Use of Acoustic Habitat Mapping to Estimate the Distribution of White Abalone, *Haliotis Sorenseni*, at Tanner Bank California

A Capstone Project

Presented to the Faculty of Earth Systems Science and Policy

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Bachelor of Science

by

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To the ESSP faculty of CSUMB:

Keeping the various fisheries of the ocean from becoming depleted is an important task. In the case of the abalone off the California coast, the situation has become one of national importance. With an estimated 96% decrease in abalone stock off of California alone, and the consequent closure of the fishery, their very existence is on the edge of collapse. Appearing on the endangered species list in 2001, *Haliotis sorenseni* is of particular concern to government and fishery personnel. With as few as two thousand individuals remaining in the wild, the National Oceanic and Atmospheric Administration (NOAA), National Marine Fishery Service (NMFS) and the California Department of Fish and Game (CDFG) have collaborated in an effort to bring their population back from near extinction.

In July of 2002, a research cruise to Tanner Bank, California was undertaken. The general approach is to use the CSUMB Seafloor Mapping Labs (SFML) acoustic remote sensing system and NMFS Remotely Operated Vehicle (ROV) survey data to map the distributions of habitat and abalone. My role in this project is the acquisition, processing and analysis of the multibeam bathymetry data collected by the SFML, and the production of *H. sorenseni* habitat maps in GIS. This project is of critical importance on several fronts. First, the maps that have been generated will enable future searches for *H. sorenseni* at Tanner Bank to be very focused, as they will utilize the *H. sorenseni* habitat maps that I create. Secondly, the habitat with specific characteristics that I declare as "predicted" *H. sorenseni* habitat will give government agencies the ability to search for additional suitable *H. sorenseni* habitat around the United States and abroad.

I believe that my capstone should be assessed in the following areas of depth:

- Acquisition, Display, and Analysis of Quantitative Data
- Application of Knowledge in the Physical and/or Life Sciences

As with any venture into science, if you wish to truly solve a problem, you must understand that problem first. In the case of the *H. sorenseni*, I have collaborated with several government agencies and multiple experts in the field of oceanography and marine biology. These people include but are not limited to Dr. Kvitek of SFML, Dr. Oliver and Dr. Butler of NMFS, and Dr. Newman of NOAA. These interactions have allowed me to understand the direct and indirect, short and long-term obstacles that face the H. sorenseni, in addition to the recovery hopes and dreams.

As an ESSP student with a Marine and Coastal Ecology concentration, I am interested in the interactions of humans and organisms in their constant struggle for balance and equilibrium. Thus the struggle of the *H. sorenseni* also peaks my interest, as humans are the direct cause of the population collapse, yet they are also the direct source of salvation. My interest in this project was aided in the fact that I was able to personally complete this project to completion. I was a part of every process, from the collection of raw data in the field, to the processing and analyzing, to finally distributing a final product that is important, and that is readily available for an information deprived society.

Thank you spending the time and energy to review this report. It is my sincere wish that you will find the information on the following pages to captivate your attention, inspire wonder and motivate your spirit.

Sincerely,

Jason Mansour

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Abstract

After extensive over harvesting of California abalone in the 1970s, less then 4% of the original stock remain today. Of the California abalone, white abalone (*Haliotis sorenseni*) is the most impacted, resulting in its placement on the Endangered Species List in 2001. Off the coast of southern California, Tanner Bank is one of the last refuges of *H. sorenseni* left in the Pacific Ocean. As estimates of the *H. sorenseni* population in the wild fell below 2,300, numerous government agencies collaborated to form the White Abalone Recovery Team (WART). In July 2002, a research cruise was organized to perform a *H. sorenseni* stock assessment at Tanner Bank, 300 kilometers offshore the San Diego coast. Utilizing a Remotely Operated Vehicle, researchers incorporated multibeam bathymetry maps which guided the ROV pilots by providing depth contours and substrate information, allowing for greater survey efficiency and increased the number of *H. sorenseni* found. Additionally, *H. sorenseni* habit was found at Tanner Bank using multibeam bathymetry habitat maps created from Topographic Positioning Index (TPI) and rugosity analysis. Based on this study, NMFS has placed increased emphasis on the use of multibeam bathymetry to aid future surveys, and WART will know the best areas for collecting abalone from Tanner Bank, as well as the ideal locations for out-planting adult abalone through a captive breeding program.

Introduction

The abalone population off the coast of California has dropped 96% since 1970. This fishery occurred almost exclusively in central and southern California. Between 1942 and 1996, the trends in total commercial landings for all abalone species were marked by four distinct stages: A) increased landings between 1942 and 1951, B) relatively stable landings between 1952 and 1968, C) a rapid decline in landings between 1969 and 1982, and D) a gradual and steady decline between 1983 and 1996. When commercial landings are separated by individual species, a serial depletion of the fishery by species becomes evident. As the more desirable abalone populations experienced stock collapse, the fishery shifted to other species (ARMP, 2000). The statewide closure of abalone fisheries has resulted in substantial economic loss. California abalone fisheries landed more than 4,000 metric tons per year during the 1950's and 1960's, split roughly equally among sport and commercial interests (State of California, 1995). For more than 20 years, sport and commercial abalone fisheries generated $15-$20 million per year for the state's economy. The abalone population trends of the 1980's, caused largely by a flawed harvest scheme, must be reversed if the productivity of these fisheries is to be restored (Gary, 2002). Landings of black, white, pink and green abalones fell in the 1990's to less than 4% of the early 1970's landings, from 882 metric tons to 32 metric tons. The California Fish and Game Commission closed the pink, green, and white abalone fisheries in 1996 to prevent extinction of reproductive stocks (Davis, 2002).

