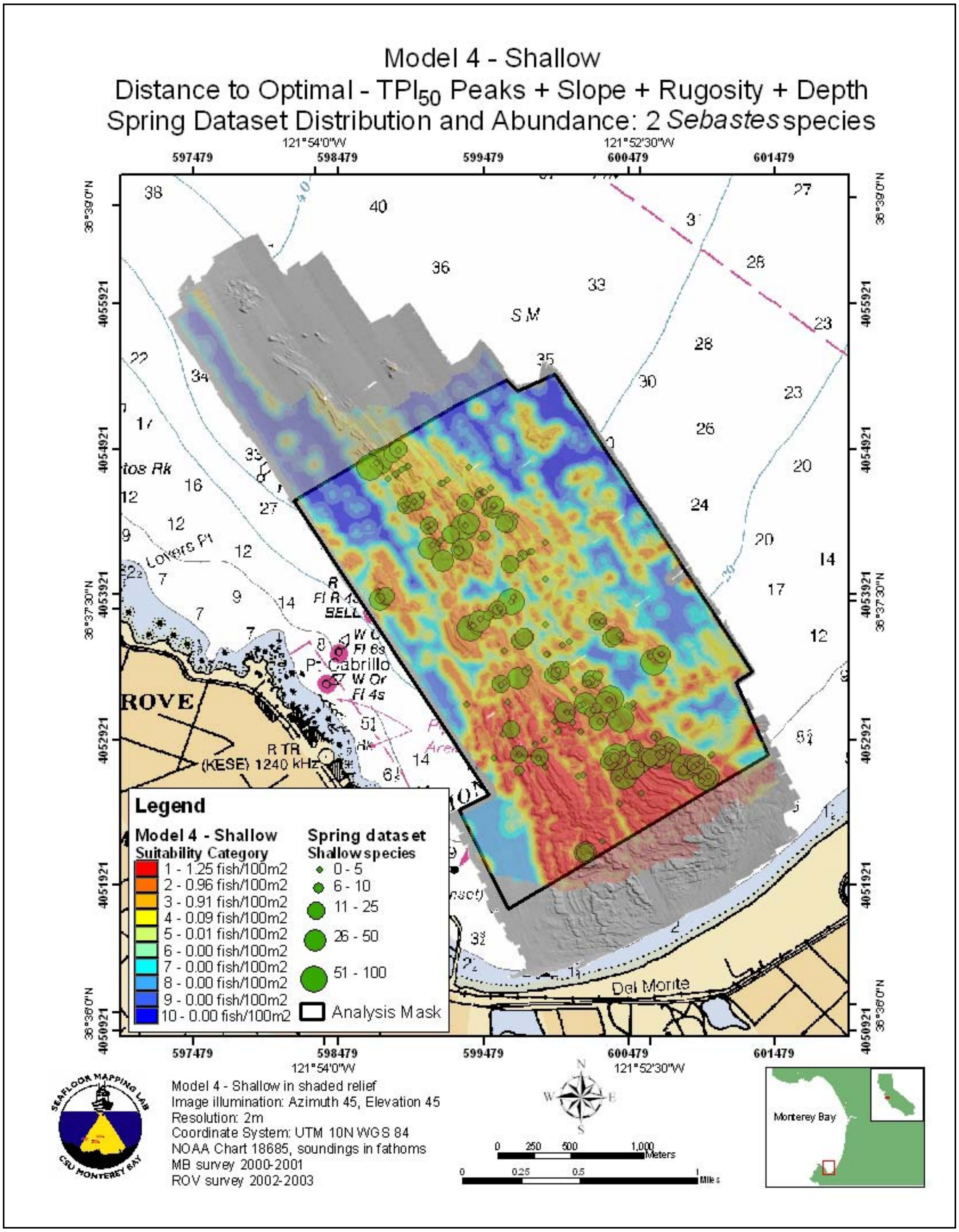
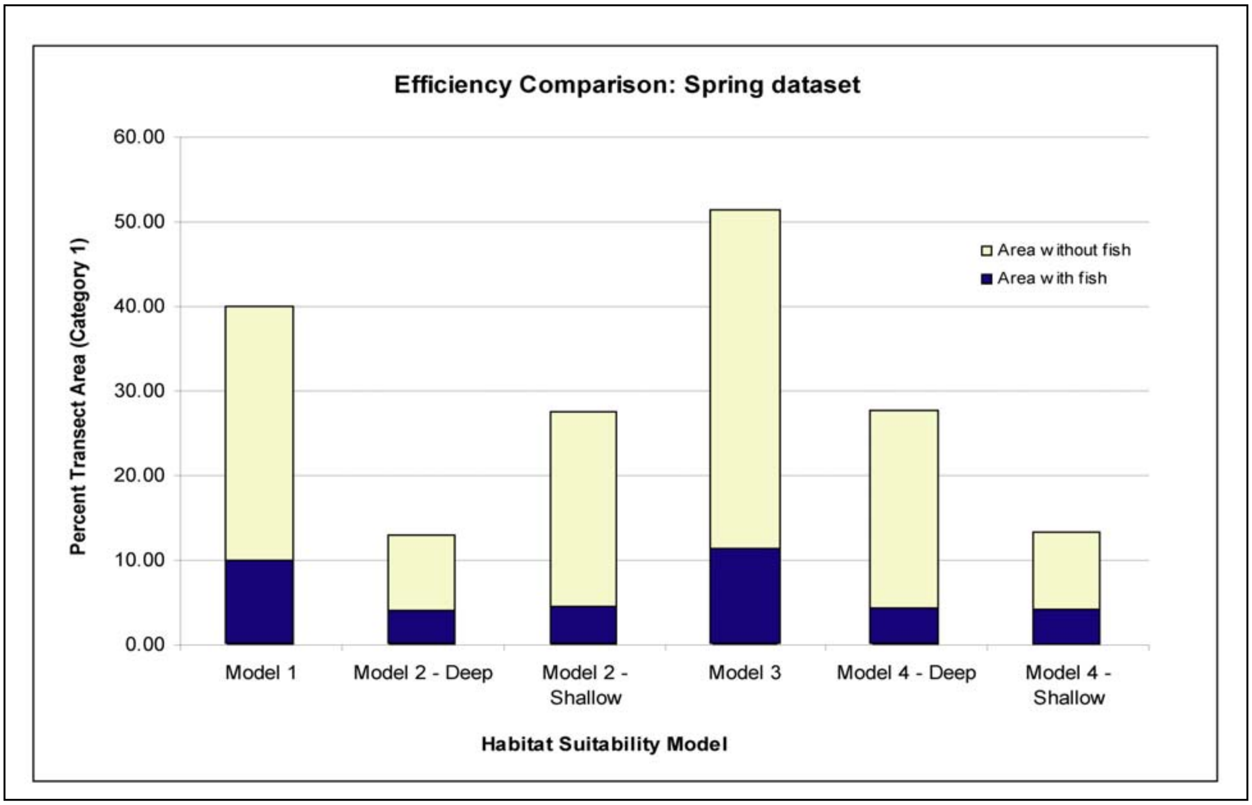


