AN ABSTRACT OF THE THESIS OF

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Title: Habitat Mapping and Identifying Suitable Habitat of Redfish Rocks Pilot Marine Reserve, Port Orford, Oregon.

Abstract approved:

Chris Goldfinger

Establishment of marine protected areas (MPAs) has been documented to effectively manage marine resource's diversity and enhance fisheries productivity. However, there must be a critical consideration of how these sites are selected and the actual description of the site itself. Its effectiveness is greatly dependent on understanding these habitats and the species that thrive in them. In 2008, the State of Oregon embarked on an effort to create a network of marine reserves within its territorial sea. Together with the active participation of the public sector in the selection process, it has to identify two (2) pilot sites and four (4) other sites that need further evaluation. During the selection process, thematic surficial geologic habitat (SGH) maps played a critical role in identifying potential sites. SGH was sufficient to identify specific sites, however a clearer and a habitat map with higher resolution is necessary in effectively managing these pilot marine reserves. Development of a more detailed habitat map will guide local and state managers in initiating specific management interventions to unique marine reserve sites such as Redfish Rock Pilot Marine Reserve.

This aim of this study is to develop a detailed habitat map of the Redfish Rock Pilot Marine Reserve to supersede the initial SGH map, and utilize it to predict species occurrence within each habitat type. The use of acoustic information collected from multibeam echo sounder will be used to produce a high resolution habitat map of its marine environment. The backscatter data along with co-registered bathymetric information can be utilized to describe marine topography and define habitat based on its surficial geologic characteristic. Information derived from the bathymetry data utilized Benthic Terrain Modeler (BTM) as a guide in identifying seafloor features and classified

zones like high relief and flat zones as well as derivative layers such as hillshade layer. Further delineation of habitat boundaries were made using the backscatter mosaic and angular response analysis (ARA) to classify layers created from the Interactive Visualization System (IVS3D) Fledermaus (FM) Geocoder. Manual digitizing of habitat polygon with automated classified layer as a guide was conducted using ArcGIS. Substrate classifications were verified from the remotely operated vehicle (ROV) videos collected by Oregon's Department of Fish and Wildlife (ODFW). Species occurrences were predicted using the depth, latitude and substrate type and species information queried from the National Marine Fisheries Service (NMFS) Habitat Use Database (HUD). A total of 89 species mostly ground fish were predicted to be present inside the marine reserve.

With the habitat map created successfully from high resolution multibeam surveys, managers now have a more detailed picture of the seafloor. This is necessary to design specific management strategies such as development of biophysical monitoring protocol, deployment of marker buoy, conduct of specific species-habitat relationship research. This study was done specifically on the Redfish Rocks Marine Reserve primarily due to the fact that this site already has available data pertinent to the creation of this habitat map; however, this approach could also be applied and replicated at other identified MPA sites including other areas of the Redfish Rocks Pilot Marine Reserve, Otter Rocks Pilot Marine Reserve and the four other sites that are being considered for the creation of MPA networks.

Habitat Mapping and Identifying Suitable Habitat of Redfish Rocks Pilot Marine Reserve, Port Orford, Oregon

by
Rizaller C. Amolo

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Rizaller C. Amolo, Author

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CHAPTER 1 - GENERAL INTRODUCTION

Background

A marine reserve is an important tool recognized to promote and conserve biodiversity. It is often defined as an area completely protected from all extractive and destructive activities such as fishing or the removal of any living and non-living marine resources, except as necessary for monitoring or research to evaluate its effectiveness (Lubchenco et al. 2003). Protection efforts have been documented to provide multiple ecological benefits such as protection of habitat, conservation of biodiversity, enhancement of ecosystem services, recovery of depleted stock, and spill over of adult to adjacent fished areas (Russ and Alcala, 2004). Moreover, the establishment of a network of marine reserves within a biographical region will make it an essential tool to an ecosystem-based approach to conservation and fisheries management (Kaplan et al. 2009).

However, setting a marine reserve or a network needs to take into account important biological and sociological criteria to achieve its objectives. Roberts et al. (2003) have enumerated some criterion in order to achieve both conservation objectives and sustaining biodiversity and fishery values. Among the criteria that need to be considered to meet the conservation objective are: biogeographic representation, habitat heterogeneity, and endemism. The first two criteria relate to how much habitat type is represented in the protection effort. Sala et al. (2002) estimated that a network of marine reserve should cover 40% of the rocky reef habitat to achieve conservation goals; however others have suggested the protection of 20% habitat to enhance fisheries.

Marine habitat mapping is crucial in establishing individual marine reserves or a network of marine reserves. It is crucial in the selection phase as well as in its implementation stage. This effort to characterize the distribution of benthic habitat is essential for management, research and monitoring purpose of the marine reserves (Kracker et al. 2008). Habitat maps help managers design protective measures for specific habitats in the establishment and management of marine reserves.

Furthermore, these maps and its derived layers were utilized to estimate important resources within the protected areas and provided managers an eye view of the resources they are protecting. For example, Iampietro et al. (2008) successfully utilized multibeam echo sounder data and ROV videos to model and predict rockfish distribution and abundance in a marine sanctuary and protected area system. The model utilizes presence/absence data to predict species distribution. However, no research has been conducted that identifies suitable habitat within its marine reserves, especially within Oregon.

Oregon Marine Reserve Initiative

Oregon is in the process of establishing a network of marine reserves. In 2008 after an extensive public participatory process (http://www.oregonocean.info), two pilot sites were identified: Redfish Rocks and Otter Rock. Four other sites needing further evaluation were also identified. This year these pilot sites will be "officially" designated as pilot marine reserves after an appropriate review of existing baseline data and policy making deliberations were conducted. Significant activities of the State's marine reserve process are highlighted in the Table 1.

Past mapping information and effort have been instrumental in Oregon's marine resource management process. This information has been summarized into a surficial geological habitat map which focuses mainly on the continental margin. This data were utilized in the evaluation process of identifying essential fisheries habitat in the Pacific Northwest (Romsos et al. 2007). In 2007, efforts were undertaken to produce a surficial lithologic interpretation of the Oregon coast and this was later added to the existing surficial geological map (Agapito 2008). Much of the information was used during the extensive site selection process of the marine reserve. Science and Technical Advisory Committee recommended to the Ocean Policy Advisory Council to use these maps in identifying "special areas" with high habitat variability to represent high species diversity that need protection. Although, a lithologic habitat map for the state territorial sea exists and was used in the preliminary selection process, a more detailed and a more reliable habitat map for these pilot sites was not available. Accurate maps are vital for effective management of these marine reserves. Thus, this study has been conducted to improve the mapping of Redfish Rock Pilot Marine Reserve located off the coast of Port Orford, Oregon.

Table 1. Significant activities from 2008 – 2010 in Oregon's Marine Reserve process (http://www.oregonocean.info).