Five abalone species formerly supported valuable commercial and recreational fisheries in southern and central California. Today, four of those species (pink, green, black, and white) are at very low population levels. *H. sorenseni* is listed as an endangered species under the federal Endangered Species Act. Black abalone is a candidate species for listing. While not at risk of extinction, red abalone’s range has been severely decreased. As a member of the consumer tier on the food chain, abalone not only keep algae levels low, but they are a keen source of food for other predators. Abalone eggs and larvae are eaten by filter-feeding animals. Though juvenile abalone hide, they are active at night (nocturnal) and crabs, lobsters, octopuses, starfish, fish and predatory snails prey on them (Fishtech, 1999). So, with the absence of abalone from the marine ecosystem, a myriad of other species are negatively affected.

The most threatened species, *H. sorenseni*, became the first marine invertebrate ever protected under the Endangered Species Act in 2001. Government agencies such as the National Oceanic and Atmospheric Administration (NOAA), National Marine Fishery Service (NMFS), United States Geological Survey (USGS) and the California Department of Fish and Game (CDFG) have collaborated to establish the White Abalone Recovery Team (WART). This team has been formed to make recommendations on effective policy procedures to protect *H. sorenseni*. The primary recommendation by WART is to initiate a captive breeding program to stabilize and eventually increase the *H. sorenseni* population. In order for the captive breeding program to be successful, WART needs to know where to collect *H. sorenseni* for a captive brood stock, density estimates of *H. sorenseni* to release the appropriate number of *H. sorenseni* from the captive breeding program, and the ideal locations to out plant *H. sorenseni* reared in captivity. Tanner Bank was identified as the primary location for the collection of brood stock and out planting of the captive breeding program.

H. sorenseni prefers a specific type of habitat. *H. sorenseni* are found in open, low relief rock or boulder habitat surrounded by sand. Sand may be important in forming channels for the movement and concentration of algal drift. *H. sorenseni* appear to be restricted to depths where algae will still grow, a function of light and substrate availability (Hobday and Tegner, 2000). The depths at which *H. sorenseni* occur are from 20 to 70m (Neuman, 2002). Thus, the three characteristics of *H. sorenseni* habitat include a depth range of 20 to 70m, the presence of rocky substrate for the growth of algae and the presence of sand channels where food accumulates.

Initial white abalone stock assessments were performed with a Remotely Operated Vehicle (ROV), which over a 3 week survey only found 130 live animals, causing researchers to estimate the total wild white abalone population to be 1500 individuals. After further consideration, acoustic remote sensing utilizing multibeam bathymetry, provided by the CSU Monterey Bay Seafloor Mapping Lab (SFML), was integrated with an ROV survey at Tanner Bank in July of 2002. By integrating the real time bathymetry maps from this project to guide the ROV search, researchers were able to locate 100 *H. sorenseni* in a single day, enabling more accurate population density estimates and drastically increasing the effectiveness and efficiency of the survey. Additionally, by performing Topographic Positioning Index (TPI) and rugosity analysis on the habitat maps made from the Tanner Bank survey in 2002, preferred abalone habitat was found, thus enabling WART to have the essential recovery information required for the successful launch of the white abalone recovery process.

Purpose of Study

The purpose of this study was to conduct a quantitative analysis of the seafloor habitat found at Tanner Bank, as well as identifying suitable habitat from which to take and transplant *H. sorenseni* in the hopes of stabilizing the population. This analysis was done by applying geospatial algorithms, TPI and rugosity analysis to high resolution multibeam bathymetry data for habitat classification.

Project Goals and General Approach

There are two primary objectives of this study. The first objective was to provide "real-time" habitat maps as Digital Elevation Models (DEMs) for the ROV surveys to locate *H. sorenseni.* The null hypothesis being that the use of DEMs would increase the efficiency and success of finding *H. sorenseni*. In July of 2002, a research cruise aboard the NOAA R/V *David Starr Jordan* was conducted to determine the distribution and abundance of *H. sorenseni* and locate potential *H. sorenseni* habitat at Tanner Bank using acoustic remote sensing and a Remotely Operated Vehicle (ROV). The preliminary habitat maps made with multibeam bathymetry were used to guide the survey efforts of the NMFS ROV team during the cruise as they looked for individual abalone, and further processing of the acoustic data generated the habitat classification results of potential *H. sorenseni* habitat presented in Figured 1 through 8.

The second objective of this study was to identify potential *H. sorenseni* habitat at Tanner Bank based on known *H. sorenseni* habitat preferences and using GIS spatial analysis tools applied to high resolution multibeam bathymetry maps. My role in this project was the acquisition, processing and analysis of the multibeam bathymetry data collected by the SFML, and the production of *H. sorenseni* habitat maps in GIS. Without these maps, the recovery efforts would be severely hampered; resulting in more funding needed to support the increased frequency and duration of research expeditions to Tanner Bank. With the habitat maps being utilized, the ideal locations for abalone reproductive success are known, thereby shrinking the cost and resources needed to stabilize the *H. sorenseni* population.