FIGURE 15. Model 4 – Shallow: Distance to Optimal – TPI$_{50}$ Peaks + Slope + Rugosity +Depth. Displays distribution and abundance of two species in the spring dataset with preference for shallower water: *S. mystinus* and *S. miniatus*. Size of symbol is proportional to number of rockfish observed, and grid color indicates Model 4 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.



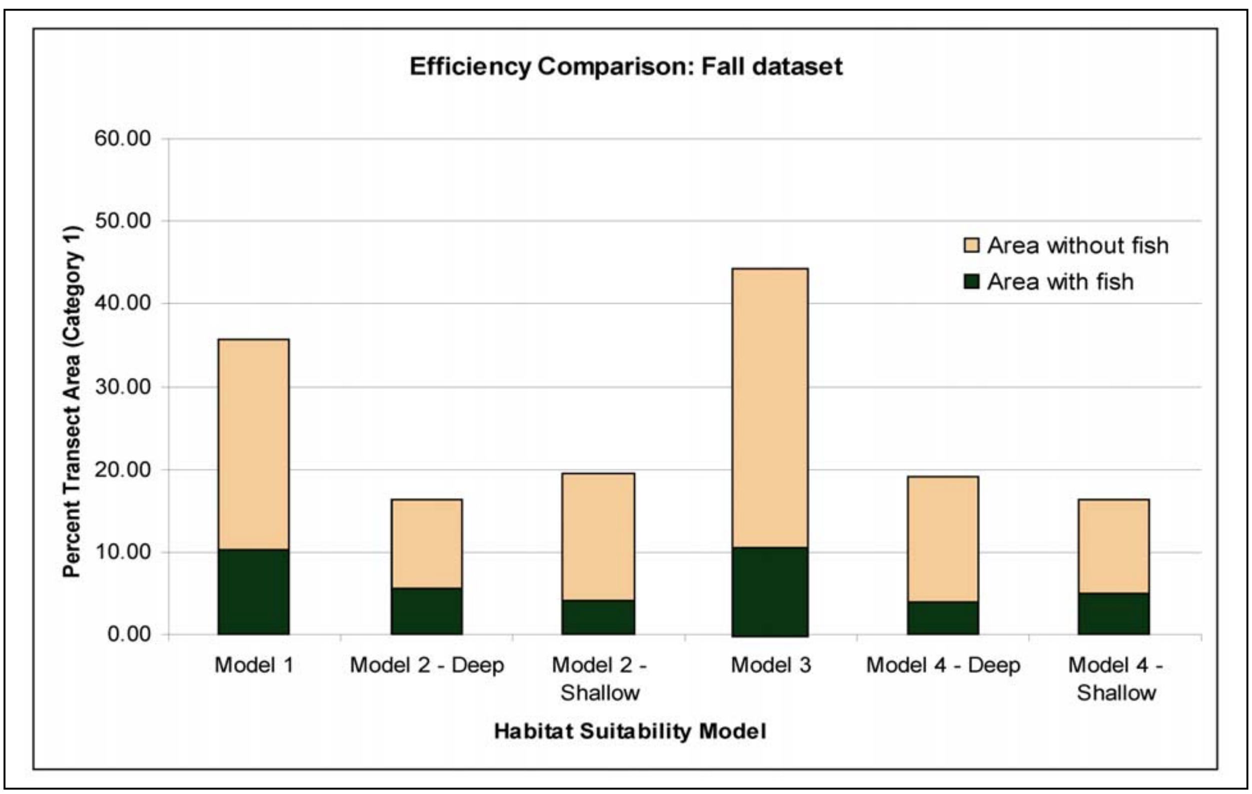


FIGURE 16. Efficiency comparison. Computes the amount of area with fish versus area without fish for transect area within category 1 for each model. Note the area with fish versus area without fish is proportional within the amount of transect area for category 1 for each model. Y-axes represent percent 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*		*Sebastes rosaceus*		*Sebastes rubrivinctus*	
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	6.25	6	18.75	0	0.00
1.12-2.61°	128676	1384	47.86	1014	45.23	224	70.00	76	50.00	20	58.82	12	26.67	20	41.67	11	34.38	7	36.84
2.61-4.86°	57052	592	20.47	489	21.81	28	8.75	28	18.42	3	8.82	13	28.89	14	29.17	10	31.25	7	36.84
4.86-8.97°	22396	337	11.65	256	11.42	24	7.50	24	15.79	7	20.59	5	11.11	11	22.92	5	15.63	5	26.32
8.97-31.9°	3812	14	0.48	11	0.49	1	0.31	1	0.66	0	0.00	1	2.22	0	0.00	0	0.00	0	0.00
total	309772	2892	100.00	2242	100	320	100	152	100	34	100	45	100	48	100	32	100	19	100
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	70.83	23	71.88	14	73.68
1.003-1.02	36996	482	16.67	366	16.32	44	13.75	28	18.42	8	23.53	8	17.78	14	29.17	9	28.13	5	26.32
1.02-1.22	1872	12	0.41	11	0.49	1	0.31	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
total	309308	2892	100.00	2242	100.00	320	100.00	152	100.00	34	100.00	45	100.00	48	100.00	32	100.00	19	100.00
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	39.58	16	50.00	9	47.37
upper slope	39096	475	16.42	344	15.34	64	20.00	41	26.97	4	11.76	9	20.00	6	12.50	6	18.75	1	5.26
mid slope	5964	130	4.50	96	4.28	9	2.81	11	7.24	2	5.88	0	0.00	11	22.92	0	0.00	1	5.26
flat	138576	872	30.15	729	32.52	57	17.81	43	28.29	10	29.41	11	24.44	8	16.67	7	21.88	7	36.84
lower slope	21828	128	4.43	103	4.59	15	4.69	2	1.32	1	2.94	3	6.67	3	6.25	1	3.13	0	0.00
valley	48568	149	5.15	96	4.28	21	6.56	18	11.84	0	0.00	10	22.22	1	2.08	2	6.25	1	5.26