	Pre – establishment	***Selection / Designation***	***Establishment***
Community participation / mobilization	Developed / submission of proposed site from community proponent		Formation of community Team
Site selection and mapping	Creation of SGH map of territorial sea		Creation of detailed Habitat map from MBES survey
Education and information sharing	Creation of website for OR marine reserve initiative		
	Science and Technical Advisory Committee workshop		
Marine reserve planning		Developed MPA work plan in consultation with STAC	Monitoring workshop
Budgetary and staff allocation		Allocation of US$ 2.3 M for marine reserve initiative	
		Hiring of personnel at ODFW, OSU	
Policy making	Passed EO 08- 07	Recommendation of 2 pilot marine reserve and 4 sites for further evaluation by OPAC	House Bill 3013
	Goal formulation and setting of marine reserve selection criteria		
Research		MBES and ROV survey of Pilot Marine Reserve sites	

Study area

Redfish Rocks lies just off the southern coast of Oregon near the town of Port Orford (Figure 1). Within the area is the newly designated Redfish Rocks Pilot Marine Reserve and Marine Protected Areas. The marine reserve is bordered by several protected areas, Port Orford Head State Park on the north, Port of Port Orford and the Humbug Mountain State Park on the southeastern portion. To its south is a large rock outcrop, commonly called in the community as Island Rock. Redfish Rocks Pilot Marine Reserve covers an area of 686 ha (6.86 km^2), extending 2.4 – 2.6 km from the extreme low water line seaward and 2.78 km wide (Figure 1). The Marine Protected Area covers an area of 132.3 ha (13.23 km^2), extending 4.1 to 5.3 km from the outmost boundary of the marine reserve.

The study area lies in the nearshore region of the Oregon continental shelf, within which various tectonic and geological investigations have been conducted primarily due to the convergence area of the Juan de Fuca and Gorda oceanic plates subducting beneath the North American Plate (Kulm et al. 1975).

In mid-2008 and in May 2009, a multibeam sonar survey was conducted over Redfish Rocks to develop a detailed bathymetric map of the reef. The survey was a collaborative effort between the Port Orford Ocean Resource Team (POORT) and the Oregon Department of Fish and Wildlife (ODFW) under the Oregon State Wildlife Grant Program. Furthermore, other efforts were initiated in the aim to develop fishery resource monitoring protocol; hence a remotely-operated survey was done. The objective of both studies was to characterize the marine flora and fauna in selected nearshore reef in Oregon’s southern coast. Data collected from both surveys were mainly used in creating the habitat map in this study.

Thesis goal and objective

This project aims to produce a habitat map of Redfish Rock Pilot Marine Reserve through the use of bathymetry and backscatter data collected from multibeam echo sounder surveys. It hopes to identify important marine habitat essential for marine reserve planning and management.

The specific objectives of this study are:

1. To develop a potential habitat map of Redfish Rocks Pilot Marine Reserve;
2. To identify suitable habitat for different species in Redfish Rocks Pilot Marine Reserve

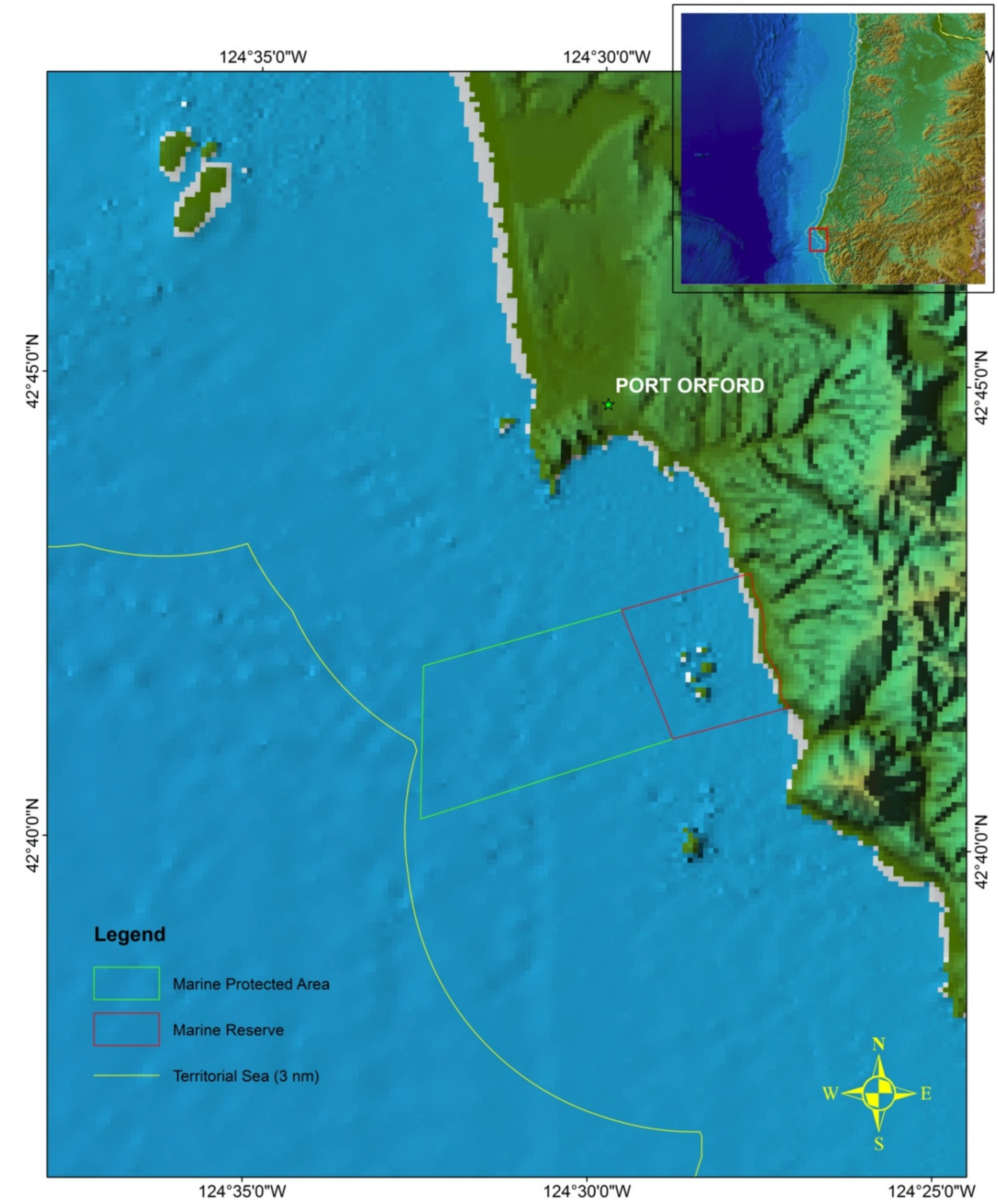


Figure 1. Study area, Redfish Rock Pilot Marine Reserve and Marine Protected Area, Oregon.

Thesis structure

This thesis is presented in five (5) different chapters in the following manner:

Chapter 1 presents the general introduction on why the work was conducted. It includes a description of the study area and a review of the Oregon marine reserve initiative.

Chapter 2 will describe the procedure used with the acoustic information from multibeam survey to create the habitat map produce in the study. It includes a discussion of basic concepts of how multibeam data are used to map the seafloor, the methods being employed in creating the maps, and results and discussion related to the development of the habitat map.