Methods

Study Site

Tanner Bank is located approximately 300 kilometers off the coast of San Diego. The known underwater geology consists of rocks and sediment that have a depth range from 17 to 144 meters which is ideal abalone and cow cod habitat. Figure 1 below illustrates the location of Tanner Bank relative to the California coast (Fishing, 2003).

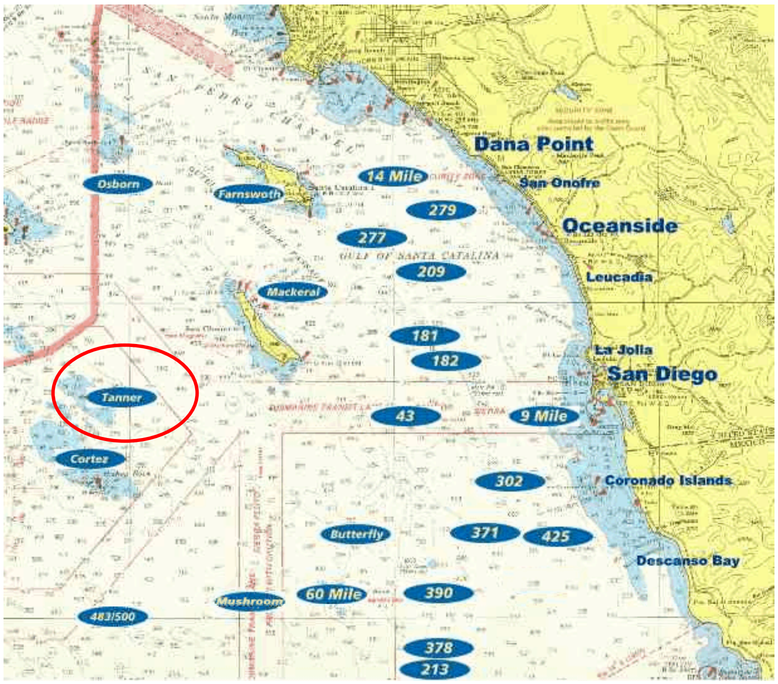

Fig 1. Location of Tanner Bank off the California coast.

Survey Design

The survey vessel was the NOAA R/V David Starr Jordan, a 52 meter research vessel. The cruise ran from July 8th to July 20th 2002 with personnel from NMFS, USGS and the SFML. The SFML survey team consisted of four people operating at night (1700 to 0800 hrs). Tanner Bank, approximately 20 kilometers long by 5 kilometers wide required a total of 75 lines or passes, which were spaced 200 meters apart to enable complete sonar coverage with 50% overlap. The swath of the multibeam was 150 degrees, depths ranged from 20 to 125 meters, and survey speed was 3 to 10 knots. Coastal Oceanographics Hypack Max software was used for survey design and execution. Tanner Bank is approximately 20 kilometers long by 5 kilometers wide.

The SFML's Reson 8101 SeaBat multibeam sonar was used for bathymetry mapping. This system operates at a frequency of 240 KHz with a swath of 150 degrees, and was attached to a steel beam fixed to the stern starboard side of the boat. All raw data was logged using a Triton-Elics International Isis Sonar data acquisition system, with real-time bathymetry DTM (digital terrain model) generation.

Differential GPS (DGPS) vessel positioning for multibeam surveys was provided by a Trimble 4700 GPS with USCG RTCM differential corrections provided by a Trimble ProBeacon receiver. Vessel motion (heave, pitch, heading, and roll) corrections were generated by a TSS HDMS heading and motion sensor (±0.02 degree accuracy).

Water column sound velocity profiles were collected using an AML SV+ sound velocity profiler. Tide corrections were calculated using predicted values from Tides and Currents. Further information on the SFML multibeam bathymetry capabilities can be found via the Internet at http://seafloor.csumb.edu/descriptions/multibeamdescrip.html.

The ROV survey team consisted of four people operating during the day (0500 to 1700 hrs). Utilizing an ROV capable of depth up to 330m, the ROV detected very few white abalone in deeper (> 60 m) and shallower (< 30 m) waters (WART Minutes, 2002). By superimposing both the real-time ROV and support-vessel positions on these three-dimensional multibeam bathymetry DEM maps in shaded relief colored by depth, the ship captain and ROV pilot were able to effectively navigate and focus their search efforts within specifically targeted habitat types. Approximately 194 individuals were identified during 60 hours of ROV searching, and their GPS coordinates were logged (USGS, 2002).

Data Processing

Initial multibeam processing was done onboard the R/V David Starr Jordan via PC computers utilizing Caris HIPS hydrographic cleaning software. Further cleaning was performed at the Seafloor Mapping Lab at CSU Monterey Bay. Soundings were corrected for vessel motion using TSS HDMS data, variations in water column sound velocity using AML SV+ data, and adjusted to MLLW using predicted tide charts for the local region. Erroneous soundings were removed in CARIS HIPS. Geotiffs were exported from CARIS HIPS Spatial Editor with 3m resolution in sunshaded grayscale and rainbow 16 color imagery. XYZ Soundings were exported from CARIS HIPS as a decimated x, y, z ASCII text (shoal biased) with 3m, 50m, 100m, 250m, and 500m spacing. The 3m decimated x,y,z ASCII text was imported into Fledermaus Average Gridder to generate

3m grid(s). The 3m ArcInfo ASCII raster grid (.asc) was imported into Spatial Analyst to generate a 3m bathymetry grid. Five meter contour lines were then generated from the 3m bathymetry grid within Spatial Analyst.