total	309772	2892	100	2242	100	320	100	152	100	34	100	45	100	48	100	32	100	19	100
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	2.08	0	0.00	0	0.00
25-35	81472	556	19.23	460	20.52	18	5.63	46	30.26	6	17.65	19	42.22	4	8.33	3	9.38	0	0.00
35-45	69072	575	19.88	472	21.05	23	7.19	20	13.16	15	44.12	10	22.22	24	50.00	10	31.25	1	5.26
45-55	56612	712	24.62	521	23.24	112	35.00	23	15.13	11	32.35	8	17.78	18	37.50	11	34.38	8	42.11
55-65	30424	362	12.52	173	7.72	148	46.25	20	13.16	2	5.88	0	0.00	1	2.08	8	25.00	10	52.63
total	309772	2892	100	2242	100	320	100	152	100	34	100	45	100	48	100	32	100	19	100

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*		*Sebastes pinniger*		*Sebastes rosaceus*		*Seba rubrivi*
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	39	81.25	23	71.88	17
2	687	23.76	540	24.09	79	24.69	35	23.03	11	32.35	6	13.33	6	12.50	9	28.13	1
3	59	2.04	39	1.74	11	3.44	7	4.61	0	0.00	2	4.44	0	0.00	0	0.00	0
4	35	1.21	30	1.34	0	0.00	3	1.97	0	0.00	1	2.22	0	0.00	0	0.00	1
5	11	0.38	6	0.27	0	0.00	0	0.00	2	5.88	0	0.00	3	6.25	0	0.00	0
6	6	0.21	1	0.04	0	0.00	1	0.66	0	0.00	4	8.89	0	0.00	0	0.00	0
7-10	3	0.10	0	0.00	3	0.94	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
total	2892	100	2242	100	320	100	152	100	34	100	45	100	48	100	32	100	19
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	42	87.50	27	84.38	17
2	589	20.37	459	20.47	89	27.81	19	12.50	5	14.71	5	11.11	5	10.42	5	15.63	2
3	16	0.55	9	0.40	0	0.00	3	1.97	0	0.00	4	8.89	0	0.00	0	0.00	0
4	9	0.31	1	0.04	3	0.94	2	1.32	2	5.88	0	0.00	1	2.08	0	0.00	0
5	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
6	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
7-10	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
total	2892	100	2242	100	320	100	152	100	34	100	45	100	48	100	32	100	19
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	40	83.33	25	78.13	15
2	288	9.96	222	9.90	17	5.31	18	11.84	5	14.71	12	26.67	5	10.42	7	21.88	2
3	57	1.97	33	1.47	14	4.38	5	3.29	0	0.00	2	4.44	2	4.17	0	0.00	1
4	11	0.38	6	0.27	4	1.25	1	0.66	0	0.00	0	0.00	0	0.00	0	0.00	0
5	5	0.17	1	0.04	0	0.00	1	0.66	0	0.00	2	4.44	0	0.00	0	0.00	1
6	6	0.21	1	0.04	0	0.00	2	1.32	2	5.88	0	0.00	1	2.08	0	0.00	0
7-10	1	0.03	0	0.00	0	0.00	0	0.00	0	0.00	1	2.22	0	0.00	0	0.00	0
total	2892	100	2242	100	320	100	152	100	34	100	45	100	48	100	32	100	19