Chapter 3 focuses on methods to identify suitable habitat of different species within the habitat map created in Chapter 2 from the species found in Habitat Use Database (HUD).

Chapter 4 enumerates the ways in which the output of this work can be utilized in the management of Redfish Rocks Pilot Marine Reserve, along with potential research activities that can be conducted in the future.

Chapter 5 provides some conclusion about on the process of using multibeam information to develop a habitat map and habitat suitability map of Redfish Rocks Pilot Marine Reserve.

CHAPTER 2 - DEVELOPING A HABITAT MAP FOR REDFISH ROCKS PILOT MARINE RESERVE

Introduction

Identifying marine habitats plays a crucial role in understanding the ecology of other marine living resources. The location of habitat elements determines the distribution, abundance and diversity of important resources being or will be protected. Mapping seafloor habitat has become a good strategy to describe the topography of the marine environment and the distribution of important features. It has become an important tool to identify areas that need special marine management interventions such as establishment of marine protected areas and identification of important fisheries habitats.

Mapping these habitats has recently become the focus of many research and government organization initiatives, along with constant and continuous effort to improve map quality, accuracy and area covered. The advancement of seafloor mapping technologies, geographic information system (GIS) methods, and data visualization have increasingly improved its efficiency. Numerous approaches have been developed to utilize information and to provide as much as possible an accurate characterization of the seafloor environment. This part of the study discusses the processes that were employed in creating the seafloor map using the data collected from the multibeam survey, as well as ground truthing.

Defining a marine habitat

A habitat is generally defined as the environment in which an organism, species, or community lives (OPAC 2008; Odum 1971). It also includes physico-chemical attributes such as temperature, salinity, depth, currents, nutrient composition and existing ecological conditions such as competition, predation, survival, reproduction and the various interactions between the species all of which allow organisms to thrive in such environment (Valentine et al. 2004; Vestfal, 2009; Green et al. 2008; Hall et al. 1997). It can also be defined based on the assumption that organisms distribute themselves along environmental gradients and their cluster defines distinct sets of environmental factors (Brown and Blondel 2009). Attribute values of various conditions can be presented in GIS layers to describe the seafloor conditions and this information can be utilized to produce a prospective benthic habitat map (Green et al. 2008).

Defining the marine habitat is difficult considering the complexity and the dynamic characteristics of this environment. It has always been a challenge in habitat mapping to spatially represent this complex environment despite the scarcity of available information. Greene et al. (2008) classify marine habitat according to scale. This scale is greatly dependent on the availability and resolution of the information one can infer from it. The quality of these maps is often dependent on the technologies that were used to generate it.

Identifying the habitat does not only entail describing only the surface lithology of the seafloor and topology, but rather it is a description the various environmental conditions such as temperature, currents, chemical characteristics and biological compositions of the area. One of its drawbacks of multibeam mapping is that the information collected includes mainly the geomorphologic characteristic of the seafloor only. It does not take into consideration factors such as food availability and biological community structures which are crucial in determining the habitat of fishery resources that will be protected. It is essential that a more holistic interpretation of these habitats be done to provide the clearer perspective essential to marine resource protection. A habitat map should be an integration of substrate, vegetation, fish abundance, and physio-chemical parameters. Ideally, it should contain information that provide enough ecological context for managers to better distinguish habitat features for target or valued marine resources that is being protected (Kurland and Woody 2008). Various studies have attempted to include as much data input as possible using several of these parameters employing methods like decision tree nodes and inclusion of additional spatial data. (Whitmire 2008).

Creating seafloor maps is dependent on the purpose by which it was created. For marine resource management, it is vital that one should know the scope of the resources it is managing. Thus, it is crucial to identify critical marine habitats in order to have an effective management intervention. In the establishment of marine protected areas, it is crucial for managers and stakeholders to identify these critical habitats at the onset of the selection process. Habitat mapping, resource inventory and monitoring is equally important in the implementation aspect of this management approach. Much research has been done to map seabeds primarily to determine distribution and structure of marine environment as a surrogate to biodiversity (Jordan et al. 2005; Iampietro et al. 2008). Geologists are interested on the geomorphological characteristics of the seafloor, while biologists on the other hand wants to identify in detail the biological habitat and environment of a particular marine species. Kurland and Woodby (2008) suggest that for habitat maps to be helpful to decision makers, they should integrate both physical and biological data spatially to suggest which environmental features may matter most for particular marine species. Habitat maps may include bathymetry, geological substrate, marine vegetation, attached epifauna, and features that can be quite ephemeral such as temperature, currents, and prey availability.

Mapping the seafloor using sound

While sound waves propagating in water have been observed a long time ago, the first practical application of this phenomenon was at the beginning of the 20th century when Leonardo da Vinci first to proposed to use sound to detect distant ships, simply by listening to the noise they radiate in the water. It was during World War I that underwater acoustic devices were used by the Allied forces to efficiently detect the threat of German submarines. Considerable improvements have thus far been made on sonar technology since the two world wars. Aside from being important military tools, oceanographic industries have also been able to make use of the development in sonar technology. Acoustic sounders quickly replaced traditional lead lines to measure water depth. The same technology was used to detect fish shoals in the early 1920’s. It has since become an important tool in fishing and scientific monitoring of fish biomass. The use of sidescan sonar to obtain an “acoustic image” was used by geologists after its invention in the 1960’s. The emergence of multibeam echo sounder in the 1970’s has dramatically developed seafloor mapping using acoustic.

The number of applications for underwater acoustics has dramatically grown such that this technology in the ocean today plays similar essential roles played by radar and radio waves in the atmosphere and in space. Apart from its primary function in the military to detect and locate obstacles and targets, sound waves are now used to characterize the seafloor by using underwater scientific instrumentation (e.g., remotely operated vehicles or ROVs). An example of such equipment for military and civilian application is shown in Figure 2.