Data Analysis

With the specific habitat preferences for *H. sorenseni* being a depth range of 20 to 70 meters, rocky substrate, and the presence of sand channels which the abalone exploit for food (Iampietro, Personal Communication), the Digital Elevation Model (DEM) was used in Arc View 8 for habitat classification via rugosity and Topographic Position Index (TPI) analysis (Weiss, 2000). To determine the areas of various habitats within Tanner Bank, the raster calculator extension was used within ArcMap 8. By defining the parameters of the type of habitat such as depth, TPI or rugosity value, the raster calculator would highlight the cells within the DEM that matched the query. Since each cell is 3m multiplying the number of cells that matched the query by 9, then dividing by 1,000,000 converts meters into km^2.

Rugosity

Rugosity analysis, a habitat classification tool applied to the DEM, located the areas of rough substrate (rock) by comparing the surface to planar ratios. If an area is smooth, then the planar to surface ratio is around 1, whereas bumpy and boulder like substrate reflects values of 3. To locate the rocky areas within Tanner Bank, values of 1.12 and above were classified as rock, where everything less was considered smooth substrate. Rugosity grids were created using the ArcView 3.x extension Surface Areas and Ratios from Elevation Grids (Jeness, Jeff 2002).

Topographic Position Index (TPI)

Topographic Position Index (TPI) analysis found the sand channels and depressions within the substrate of Tanner Bank that *H. sorenseni* prefer. 50, 100, 250 and 500 meter scales were produced although the 250m scale was chosen for the identification of rocky habitat, whereas a 50m scale was chosen for the identification of sand channels. TPI compares the elevation of a given cell on the DEM, extending a given scale value, and comparing the elevation of that cell to the original. Depending on the positive or negative difference in the elevation between the two cells, a value of slope was given between 1 (ridge) and 5 (depression) which was re-classified as Ridge, Upper / Middle / Lower slope, Flat and finally Depression. By superimposing the locations of the depressions at Tanner Bank with the rugosity analysis, sand channels and rocky habitat with a rugosity value of >1.1 were located within areas of ridges and terraces. These analyses displayed areas of varying slope and substrate type at Tanner Bank.

Final Product

By combining the results from these analyses, several layouts were made showing the locations of potential *H. sorenseni* habitat at Tanner Bank, California.

Results

Locations of habitat that meet the three characteristics for *H. sorenseni* were located at Tanner Bank. By identifying the area of habitat available to *H. sorenseni*, accurate estimates of further survey and rehabilitation measures can be made (Table 1). Tanner Bank is an anticline composed of folded sedimentary rocks. Erosion has also formed a depression in the center of the Bank giving it an atoll or volcanic crater physiology as illustrated by multibeam bathymetry (Figure 2). By integrating the real time bathymetry maps from this project to guide the ROV search, researchers were able to locate 100 *H. sorenseni* in a single day, enabling more accurate population density estimates and drastically increasing the effectiveness and efficiency of the survey (Figure 3). Geospatial algorithms, such as rugosity, are critical for *H. sorenseni* habitat classification of rocky habitat (Figure 4). TPI analysis revealed different slopes and aspects found at Tanner Bank (Figure 5). Rocky substrate is preferred by *H. sorenseni*, thus the locations of this habitat type were located within the *H. sorenseni* depth range (Figure 6). Sand channels located within the rocky *H. sorenseni* habitat easily accumulate food, essential to the *H. sorenseni* survival (Figure 7). The locations of the predicted *H. sorenseni* habitat at Tanner Bank (Figure 8). All multibeam bathymetry shaded relief maps are at 3 meter resolution with WGS 1984 UTM Zone 11N coordinate system.

Table 1. Habitat areas at Tanner Bank.

Habitat Type	**Area (km^2)**
Total Area of Tanner Bank	81
Area within *H. sorenseni* depth range	15
Rocky habitat within *H. sorenseni* depth range	3.52
Sand channels within *H. sorenseni* depth range	0.42