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 1	2	3	4	5	6	7-10
Deep							
S. serranoides/ S. flavidus	69.38	22.19	6.25	2.19	0.00	0.00	0.00
S. rosaceus	50.00	46.88	3.13	0.00	0.00	0.00	0.00
S. rubrivinctus	84.21	10.53	5.26	0.00	0.00	0.00	0.00
Shallow							
S. mystinus	43.89	37.15	17.84	1.07	0.04	0.00	0.00
S. miniatus	49.34	31.58	15.79	3.29	0.00	0.00	0.00

FALL

Model 1: Distance to TPI50 Peaks - % fish

	category 1	2	3	4	5	6	7-10
S. mystinus	***89.11***	6.60	4.29	0.00	0.00	0.00	0.00
S. serranoides/ S. flavidus	***100.00***	0.00	0.00	0.00	0.00	0.00	0.00
S. miniatus	***39.47***	39.47	13.16	2.63	0.00	0.00	5.26
S. auriculatus	***77.78***	22.22	0.00	0.00	0.00	0.00	0.00
S. carnatus	50.00	0.00	50.00	0.00	0.00	0.00	0.00
S. pinniger	7.69	46.15	0.00	0.00	46.15	0.00	0.00
S. rosaceus	66.67	16.67	0.00	16.67	0.00	0.00	0.00
S. rubrivinctus	57.14	42.86	0.00	0.00	0.00	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	0.00	91.49	0.00	8.51	0.00	0.00	0.00
S. rosaceus	16.67	66.67	16.67	0.00	0.00	0.00	0.00
S. rubrivinctus	57.14	42.86	0.00	0.00	0.00	0.00	0.00
Shallow							
S. mystinus	3.30	48.84	8.09	30.03	9.24	0.50	0.00
S. miniatus	5.26	18.42	7.89	52.63	10.53	0.00	5.26

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

	category 1	2	3	4	5	6	7-10
S. mystinus	76.40	23.60	0.00	0.00	0.00	0.00	0.00
S. serranoides/ S. flavidus	97.87	2.13	0.00	0.00	0.00	0.00	0.00
S. miniatus	31.58	34.21	28.95	0.00	0.00	0.00	5.26
S. auriculatus	55.56	22.22	22.22	0.00	0.00	0.00	0.00
S. carnatus	***50.00***	25.00	25.00	0.00	0.00	0.00	0.00
S. pinniger	***7.69***	92.31	0.00	0.00	0.00	0.00	0.00
S. rosaceus	66.67	0.00	33.33	0.00	0.00	0.00	0.00
S. rubrivinctus	***71.43***	28.57	0.00	0.00	0.00	0.00	0.00

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

	category 1	2	3	4	5	6	7-10
Deep							
S. serranoides/ S. flavidus	89.36	10.64	0.00	0.00	0.00	0.00	0.00
S. rosaceus	***66.67***	16.67	16.67	0.00	0.00	0.00	0.00
S. rubrivinctus	71.43	28.57	0.00	0.00	0.00	0.00	0.00
Shallow							
S. mystinus	33.66	55.78	10.56	0.00	0.00	0.00	0.00
S. miniatus	13.16	23.68	39.47	18.42	0.00	0.00	5.26

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

FALL

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

	category 1	2	3	4	5	6	7-10
S. mystinus	1.8942	0.2492	0.2182	0.0000	0.0000	0.0000	0.0000
S. serranoides/ S. flavidus	0.1649	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S. miniatus	0.0526	0.0934	0.0420	0.0131	0.0000	0.0000	0.0693
S. auriculatus	0.0246	0.0125	0.0000	0.0000	0.0000	0.0000	0.0000
S. carnatus	0.0070	0.0000	0.0168	0.0000	0.0000	0.0000	0.0000
S. pinniger	0.0035	0.0374	0.0000	0.0000	0.1408	0.0000	0.0000
S. rosaceus	0.0140	0.0062	0.0000	0.0131	0.0000	0.0000	0.0000
S. rubrivinctus	0.0140	0.0187	0.0000	0.0000	0.0000	0.0000	0.0000

SPRING

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

FALL

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	0.0000	0.3081	0.0000	0.0179	0.0000	0.0000	0.0000
S. rosaceus	0.0177	0.0287	0.0079	0.0000	0.0000	0.0000	0.0000
S. rubrivinctus	0.0710	0.0215	0.0000	0.0000	0.0000	0.0000	0.0000
Shallow							
S. mystinus	0.3805	1.7379	0.4119	1.0569	0.4518	0.0586	0.0000
S. miniatus	0.0381	0.0411	0.0252	0.1161	0.0323	0.0000	0.0566

SPRING

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

FALL

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

	category 1	2	3	4	5	6	7-10
S. mystinus	1.6003	0.7904	0.0000	0.0000	0.0000	0.0000	0.0000
S. serranoides/ S. flavidus	0.1590	0.0055	0.0000	0.0000	0.0000	0.0000	0.0000
S. miniatus	0.0415	0.0719	0.0920	0.0000	0.0000	0.0000	0.2604
S. auriculatus	0.0173	0.0111	0.0167	0.0000	0.0000	0.0000	0.0000
S. carnatus	0.0069	0.0055	0.0084	0.0000	0.0000	0.0000	0.0000
S. pinniger	0.0035	0.0663	0.0000	0.0000	0.0000	0.0000	0.0000
S. rosaceus	0.0138	0.0000	0.0167	0.0000	0.0000	0.0000	0.0000
S. rubrivinctus	0.0173	0.0111	0.0000	0.0000	0.0000	0.0000	0.0000