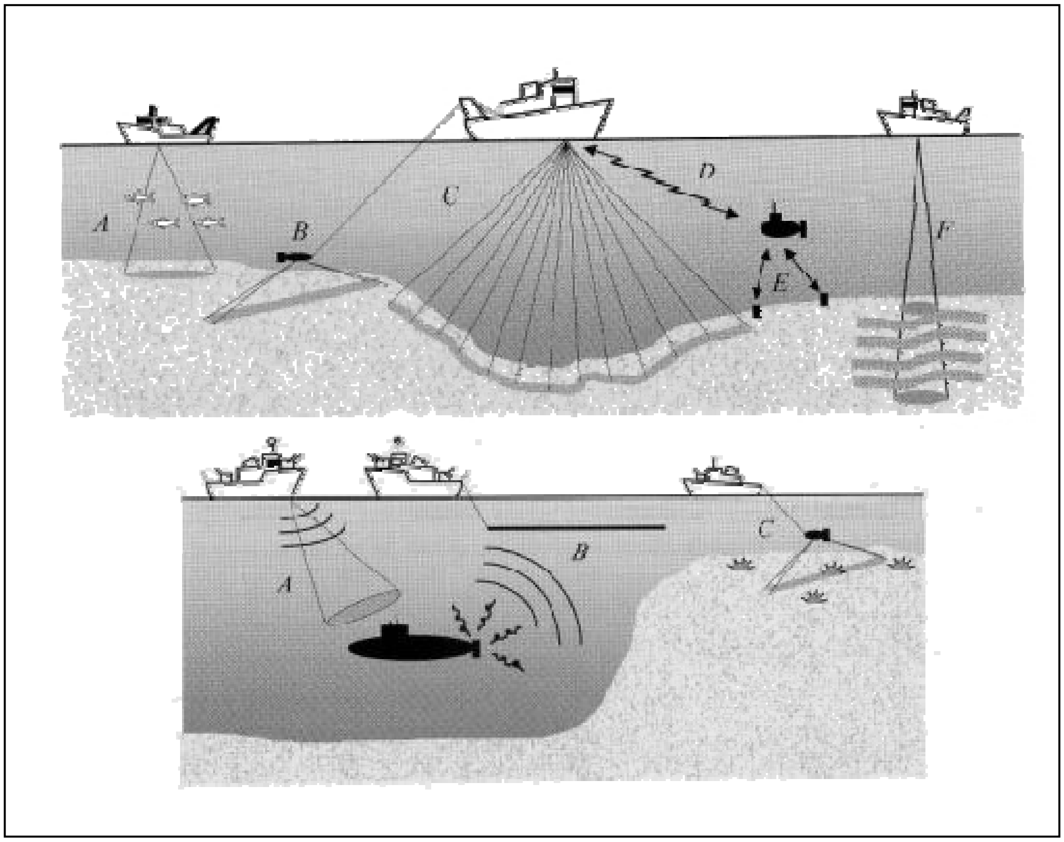


Figure 2. Several civilian and military applications of sonar.

Acoustic remote sensing technologies have been primarily used since the 1930's as a tool that provides an accurate and comprehensive seafloor map necessary in critical ocean management decisions (Anderson et al. 2008; Brown and Blondel, 2009). Seafloor information such as bathymetry, surficial geology and benthic habitats are important in fisheries management, marine spatial planning, monitoring environmental change or assessing natural cause and anthropogenic disturbance of marine benthic organisms.

In recent years, the improvement of Sound Navigation and Ranging (SONAR) technology, positioning capabilities and computer processing power have revolutionized mapping, imaging and seafloor exploration (Mayer, 2006). The use of sidescan and multibeam sonar with innovative transducers capable of sophisticated processing techniques, along with ROV and autonomous underwater vehicle (AUV) has greatly improved seafloor maps. Combinations of these technologies are commonly used to identify the distribution and topology of marine habitat as criteria in the marine protected area planning process (Jordan, et al. 2005).

Currently, acoustic seafloor mapping practices involve data acquisition, data processing, ground truthing, seafloor classification and data visualization. There are three types of sonar systems that are extensively used in data acquisition, namely side scan sonar, multibeam echo sounder and sediment profilers. Lurton (2002) provides an overview of the advantages and limitations of these sonar technologies. Mayer (2006) also describes other current advancements in seafloor mapping technologies such as sonar, ancillary sensors, platform data processing, and visualization and data products.

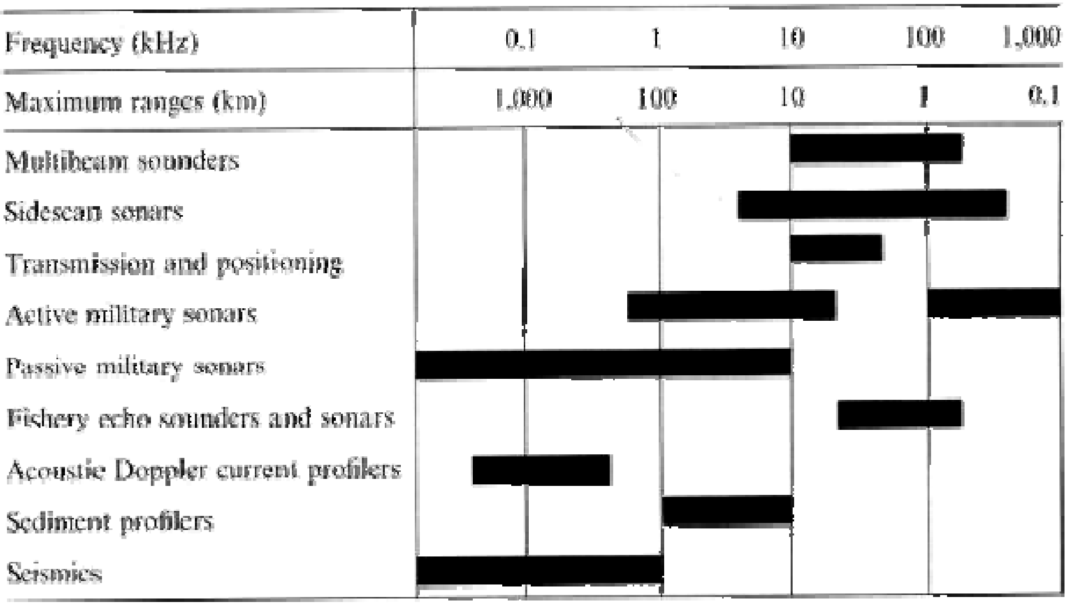
Ocean mapping system advancements are now geared toward developing complex and integrated collection of technologies in every phase of the seafloor mapping process. The remarkable advances in positioning system over the recent decades from sextant navigation in the 1960s, to global positioning system (GPS) and differential GPS (DGPS) in the 1980s to the late 1990s, and real-time kinetic GPS have provided significant changes to accuracies of seafloor maps Improvements in measuring vessel movement (i.e., heave, pitch, roll and yaw) which have allowed precise correction of the position of the sonar beam leaving the transducer and returning from the seafloor. Apart from correcting from vessel movement, the ability to determine water column properties (i.e. temperature, salinity and depth) with conductivity, temperature and depth (CTD) or measurement of sound speed with a sound velocity profiler (SVP) allows to correction of spatial and temporal variability of sound speed in the water column. Lastly, the current advancement of seafloor mapping is associated with the advancements in computing power. The huge density data collected using multibeam sounder is between tens to hundreds of megabytes per hour or in shallow water may even reach 1 gigabyte of data per hour. Computer technology has been able to keep up with the processing and storage along with various GIS processing and visualization software needed to interpret the data generated (Mayer, 2006).

Basic principle of SONAR

An active sonar system in water operates by transmitting sound waves and receiving the echo from an object or target (e.g., seafloor). Sound waves originate from the propagation of a mechanical perturbation and then local compression and dilations are passed on from one point to the surrounding points within a medium's elastic properties such as seawater. In seawater sound waves travel at a speed close to 1,500 m/s (usually between 1,450 to 1,550 $^{m}/_{s}$) depending on the pressure, salinity, and temperature of seawater. Sound as waves is often described in terms of frequency (number of vibration per second, in Hz) which remains constant even though its wavelength changes as local speed changes. The frequencies used in underwater acoustics range roughly from 10Hz to 1 MHz, depending on the application (Table 2) list the common frequency used in various sonar.