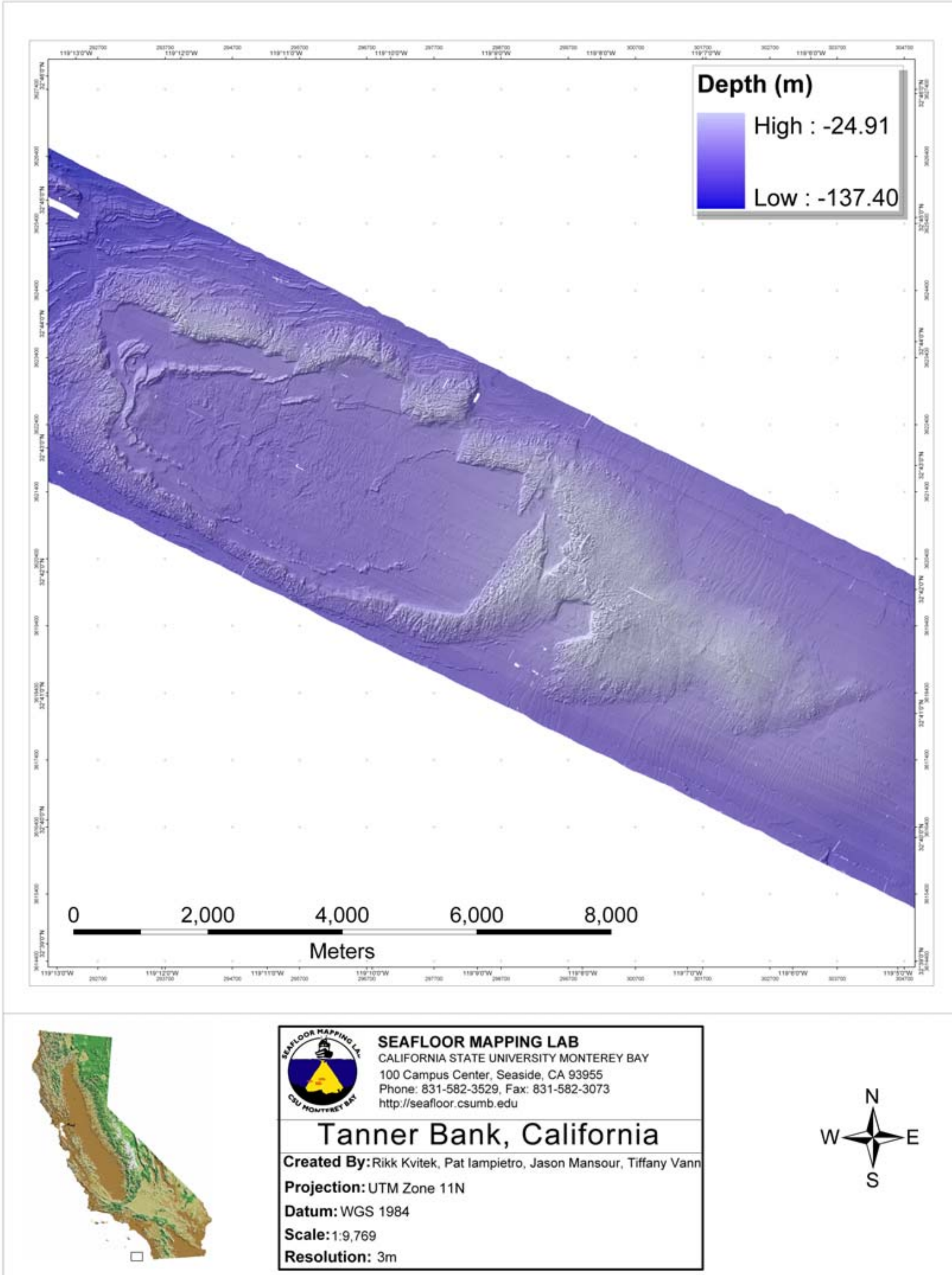

Fig 2. Blue multibeam bathymetry shaded relief displaying the large depression and fringe reefs of Tanner Bank.