SPRING

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 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	0.3288	0.0204	0.0000	0.0000	0.0000	0.0000	0.0000
S. rosaceus	0.0313	0.0041	0.0061	0.0000	0.0000	0.0000	0.0000
S. rubrivinctus	0.0391	0.0082	0.0000	0.0000	0.0000	0.0000	0.0000
Shallow							
S. mystinus	1.3499	1.7123	0.3822	0.0000	0.0000	0.0000	0.0000
S. miniatus	0.0331	0.0456	0.0896	0.0588	0.0000	0.0000	0.0752

TABLE 6. Efficiency table calculations. These values were used to generate Figure 16. 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

	TPI Category						
Video Analysis: Substrate 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

PERCENT OF FISH OBSERVATIONS

	TPI Category					
Video Analysis: Substrate Category	valley	lower slope	flat	mid slope	upper slope	peak
	TPI_{10}: PERCENT OF FISH OBSERVATIONS					
boulders	20.0	N/A	40.0	0.0	N/A	40.0
ledges	15.9	N/A	52.2	8.7	N/A	23.2
outcrop	0.0	N/A	7.7	0.0	N/A	92.3
rubble	5.0	N/A	71.7	0.0	N/A	23.3
sand	0.0	N/A	61.5	0.0	N/A	38.5
small ledges	7.5	N/A	55.9	4.3	N/A	32.3
no relief	0.0	N/A	33.3	0.0	N/A	66.7
low relief	5.3	N/A	58.5	2.3	N/A	33.9
high relief	16.5	N/A	51.9	7.6	N/A	24.1
	TPI_{20}: PERCENT OF FISH OBSERVATIONS					
boulders	20.0	20.0	0.0	20.0	20.0	20.0
ledges	20.3	15.9	24.6	5.8	10.1	23.2
outcrop	0.0	0.0	7.7	0.0	7.7	84.6
rubble	5.0	15.0	45.0	0.0	10.0	25.0
sand	0.0	0.0	38.5	0.0	23.1	38.5
small ledges	4.3	5.4	35.5	2.2	15.1	37.6
no relief	0.0	0.0	0.0	0.0	0.0	100.0
low relief	4.1	7.0	11.7	1.2	14.0	36.8
high relief	19.0	17.7	25.3	6.3	10.1	21.5
	TPI_{30}: PERCENT OF FISH OBSERVATIONS					
boulders	20.0	20.0	0.0	20.0	0.0	40.0
ledges	20.3	13.0	27.5	5.8	5.8	27.5
outcrop	0.0	0.0	7.7	0.0	15.4	76.9
rubble	18.3	10.0	31.7	1.7	11.7	26.7
sand	0.0	0.0	38.5	0.0	30.8	30.8
small ledges	8.6	8.6	28.0	4.3	7.5	43.0
no relief	0.0	0.0	33.3	0.0	33.3	33.3
low relief	10.5	8.2	12.3	2.9	9.9	40.4
high relief	20.8	13.0	27.3	6.5	5.2	27.3

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.

	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 Category					
Video Analysis: Substrate Category	valley	lower slope	flat	mid slope	upper slope	peak
TPI_{40}: PERCENT OF FISH OBSERVATIONS						
boulders	40.0	0.0	0.0	20.0	0.0	40.0
ledges	14.5	13.0	23.2	5.8	10.1	33.3
outcrop	0.0	0.0	7.7	0.0	0.0	92.3
rubble	18.3	5.0	35.0	0.0	6.7	35.0
sand	0.0	0.0	38.5	0.0	15.4	46.2
small ledges	3.2	16.1	17.2	4.3	10.8	48.4
no relief	0.0	0.0	33.3	0.0	33.3	33.3
low relief	7.6	10.5	11.1	2.3	9.4	47.4
high relief	16.5	11.4	24.1	6.3	7.6	34.2
TPI_{50}: PERCENT OF FISH OBSERVATIONS						
boulders	40.0	0.0	0.0	0.0	0.0	60.0
ledges	11.6	7.2	30.4	4.3	10.1	36.2
outcrop	0.0	0.0	7.7	0.0	7.7	84.6
rubble	16.7	3.3	30.0	0.0	21.7	28.3
sand	0.0	0.0	38.5	0.0	38.5	23.1
small ledges	5.4	5.4	26.9	4.3	12.9	45.2
no relief	0.0	0.0	0.0	0.0	100.0	0.0
low relief	8.2	4.1	13.5	2.3	15.8	42.1
high relief	13.9	6.3	29.1	3.8	10.1	36.7
TPI_{60}: PERCENT OF FISH OBSERVATIONS						
boulders	40.0	0.0	0.0	0.0	20.0	40.0
ledges	13.0	5.8	31.9	4.3	8.7	36.2
outcrop	0.0	0.0	15.4	0.0	0.0	84.6
rubble	16.7	0.0	40.0	3.3	13.3	26.7
sand	0.0	7.7	53.8	0.0	15.4	23.1
small ledges	7.5	5.4	31.2	4.3	6.5	45.2
no relief	0.0	0.0	100.0	0.0	0.0	0.0
low relief	9.4	3.5	14.6	3.5	9.4	41.5
high relief	15.2	5.1	31.6	3.8	8.9	35.4