The propagation of sound is associated with acoustic energy. As it is propagates from the transducers through the seawater and back, it loses its intensity due to geometrical spreading losses (acoustic energy is lost as it is transmitted to larger volumes) and absorption of the acoustic energy by the seawater or attenuation losses. The amount of loss is dependent upon the distance it travels, therefore the farther a wave travels the weaker it gets. Depending upon the seafloor substrate, a certain amount of that energy will be absorbed and reflected. Softer seafloor substrates like sand and mud will absorb much of the energy whereas harder substrates like rocks and metal will reflect it. The fraction of incident energy per unit area that is directed back to the receiving hydrophone is called the backscattering strength (Lanier 2007).

Table 2. Frequency range of underwater sonar system (Lurton, 2002).



Multibeam Echo Sounders

Recently, Multibeam Echo Sounder (MBES) technology has been preferred in seafloor mapping. Its developments have provided a mapping tool which has begun to supersede other types of conventional acoustic survey systems (e.g., single beam echo sounders, sidescan sonar) for wide-scale offshore mapping. By using MBES, it is now possible to produce accurate, aerial-like images of the seafloor, and a number of nations are now using MBES to systematically map their territorial waters along with other similar types of application (Brown and Blondel 2009). Its capacity to co-register bathymetric and backscatter information has made it a system more preferred by many seafloor mapping initiatives. Le Bas and Huvenne (2009) have compared the two systems in term of cost of analysis at varying resolutions and survey coverage.

MBES system transducer frequencies greatly affect the formation and quality of imagery produced. Transducer frequencies define the range of useful signals, the lower the frequency the greater the range as it reaches deeper water. For most MBES systems, they produce higher frequencies from 100 kHz to up to 400 kHz. They are ideal only for shallow areas since it losses energy to attenuation after a depth of about 100 to 400m. (Le Bas and Huvenne, 2009).

Multibeam measures bathymetry and backscatter values by looking at time and angle as each beam impacts on the seabed. To accurately measure it, it should account precisely the movement of the survey vessel and the refraction of acoustic path by the sound velocity as it travels through the water column (Lurton 2002). Sounding data is then georeferenced using the navigation data provided by an operational positioning system. Like side scan sonar, multibeam also records the acoustic return signals using the similar principle. The performance of this type of backscatter however is less compared to a deep-towed side scan sonar system which record many more samples of the returning beam intensity. Despite this limitation, marine geologists use this mainly because it collects both bathymetry and reflectivity information simultaneously. Some systems record detailed intensity “snippets” across each beam, making these systems more like high-resolution sidescan sonars. Coupled with seismic profiles, sediment profile and ground truth information such as ROV video, photographs and bottom samples, it provides a much clearer picture of the seafloor structure. The information collected by multibeam has been widely used to develop seafloor characterization. The main difficulty in this approach is the subsequent interpretation of the seafloor characteristic and features. Some interpretation techniques will be discussed and will be used in this study.

This study utilizes acoustic data collected from a Kongsberg EM 3002 multibeam echo sounder. The system uses frequencies in the 300 kHz band which is ideal for shallow water (typically < 1m to 200m depth) survey. The system used is composed of a single sonar head with maximum angular coverage of 130^o. The system was operated in high density, equidistance mode which acquired a maximum of 254 soundings equally spaced in distance, over the 130 degree swath.

Processing of Multibeam SONAR data

Sonar processing involves cleaning of raw data and interpretation to generate an accurate map. Though the process may vary among researchers, it can be divided into three (3) main stages, pre-processing, processing and post processing (Blondel and Murton 1997). The pre-processing includes cleaning of the navigation and sensor’s altitude and conversion of raw swath data in preparation for different processing software, and cleaning and smoothing of errors brought about by the changes of vessel movement (e.i. heave, roll, pitch and yaw) will be corrected. Moreover, tide and sound velocity profile corrections will also be conducted especially in shallow water surveys. This systematic correction must be done at a very high level of accuracy to obtain a good processing and interpretation of the map of the seafloor (Le Bas and Huvenne 2009). The processing stage involves transformation of raw swath data to a usable image or grid that is radiometrically and geometrically correct representation of the seafloor. This includes gridding of bathymetry data and mosaicing of the acoustic backscatter data, as well as removal of the topographic component of backscatter data, and the changes in intensity due to range, power, and gain changes made during the survey. This stage is crucial for the final stage, the post processing stage which involves the seabed classification process and production of the maps. Various approaches have been used to classify these data. A more detailed schematic diagram of the process is shown in Figure 3 along with common techniques in every stage.

In this thesis, much of what was done was on the last two stages, particularly on

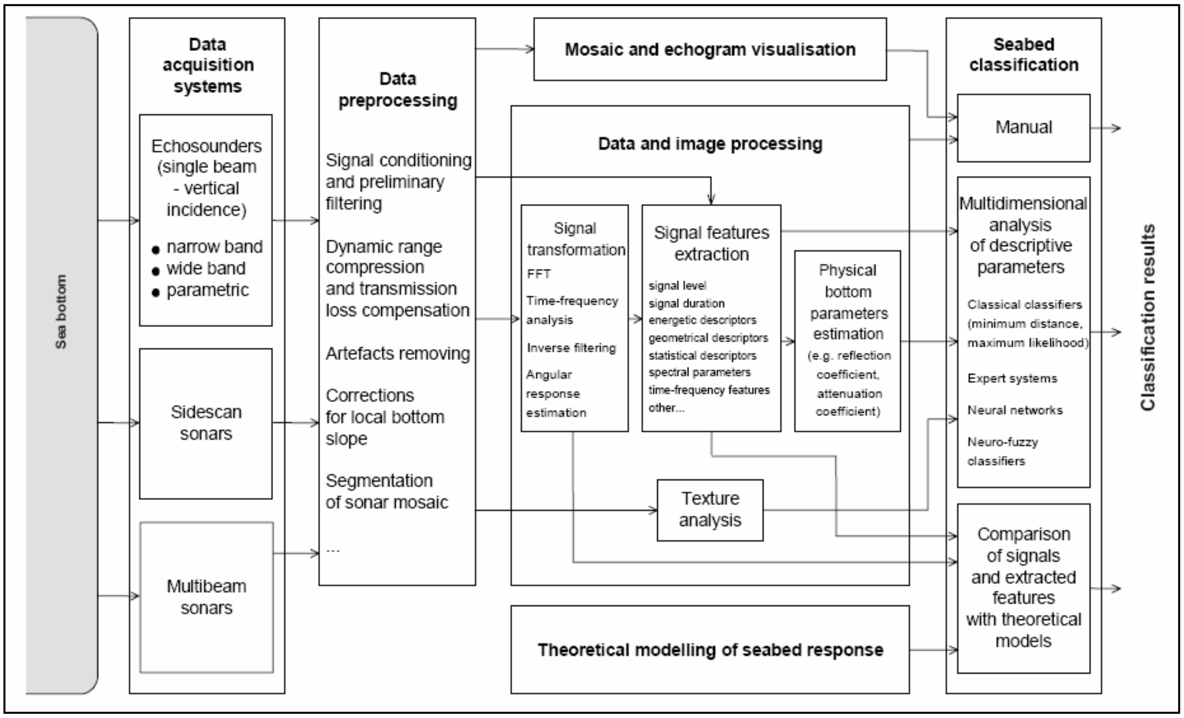


Figure 3. Schematic diagram of acoustic data-processing paths and methods of seabed classification (Anderson et al. 2007).

gridding bathymetric data, mosaicing backscatter images and transformation of the both grids and images to aid in the interpretation of the seafloor habitats.