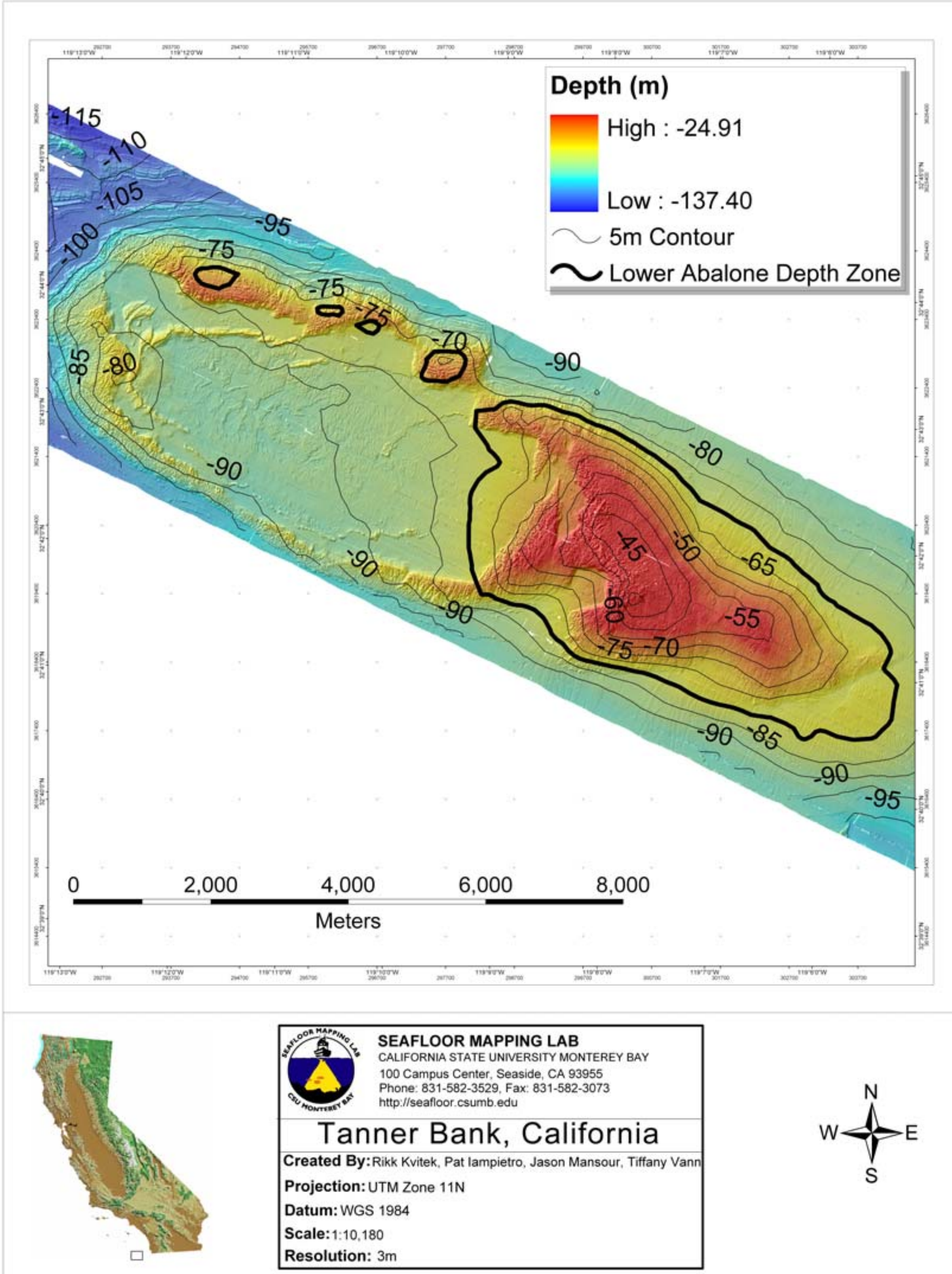

Fig 3. Rainbow multibeam bathymetry shaded relief with 5m contours, outlining *H. sorenseni* depth range.