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 OF FISH OBSERVATIONS

	TPI Category					
Video Analysis: Substrate Category	valley	lower slope	flat	mid slope	upper slope	peak
TPI_{40}: PERCENT OF FISH OBSERVATIONS						
boulders	40.0	0.0	0.0	20.0	0.0	40.0
ledges	14.5	13.0	23.2	5.8	10.1	33.3
outcrop	0.0	0.0	7.7	0.0	0.0	92.3
rubble	18.3	5.0	35.0	0.0	6.7	35.0
sand	0.0	0.0	38.5	0.0	15.4	46.2
small ledges	3.2	16.1	17.2	4.3	10.8	48.4
no relief	0.0	0.0	33.3	0.0	33.3	33.3
low relief	7.6	10.5	11.1	2.3	9.4	47.4
high relief	16.5	11.4	24.1	6.3	7.6	34.2
TPI_{50}: PERCENT OF FISH OBSERVATIONS						
boulders	40.0	0.0	0.0	0.0	0.0	60.0
ledges	11.6	7.2	30.4	4.3	10.1	36.2
outcrop	0.0	0.0	7.7	0.0	7.7	84.6
rubble	16.7	3.3	30.0	0.0	21.7	28.3
sand	0.0	0.0	38.5	0.0	38.5	23.1
small ledges	5.4	5.4	26.9	4.3	12.9	45.2
no relief	0.0	0.0	0.0	0.0	100.0	0.0
low relief	8.2	4.1	13.5	2.3	15.8	42.1
high relief	13.9	6.3	29.1	3.8	10.1	36.7
TPI_{60}: PERCENT OF FISH OBSERVATIONS						
boulders	40.0	0.0	0.0	0.0	20.0	40.0
ledges	13.0	5.8	31.9	4.3	8.7	36.2
outcrop	0.0	0.0	15.4	0.0	0.0	84.6
rubble	16.7	0.0	40.0	3.3	13.3	26.7
sand	0.0	7.7	53.8	0.0	15.4	23.1
small ledges	7.5	5.4	31.2	4.3	6.5	45.2
no relief	0.0	0.0	100.0	0.0	0.0	0.0
low relief	9.4	3.5	14.6	3.5	9.4	41.5
high relief	15.2	5.1	31.6	3.8	8.9	35.4

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

Video Analysis: Substrate Category	TPI 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

PERCENT OF FISH OBSERVATIONS

Video Analysis: Substrate Category	TPI Category: valley	lower slope	flat	mid slope	upper slope	peak
TPI_{80}: PERCENT OF FISH OBSERVATIONS						
boulders	20.0	20.0	0.0	0.0	0.0	60.0
ledges	10.1	7.2	17.4	4.3	18.8	42.0
outcrop	0.0	7.7	0.0	0.0	7.7	84.6
rubble	15.0	6.7	30.0	5.0	15.0	28.3
sand	7.7	15.4	30.8	0.0	23.1	23.1
small ledges	5.4	7.5	22.6	2.2	12.9	49.5
no relief	0.0	0.0	0.0	0.0	100.0	0.0
low relief	8.1	8.1	8.1	2.9	12.8	44.2
high relief	11.4	7.6	17.7	3.8	17.7	41.8
TPI_{100}: PERCENT OF FISH OBSERVATIONS						
boulders	0.0	20.0	0.0	20.0	0.0	60.0
ledges	11.6	4.3	18.8	4.3	20.3	40.6
outcrop	0.0	7.7	7.7	0.0	7.7	76.9
rubble	10.0	11.7	35.0	3.3	15.0	25.0
sand	7.7	23.1	30.8	0.0	7.7	30.8
small ledges	3.2	10.8	23.7	2.2	10.8	49.5
no relief	0.0	33.3	33.3	0.0	0.0	33.3
low relief	5.3	11.7	8.8	2.3	12.3	42.1
high relief	11.4	5.1	19.0	5.1	17.7	41.8
TPI_{120}: PERCENT OF FISH OBSERVATIONS						
boulders	20.0	0.0	20.0	0.0	0.0	60.0
ledges	8.7	7.2	20.3	5.8	24.6	33.3
outcrop	0.0	0.0	15.4	0.0	7.7	76.9
rubble	10.0	3.3	36.7	3.3	18.3	28.3
sand	7.7	0.0	53.8	0.0	7.7	30.8
small ledges	3.2	7.5	29.0	1.1	15.1	44.1
no relief	0.0	0.0	66.7	0.0	0.0	33.3
low relief	5.3	5.3	9.9	1.8	15.8	40.4
high relief	10.1	6.3	21.5	5.1	21.5	35.4

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_{150}: NUMBER OF FISH OBSERVATIONS							
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

PERCENT OF FISH OBSERVATIONS

	TPI Category					
Video Analysis: Substrate Category	valley	lower slope	flat	mid slope	upper slope	peak
TPI_{150}: PERCENT OF FISH OBSERVATIONS						
boulders	20.0	0.0	0.0	0.0	0.0	80.0
ledges	4.3	10.1	33.3	5.8	10.1	36.2
outcrop	0.0	0.0	15.4	7.7	0.0	76.9
rubble	8.3	10.0	41.7	3.3	10.0	26.7
sand	7.7	15.4	46.2	0.0	7.7	23.1
small ledges	4.3	7.5	35.5	1.1	14.0	37.6
no relief	0.0	0.0	50.0	0.0	0.0	50.0
low relief	5.2	8.7	15.1	2.3	11.6	36.0
high relief	6.3	8.9	32.9	5.1	8.9	38.0