With various factors affecting the acquisition of acoustic data, errors are always inevitable. These errors often called *artifacts* or *anomalies* are then propagated as the data undergoes the succeeding stages of data processing and interpretation. All the stages of processing acoustic data are prone to error or artifacts, some of them are unavoidable, but most of them are should be recognizable. The presence of artifacts and anomalies are sometimes ignored in order to get enough survey coverage given the specific sonar being used. Other common errors are often corrected during the data processing stage while others are considered during the interpretation aspect of the process.

Among the common artifacts present in acoustic data collected from multibeam echo sounder as well as the process by which they should be corrected were reported in numerous research by Hudges et al. in 1996. Bathymetric data error such as roll, refraction, positioning is often cause by imperfect motion sensing and needs to be corrected, though this is not always possible. Moreover, effect of tides, heave vessel lift/squat, antenna motion and internal time delay should also be corrected especially in shallow water survey. Most of these artifacts cause greater errors in hydrographic data quality or bathymetry data than bottom detection. For backscatter data, while the system response is well characterized, significant post processing is required to remove residual effect of imaging geometry, gain adjustment and water column effect. If these artifacts are properly removed or recognized, one can easily interpret or perform subsequent analysis to aid seafloor classification.

Various methods in classifying acoustic data

Using the processed acoustic data, it is then used to classify different marine habitats. In order for it to be useful to management and research, it is vital to identify correctly potentially good habitats for marine resources management. The goal of classifying marine habitat is to define the spatial extent of the potential habitat in terms of its geological, biological or oceanic attributes. However, the complexity of the marine habitat cannot be equated to seabed substrate type only derived from acoustic data. Several authors have stressed the need to differentiate substrate mapping and seafloor habitat mapping. Habitat requires more than just substrate interpretation but also on an extensive environmental preference and groundtruth data (Diaz et al. 2004). However, information on species and substrate is often the starting point. Capturing the distinguishing characteristic of each seabed type and the organism within it has become the main objective in most habitat mapping efforts. Because of these limitations, seafloor mapping researchers stress that all habitats in such reports are referred to as "potential habitat" and further investigation is necessary to address this limited information.

Using acoustic seafloor maps as a tool has gained broad acceptance in many marine resource management initiatives. However, its accuracy in delineating unique seafloor feature is based on how it was interpreted. Interpretation of seafloor feature using bathymetry and backscatter image along with ground truth information always have been conducted for over a decade. Classification of seafloor involves the segmentation or partitioning of the whole dataset into homogeneous class (Simard and Stepnowski, 2007). Seafloor classification can mainly be done either through manual or automated approaches. Both approaches have advantages and disadvantages. Commonly, researchers have to base the exact choice of approach primarily based on time, availability and quality of ground truth information, even though uniformity of methods is also a desirable, but typically unattainable goal.

Manual interpretations are done by dividing the seabed into polygons to represent homogeneous acoustic characteristic or morphological features. Substrate classification can be discerned through a careful visual examination of a bathymetric layer and backscatter mosaic. The layers are georeferenced and overlaid with GIS software such as ArcGIS tools. It often requires technical skills to visually interpret bathymetric layer or backscatter mosaic and draw polygons around distinct seafloor features or substrate class. Often this approach is highly subjective, especially in areas with subtle transitions from one substrate class to another. Recognizing different substrate classes or seafloor features greatly depends on the ability of the observer to detect features or artifacts and to understand how these images were created. It is the artifacts primarily that prevent fully automated classifications from being successful. However, for most data set seafloor features such bedrock, structure (faults, folds, landslide) and bed forms of unconsolidated sediment such sand waves are easily distinguished (Green et al. 2004, Kendall 2004). The use of shaded-relief layer and 3D model of the bathymetry layer provides an easy guide to identifying features such as bedrock and rock outcrops (Christensen et al. 2008).

On the other hand, automated classification approaches have increasingly been used in the recent years. In recent developments in the processing of MBES data, there has been a need to create an appropriate classification techniques and approaches for bathymetry or backscatter images or the combination of both data. Concurrent use of advanced computer technologies, underwater videography and navigation has been used in many seafloor mapping initiatives. With increasing volume and complexity of available dataset, automated techniques are becoming more important in providing repeatable and efficient method for improving seafloor characterization, though often at the expense of accuracy and quality.

Several approaches have utilized bathymetry data solely to classify the seafloor topography. Analysis and interpretation were mainly based on benthic terrain data created from the multibeam bathymetry. Lundblad et al. 2006 uses bathymetric position index (BPI) along with slope and rugosity to classify the seafloor topography to distinguish features such as slopes, flats, crests and depressions (Lundblad et al. 2006). BPI is a second-order derivative of the bathymetry data which was modified from topographic position index used by Weiss (2001) to classify terrestrial landforms. It is calculated using neighborhood analysis functions and produces an output raster of BPI values based on its surrounding areas. Positive cell values within a BPI data set denote features and regions that are higher than the surrounding area such as ridges. Likewise, negative cell values denote features and regions that are lower than the surrounding area such as valleys and values near zero are either flat areas (where the slope is near zero) or areas of constant slope (Weiss 2001). Details on how BPI is calculated are explained in Lundblad et al. (2006). Other benthic terrain studies using a similar approach include Iampietro and Kvitek (2002) and Copps et al. (1998).

Benthic Terrain Modeler (BTM) was created to classify bathymetry data from acoustic surveys (Wright et al. 2005). BTM contains a set of ESRI ArcGIS-based tools to create grids of slope, bathymetric position index and rugosity from a bathymetry data set. A unique feature of the tool is its wizard-like functionality that steps up users through the processes involved in benthic terrain characterization, and provides access to information on key concepts along the way. An integrated XML-based terrain classification dictionary gives users the freedom to create their own classifications and define the relationships that characterize them. This tool was used with some caution however, and choices of “scale” are arbitrary, and differ from one area to another.