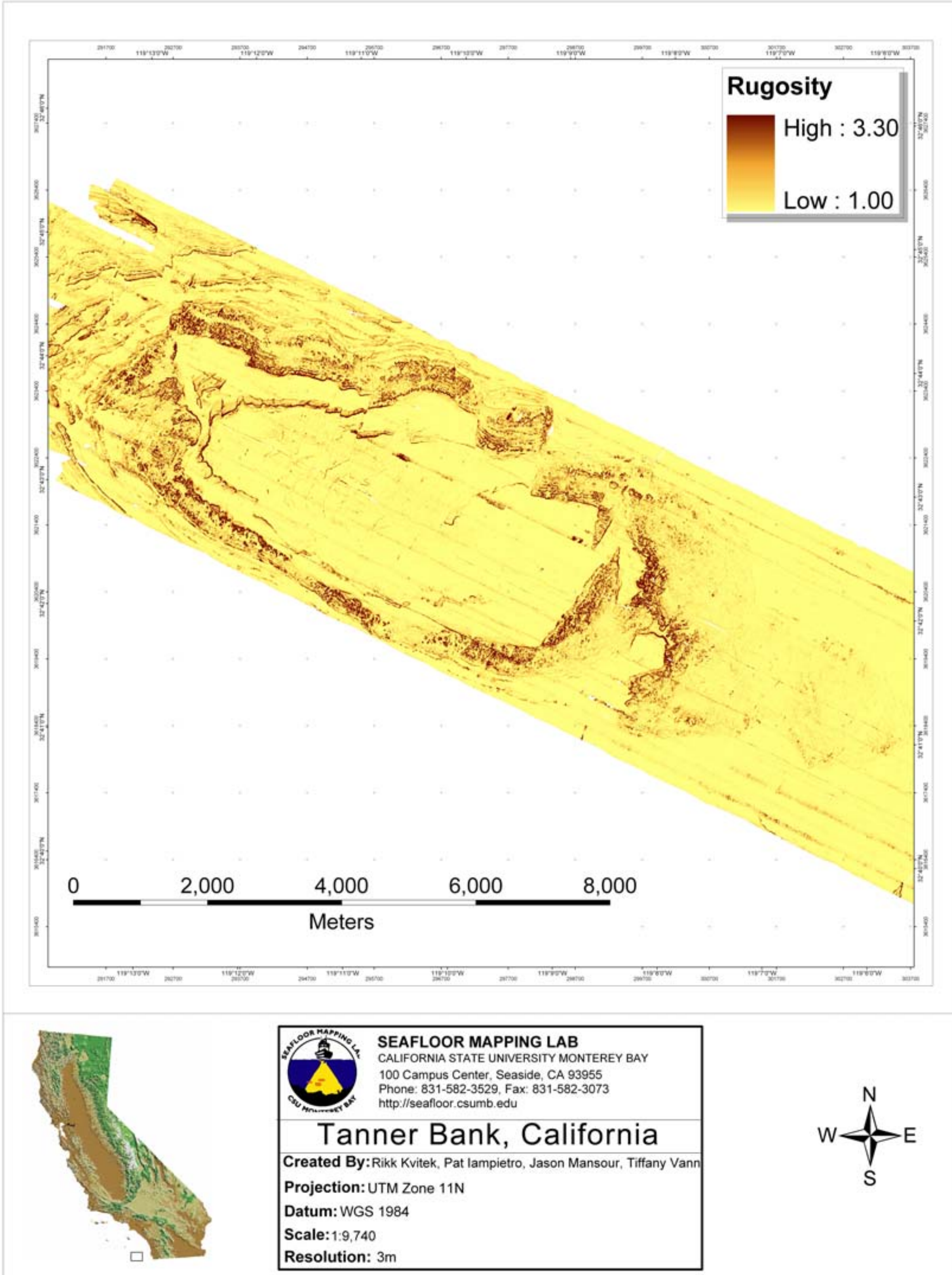

Fig 4. Results from rugosity analysis indicating areas of rough and smooth substrate. Values of 1 to 1.10 are smooth substrate, 1.10 to 3.30 are rough substrate.

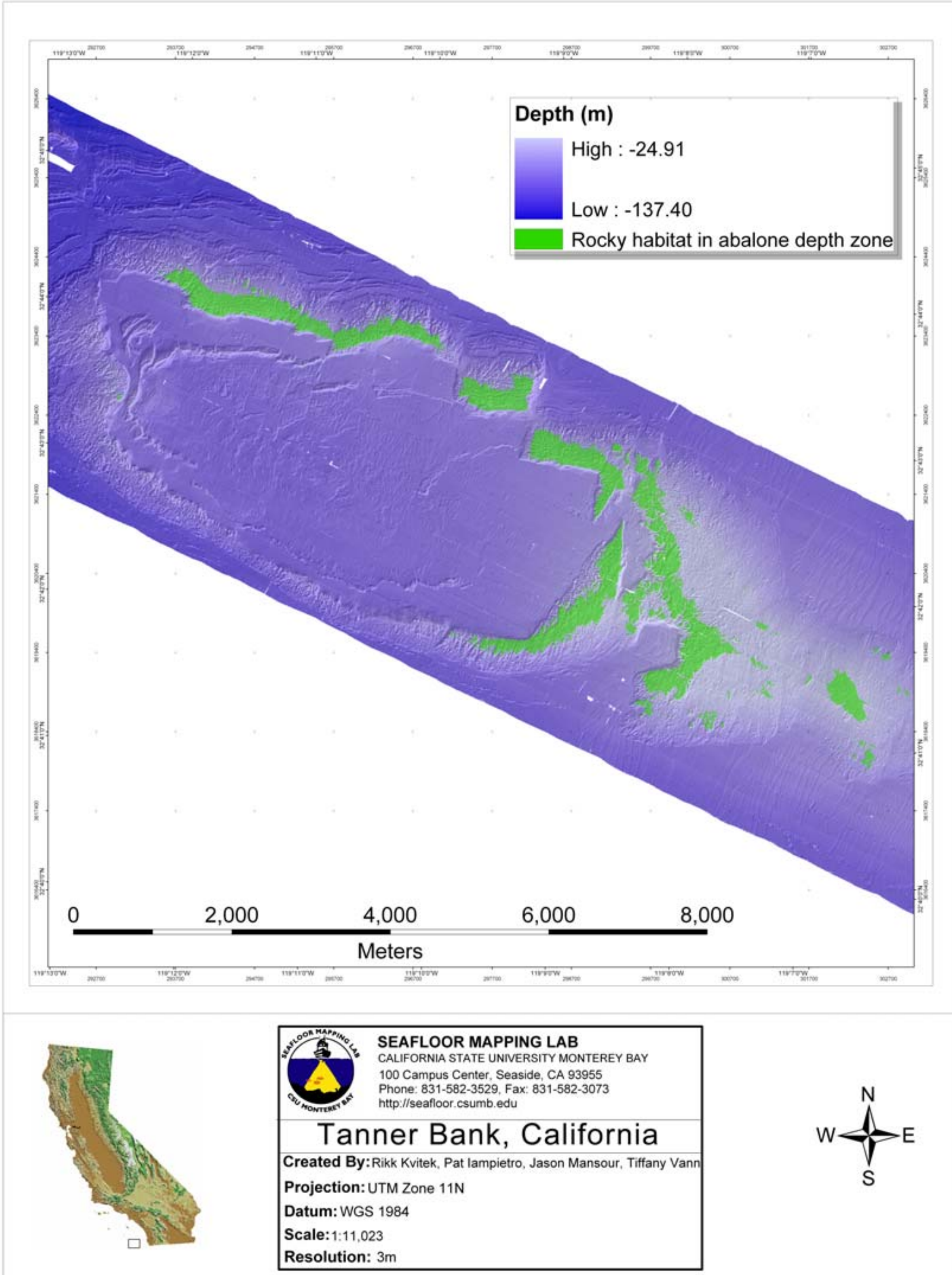

Fig 5. Blue multibeam bathymetry with rough, rock habitat within *H. sorenseni* depth range.

Fig 6. 250m TPI analysis results showing varying degrees of substrate slope and aspect.

Fig 7. Blue multibeam bathymetry showing sand channels within rocky habitat in *H. sorenseni* depth range.

Fig 8. Predicted *H. sorenseni* habitat at Tanner Bank, California.