APPENDIX 2. **Proportion table for adjusted stock estimates. Calculation of proportion value used the formula for each category: (area with fish/transect area). Proportion values were used for calculating adjusted stock estimates by multiplying the original stock assessment by the proportion value.**

	SPRING				FALL			
MODEL 1	Area with fish	Area without fish	transect area	proportion values	Area with fish	Area without fish	transect area	proportion values
Category 1	30232	92892	123124	0.10	8052	20112	28164	0.10
Category 2	8800	52296	61096	0.03	1620	14260	15880	0.02
Category 3	3196	40172	43368	0.01	944	10824	11768	0.01
Category 4	648	24932	25580	0.00	300	7292	7592	0.00
Category 5	792	13248	14040	0.00	136	4096	4232	0.00
Category 6	380	9028	9408	0.00	0	3208	3208	0.00
Category 7	72	8368	8440	0.00	0	2596	2596	0.00
Category 8	148	6416	6564	0.00	0	1448	1448	0.00
Category 9	0	3976	3976	0.00	16	948	964	0.00
Category 10	0	11908	11908	0.00	224	2684	2908	0.00
MODEL 2 - DEEP								
Category 1	12184	27916	40100	0.04	4340	8460	12800	0.06
Category 2	9824	26824	36648	0.03	1444	8116	9560	0.02
Category 3	9080	46012	55092	0.03	3600	13500	17100	0.05
Category 4	8936	59900	68836	0.03	1016	12224	13240	0.01
Category 5	2196	35316	37512	0.01	500	8720	9220	0.01
Category 6	1064	22564	23628	0.00	148	5708	5856	0.00
Category 7	836	21108	21944	0.00	4	5764	5768	0.00
Category 8	148	6008	6156	0.00	0	1248	1248	0.00
Category 9	0	14376	14376	0.00	240	2888	3128	0.00
Category 10	0	3152	3152	0.00	0	836	836	0.00
MODEL 2 - SHALLOW								
Category 1	13524	70944	84468	0.04	3228	12232	15460	0.04
Category 2	9992	38964	48956	0.03	1244	8724	9968	0.02
Category 3	10160	40004	50164	0.03	3532	10348	13880	0.04
Category 4	6172	29620	35792	0.02	2088	10704	12792	0.03
Category 5	2688	23172	25860	0.01	676	7292	7968	0.01
Category 6	928	16548	17476	0.00	152	4720	4872	0.00
Category 7	652	19808	20460	0.00	132	7160	7292	0.00
Category 8	152	13448	13600	0.00	16	4248	4264	0.00
Category 9	0	10668	10668	0.00	224	2036	2260	0.00
Category 10	0	0	0	0.00	0.00	0	0	0.00

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

	SPRING				FALL			
MODEL 3	Area with fish	Area without fish	transect area	proportion values	Area with fish	Area without fish	transect area	proportion values
Category 1	34740	123472	158212	0.11	8420	26488	34908	0.11
Category 2	6144	53244	59388	0.02	1720	13620	15340	0.02
Category 3	2420	29752	32172	0.01	816	9988	10804	0.01
Category 4	512	12584	13096	0.00	96	4840	4936	0.00
Category 5	452	11252	11704	0.00	0	4536	4536	0.00
Category 6	0	8808	8808	0.00	0	2948	2948	0.00
Category 7	0	3964	3964	0.00	0	1020	1020	0.00
Category 8	0	7780	7780	0.00	128	1364	1492	0.00
Category 9	0	7564	7564	0.00	112	984	1096	0.00
Category 10	0	4816	4816	0.00	0	1680	1680	0.00
MODEL 4 - DEEP								
Category 1	12724	72284	85008	0.04	3052	12092	15144	0.04
Category 2	20300	72284	92584	0.07	4092	15764	19856	0.05
Category 3	7884	38644	46528	0.03	3100	13552	16652	0.04
Category 4	2624	29432	32056	0.01	808	11044	11852	0.01
Category 5	728	19172	19900	0.00	0	7140	7140	0.00
Category 6	8	10152	10160	0.00	0	3404	3404	0.00
Category 7	0	9784	9784	0.00	128	2520	2648	0.00
Category 8	0	7916	7916	0.00	112	480	592	0.00
Category 9	0	3388	3388	0.00	0	1472	1472	0.00
Category 10	0	180	180	0.00	0.00	0	0	0.00
MODEL 4 - SHALLOW								
Category 1	12484	27876	40360	0.04	3872	8928	12800	0.05
Category 2	17712	72432	90144	0.06	5172	19356	24528	0.07
Category 3	9336	68868	78204	0.03	1452	14904	16356	0.02
Category 4	3912	43768	47680	0.01	460	11212	11672	0.01
Category 5	824	19240	20064	0.00	96	6408	6504	0.00
Category 6	0	7816	7816	0.00	0	2072	2072	0.00
Category 7	0	7280	7280	0.00	128	684	812	0.00
Category 8	0	8824	8824	0.00	112	1344	1456	0.00
Category 9	0	5072	5072	0.00	0	2520	2520	0.00
Category 10	0	2060	2060	0.00	0	40	40	0.00