With the availability of both bathymetry and backscatter information from multibeam survey, there is a growing clamor to combine both data along with ground truth information to classify seafloor features. Multibeam bathymetry and backscatter data, coupled with validation data can provide important insights into benthic habitat distribution and complexity (Ierodiaconou et al, 2007). Moreover due to the advancement of computer processing capabilities and improvement of GIS and visualization software, numerous techniques have recently been developed. Brown and Blondel (2009) categorize these classifications into two (2) distinct approaches, geoacoustical and feature-based approaches. Geoacoustic approach aims to match individual backscattered waveforms to shapes expected from specific types of terrain (due to the sediment grain size, porosity, density, etc.). It incorporates other derivatives such as, rugosity, BPI, maximum curvature, gray-level co-occurrence matrix or a combination this parameter to classify the mosaic. Several studies combine for example the angular response of backscatter with information from the local bathymetry (Hughes-Clarke et al. 1996; Mitchell and Hughes-Clarke YEAR?; Fonseca et al. YEAR?). The angular variations of MBES backscatter have been used with models of amplitude-offset changes on series of stacked pings (Fonseca and Mayer 2007).

Among the recent techniques used in acoustic data for seafloor characterization is looking into the variation of backscatter strength with the angle of incidence which describes the intrinsic property of the seafloor. Commonly called angular response analysis (ARA) attempts to preserve backscatter angular information and use it for remote estimation of the seafloor properties. Fonseca and Mayer (2007) describe how several parameters are extracted from stacks of consecutive number of sonar pings (normally 20 to 30) across swath width. These parameters then define the distinct seafloor properties of the port and starboard side of the swath. These parameters include acoustic impedance, roughness and grain size. Fonseca et al. (2009) found a very good correlation between the classification using ARA and bottom photographs. Similar concepts are now incorporated in multibeam processing software such as Interactive Visualization System (IVS3D) Fledermaus (FM) Geocoder Version 7 and Caris Version 7 with its Geobar tools. Although, results of the ARA lack spatial resolution, they can be used to extend groundtruthed imagery into areas with limited groundtuth, and provide an ARA-based classification of the seafloor.

In any classification approach, ground truth information is essential to establish the relation between the acoustics characteristic and the seafloor. More often, ground truth may use photographs, sediment samples or video recordings. These should be georeferenced in accordance to the acoustic data. In some instances, researchers, divers and local knowledge will provide important information in the interpretation process.

Automated classification and manual interpretation both have advantages and disadvantages (Table 3). Deciding on which approach to use often takes consideration of time, logistics, data quality and skills of the researcher. However, automated classification can only be useful as a starting point for the manual interpretation (Christensen et al. 2007). Classification boundaries in an automated classification can be further adjusted to subsequent polygon during manual interpretation.

Table 3. Some advantages and dis-advantage of automated classification and manual interpretation.

Automated Classification	**Manual interpretation**
Retain graduation change in substrate [a]	Area have discrete value for several attributes [a]
Minimal time is required from data acquisition to map production [b]	Time intensive
Provide a georeferenced image of substrate distribution and depth [a]	Subjective and highly dependent to the interpreter’s knowledge and experience with acoustic information
Generate summary statistical information [a]	Greater number of classification [b]
Artifact from the data is also classified which can be mis-interpreted	

Source: [a] Cochrane 2008, [b] Christensen et al. 2007

This study utilizes a combination of both automated and manual classification approaches. Classification created from methods such as BTM and ARA were used to provide a broader guide to identify substrate classification boundaries. A detailed correction of these boundaries was manually interpreted. A combined approach aims to minimize misclassification due to unavoidable variation in data quality during sonar surveys. It should be noted that output of the both approaches will still be valuable information which can be used for further types of analysis.

Classification scheme

Generally, there are two approaches in characterizing marine habitat i.e. top-down and bottom-up classification. The top-down approach considers primarily the flora and fauna to describe each habitat and substrate or geology as secondary descriptor. This classification scheme is often preferred by biologists. On the other hand, a bottom-up classification scheme considers geological make of the seafloor as the primary descriptor (Greene et al. 2005). With the advancement of acoustic sensing technology and the ability to generate seafloor topography and predict geological composition of the substrate, the latter has become the most widely used in habitat mapping, though ultimately, a merging of the two will likely take place.

In many habitat mapping, it has always been a challenge to standardize classification schemes of seafloor habitat mapping. More often, various mapping efforts require cross-walk tables between studies for comparability purposes. Greene et al. (1999, 2005, and 2007) has proposed a standardized technique to facilitate reproducibility of habitat designation and comparison of deep-water habitat worldwide. The scheme is based on physiography and scale, indurations (hardness of substrate) and geomorphology. Each classification has its attributed code primarily based on the about feature.

Another scheme is the Coastal and Marine Ecological Classification Standard (CMECS) scheme which, aims to provide a uniform protocol for identifying and naming new and existing ecological unit within United States coastal and marine environments. The classification covers from the estuarine system toward the oceanic region of the marine environment. This study limits its classification on the Surface Geologic interpretation of the substrate given only the possible inference acoustic data can provide. Moreover, surface geology provides context and setting for many marine processes, and provide hard or soft structure for benthic flora and fauna. CMECS surface geologic component focuses only on the upper layer of the hard substrate or the upper centimeter of the soft or unconsolidated substrate (Madden et al. 2009).

Assessing accuracy of seafloor characterization

The widespread use of acoustic-based interpreted seafloor maps has been and will continue to be a more accepted approach depending on the quality of the map information derived from it. The assessment of error and inaccuracies is often a concern of any seafloor mapping effort. Accuracies of remotely-sensed map, like acoustic-based interpreted seafloor maps, are measured based mainly on two criteria: location accuracy and thematic accuracy (Conglaton and Green 1999). Location accuracy refers to how precise the map items are located on the map relative to the true location on the ground. Thematic accuracy refers to the accuracy of the map label in describing a class (e.g., substrate classification) on the seafloor.

In seafloor mapping, assessing of error or inaccuracies of generated seafloor maps is often compared to resulting seafloor maps against a georeference ground truth information. Ground truth information may use data through ROV video, bottom photographs or bottom samples. Given the dynamic characteristic of the seafloor, this information should have a short time interval between the collection of ground truth data and the acquisition of the acoustic data (Kendall et al. 2005).

Most of the accuracy assessment method employs the calculation of the error matrix used by Congalton and Green (1999) to assess accuracy of remotely-sensed images such as aerial photograph. Quantitative assessment is done by comparing seafloor map against reference information on the site. The accuracy of this reference information greatly affects the accuracy of the created seafloor maps.

Developing an error matrix is a very effective way to represent map accuracy. By comparing each category (e.g., habitat class) from the ground truth information (e.g., ROV video), it identifies which class in the created map is classified incorrectly based on the ground truth data (commission error) and errors which were excluded from the class where it should belong based on the ground truth information (omission error). It also summarizes all the correctly classified points known as overall accuracy.

Previous mapping initiatives

There have been several mapping initiatives conducted off the coast of Oregon and more particularly in Redfish Rocks. Each mapping effort employed different methods but its primary goal was to develop a habitat map of the seafloor. Output map of each effort where also used for various purposes in marine resource management and research. These maps can be used to compare with the map produced in this study. In 1975, Kulm et al. described the nature and distribution of sedimentary facies of the Oregon continental shelf and relate this to other processes such as estuarine circulation system and sediment input from the coastal drainage. The map being created was based on the data collected from grab and core samples and bottom photographs. The study was able to create a model map showing different sedimentary facies of the continental shelf as well as identify several factors that control these facies.