Discussion

By estimating the areas within Tanner Bank where *H. sorenseni* can be found, the recovery time for the abalone can be increased dramatically. Rather then spending many days at sea searching for a certain organism, narrowing the scope of the survey, through habitat classification, will likely increase your chances of finding the target species while saving a considerable amount of time and money. As illustrated in Figure 8, rather then WART having to make multiple passes with divers and ROV's, they can simply focus on the areas that have been identified as preferred *H. sorenseni* habitat. Furthermore, with a better understanding of the type of substrate and depth range that *H. sorenseni* thrive in, other agencies can use the habitat maps produced in this study and find similar locations in other parts of the world in an effort to locate additional habitat for *H. sorenseni.* In short, by focusing on a small area where *H. sorenseni* are expected to be, the overall task of ensuring the growth and protection of *H. sorenseni* at Tanner Bank through the captive breeding program suggested by WART is realistic and obtainable.

Initially, the logged GPS locations of *H. sorenseni* would have been provided to this study from NMFS in the hopes of assuring that the "predicted" *H. sorenseni* habitat shown in Figure 8 was accurate. However, those locations were not made available due to the sensitive nature of the information and concerns that should the recent GPS locations of *H. sorenseni* at Tanner Bank become accessible to the public, poaching threats could increase. Should future GPS locations become available, the results in this study could be deemed accurate and confirmed.

The efficiency of combining multibeam bathymetry with ROV technology is unprecedented. Utilizing this combined approach during the July 2002 cruise, NMFS ROV pilots found, on average, 24 *H. sorenseni* per day by using the new multibeam bathymetry maps generated the night before, in comparison with previous attempts that lasted as long as 1 month and resulted in the identification of fewer than 8 white abalone per day. The evidence above proves the null hypothesis of this study that the use of multibeam bathymetry is an excellent tool for increasing the efficiency of underwater surveys. With more accurate assessments being performed, WART will have a better idea of the current stock size, and thus make proper and informed management recommendations. The techniques employed during the July 2002 cruise should prove to be valuable for the recovery and conservation of *H. sorenseni* and, more generally, for furthering the conservation and protection mission of NMFS.

The application of ROV and acoustic remote sensing technology to other areas along the coast of southern CA, the Channel Islands, and Baja California will be crucial for re-establishing the white abalone throughout its historical range. In addition, the potential for addressing other federal and state agency initiatives exists. For example, the marriage of ROV and acoustic remote sensing technologies can help to advance ocean exploration through non-destructive sampling techniques, determine critical habitat for endangered and threatened species, aid in establishing marine reserves, and manage fisheries resources. For example, Tanner Bank is part of the cowcod (*Sebastes levis*) conservation area, and bottom fishing on the Bank is restricted to depths < 20 fathoms. This area has been designated by the Pacific Marine Fisheries Council as part of the rebuilding plan for cowcod. The high resolution habitat map of Tanner Bank will be used to direct the recovery monitoring for cowcod and perhaps other exploited species that occur on the Bank (Neuman, 2002).

The primary concern of marine biologists is that the *H. sorenseni* fishery lasted less than a decade before the species was reduced to below commercially viable numbers.

Over harvest from this fishery depleted abalone populations such that surviving unharvested white abalone were left too far apart to successfully reproduce (Cummins, 2002). Abalone are broadcast spawners, and the sexes are separate, which means that males and females must aggregate in groups and simultaneously spawn their gametes into the water for efficient fertilization to occur. This is another reason why natural populations of abalone are always found in groups, not singly. The "thinning out" effect of fishing, which results in abalone becoming separated and the decline in size of groups, may have negative effects on the percentage of eggs fertilized at each spawning event. (Tarr, 2000). In my opinion, we caused the damage; we need to fix it by whatever means necessary.

In addition to the economic benefit of restoring the *H. sorenseni* population, I believe that we have a moral obligation as well. According to the California Department of Fish and Game there is a shared responsibility for the decline of *H. sorenseni* and many other contributing factors in addition to commercial take. These include sport take, inadequate management (managing as a group, not by species and area), poaching, pollution, habitat loss, disease, predation (mostly sea otter), and natural environmental changes such as the frequency of El Niño events in the last two decades (CDFG, 2002). The current population size and density of white abalone indicate that recruitment failure is inevitable, and probably has already occurred in California. Density is too low to allow the fertilization success that is necessary for natural recovery of the population. Without [human] intervention, the white abalone is likely to become extinct in California within 10 years, as aging animals succumb to natural causes (Hobday and Tegner, 2000).

Through the consistent and conscience attention of conservation activists, government agencies and scientists, the outlook for *H. sorenseni* has changed dramatically. By providing the information and estimates needed for effective recovery strategies, the use of multibeam bathymetry and GIS continues to play a critical role in the restoration efforts for this threatened species.

Acknowledgements

The entire staff at the CSU Monterey Bay Seafloor Mapping Lab has been instrumental in allowing me to see this project through completion. Thank you to Dr. Rikk Kvitek, Pat Iampietro and Tiffany Vann for their support, humor and professionalism onboard the NOAA R/V *David Starr Jordan.* With regard to data processing Kate Thomas kept me to my assigned deadlines and made sure that I could distinguish between the “good” and “bad” data. Additionally, thank you Greg Riley II, Nathan Russell, Summer Middleton and Tony Perry III for keeping me company during the long nights in the SFML, and the countless requests for peer-reviewing this project.

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