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/transect area)*total transect area]*proportion value

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	3622	96	10	1	0	0	0
S. serranoides /S. flavidus	522	7	4	0	0	0	0
S. miniatus	229	8	1	0	0	0	0
S. auriculatus	49	2	0	0	0	0	0
S. carnatus	51	5	1	0	0	0	0
S. pinniger	73	2	1	0	0	0	0
S. rosaceus	46	3	0	0	0	0	0
S. rubrivinctus	27	1	0	0	0	0	0

Model 2 - Stock Estimate [(# species/transect area)*total transect area]*proportion value

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
Deep							
S. serranoides /S. flavidus	0	53	0	3	0	0	0
S. rosaceus	5	5	4	0	0	0	0
S. rubrivinctus	18	4	0	0	0	0	0
Shallow							
S. mystinus	124	194	133	288	112	0	0
S. miniatus	12	5	8	32	3	0	1

Model 3 - Stock Estimate [(# species/transect area)*total transect area]*proportion value

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	3298	233	3	0	0	0	0
S. serranoides /S. flavidus	436	38	2	0	0	0	0
S. miniatus	237	9	2	0	0	0	0
S. auriculatus	48	3	0	0	0	0	0
S. carnatus	59	4	1	0	0	0	0
S. pinniger	75	3	1	0	0	0	0
S. rosaceus	5	1	0	0	0	0	0
S. rubrivinctus	33	0	0	0	0	0	0

Model 4 - Stock Estimate [(# species/transect area)*total transect area]*proportion value

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
Deep							
S. serranoides /S. flavidus	82	12	0	0	0	0	0
S. rosaceus	8	2	3	0	0	0	0
S. rubrivinctus	10	5	0	0	0	0	0
Shallow							
S. mystinus	726	1265	58	0	0	0	0
S. miniatus	18	34	14	3	0	0	1

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.

FALL - ORIGINAL

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

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	8288	766	585	0	0	0	0
S. serranoides /S. flavidus	721	0	0	0	0	0	0
S. miniatus	230	287	113	30	0	0	110
S. auriculatus	107	38	0	0	0	0	0
S. carnatus	31	0	45	0	0	0	0
S. pinniger	15	115	0	0	262	0	0
S. rosaceus	61	19	0	30	0	0	0
S. rubrivinctus	61	57	0	0	0	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	0	684	0	64	0	0	0
S. rosaceus	16	64	13	0	0	0	0
S. rubrivinctus	65	48	0	0	0	0	0
Shallow							
S. mystinus	248	3517	714	3635	1236	84	0
S. miniatus	25	83	44	399	88	0	78

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

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	7446	2779	0	0	0	0	0
S. serranoides /S. flavidus	740	19	0	0	0	0	0
S. miniatus	193	253	284	0	0	0	201
S. auriculatus	80	39	52	0	0	0	0
S. carnatus	32	19	26	0	0	0	0
S. pinniger	16	233	0	0	0	0	0
S. rosaceus	64	0	52	0	0	0	0
S. rubrivinctus	80	39	0	0	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	541	61	0	0	0	0	0
S. rosaceus	51	12	18	0	0	0	0
S. rubrivinctus	64	24	0	0	0	0	0
Shallow							
S. mystinus	3234	4183	1052	0	0	0	0
S. miniatus	79	111	247	160	0	0	222

FALL - ADJUSTED

Model 1 - Stock Estimate [(# species/transect area)*total transect area]*proportion value

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	3622	96	10	1	0	0	0
S. serranoides /S. flavidus	522	7	4	0	0	0	0
S. miniatus	229	8	1	0	0	0	0
S. auriculatus	49	2	0	0	0	0	0
S. carnatus	51	5	1	0	0	0	0
S. pinniger	73	2	1	0	0	0	0
S. rosaceus	46	3	0	0	0	0	0
S. rubrivinctus	27	1	0	0	0	0	0

Model 2 - Stock Estimate [(# species/transect area)*total transect area]*proportion value

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
Deep							
S. serranoides /S. flavidus	0	53	0	3	0	0	0
S. rosaceus	5	5	4	0	0	0	0
S. rubrivinctus	18	4	0	0	0	0	0
Shallow							
S. mystinus	124	194	133	288	112	0	0
S. miniatus	12	5	8	32	3	0	1

Model 3 - Stock Estimate [(# species/transect area)*total transect area]*proportion value

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
S. mystinus	3298	233	3	0	0	0	0
S. serranoides /S. flavidus	436	38	2	0	0	0	0
S. miniatus	237	9	2	0	0	0	0
S. auriculatus	48	3	0	0	0	0	0
S. carnatus	59	4	1	0	0	0	0
S. pinniger	75	3	1	0	0	0	0
S. rosaceus	5	1	0	0	0	0	0
S. rubrivinctus	33	0	0	0	0	0	0

Model 4 - Stock Estimate [(# species/transect area)*total transect area]*proportion value

	category						
	1	**2**	**3**	**4**	**5**	**6**	**7-10**
Deep							
S. serranoides /S. flavidus	82	12	0	0	0	0	0
S. rosaceus	8	2	3	0	0	0	0
S. rubrivinctus	10	5	0	0	0	0	0
Shallow							
S. mystinus	726	1265	58	0	0	0	0
S. miniatus	18	34	14	3	0	0	1