Since 1995, ODFW have been conducting numerous mapping efforts needed as the basis in sound decision making in managing the territorial sea. Maps being produced include data from side scan sonar, multibeam surveys, ROV videos and SCUBA survey (Fox et al. 1998, Fox et al. 1999, Weeks and Merems 2004; Fox et al. 2004; Donellan et al. 2008). This includes a side scan sonar survey conducted in 1995 in Redfish Rocks Reef. A side scan mosaic of the survey was interpreted visually along with ground truth information from SCUBA surveys. Figure 4 shows the bottom type as interpreted from the side scan sonar data. Habitat types being identified include bedrock, small (<2m) and large (>2m) boulders, gravel / cobble and sand. Fracture-like structure high relief and emergent rock was also noted.

Together with the ODFW, the Active Tectonic and Seafloor Mapping Lab (ATSML) of Oregon State University have been continuously improving the surficial geologic habitat (SGH) map for the states of Oregon and Washington (Romsos 2004; Romsos et al. 2007). The SGH map is based on the various geophysical datasets, including bathymetric grids, sidescan sonar imagery, seismic reflection profiles, sediment sample and human occupied submersibles. The broad scale maps produced have been used to aid in identifying species management action such as delineating essential fisheries habitat (EFH). The current versions of SGH includes a details, especially on the near shore habitat, incorporating the map created by Agapito (2008) which was a lithogic interpretation of Oregon’s territorial sea from sounding data. This map has become an important tool in the selection process of Oregon’s marine reserve initiative.

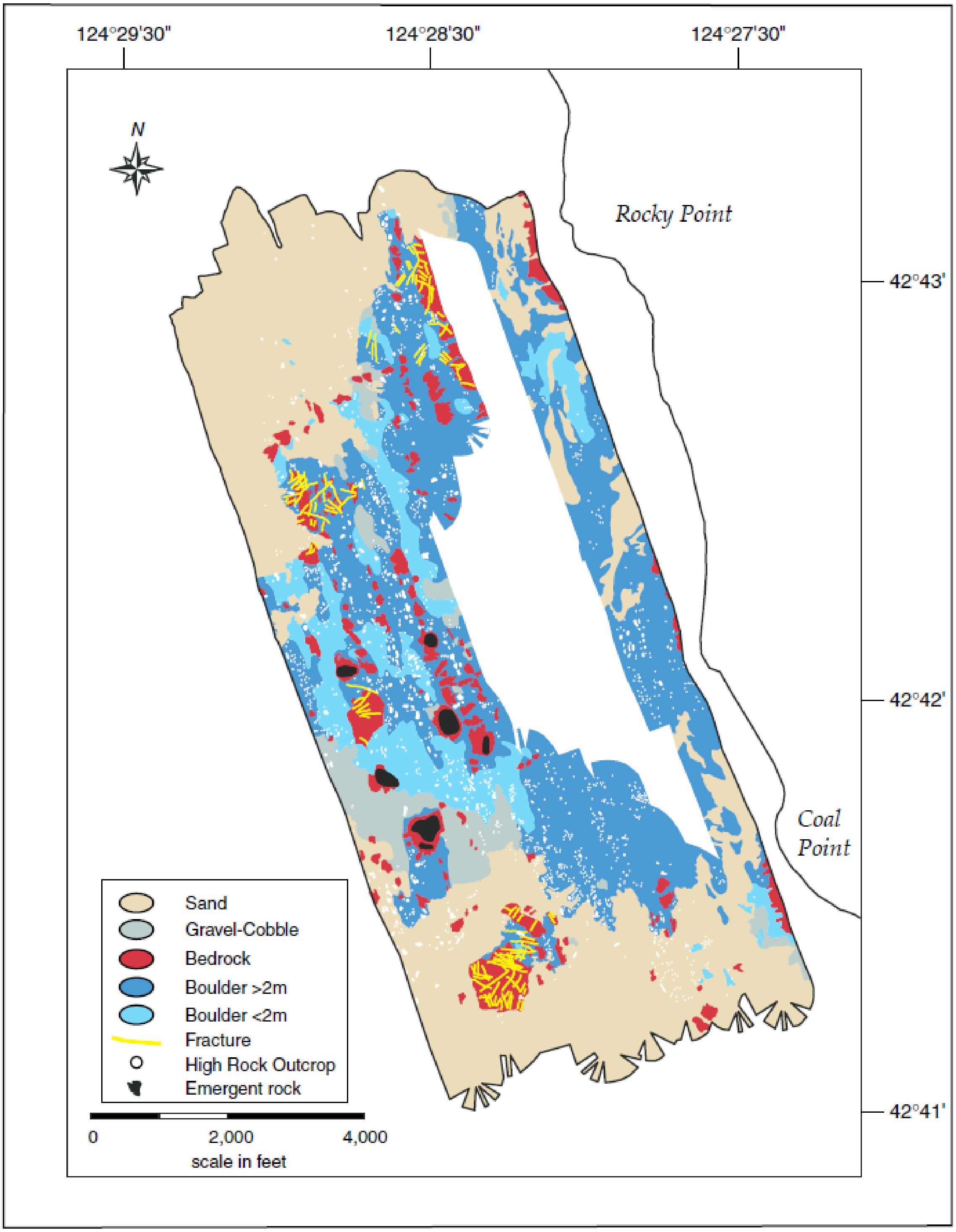


Figure 4. Bottom habitat type interpreted from 1995 sidescan sonar survey (Fox et al. 1998).

Method

This section describes the methodologies that were employed to create the habitat map of the Redfish Rocks Pilot Marine Reserve. It includes data collection methods (multibeam sonar survey, ROV survey), data processing and how the habitat was interpreted using various derived layer from the bathymetric data and acoustic backscatter mosaic.

Multibeam data acquisition

Multibeam sonar data were collected by Seavisual Consulting Inc. headed by hydrographer, Terry Sullivan using a Kongsberg EM3002 sonar system mounted on the side of F/V JC. The sonar surveys were conducted in July 2008 and May 2009. The survey was an effort of the ODFW along with POORT and Golden Marine Consulting to develop a high resolution seafloor bathymetric map of Redfish Rock needed for detailed habitat research and marine protected area planning. Sound velocity profile was recorded using Seabird SBE-19 CTD for sound velocity and ray path bending correction of the sonar. Post survey data processing was done using Caris HIPS hydrographic processing software to resolve tide, draft and sound velocity corrections. Detail of the pre-processing procedures and multibeam sonar system are described in Sullivan (2009). Raw bathymetric data (xyz file) was imported from Caris HIPS to create a bathymetric grid. Raw Simrad .all survey line files were used to create acoustic backscatter mosaic using IVS 3D FM Geocoder.

Processing of bathymetry, backscatter and derivatives

Bathymetry. A XYZ ASCII file from the multibeam bathymetry data of the July 2008 and May 2009 survey was combined and gridded to create a 2m resolution bathymetric digital elevation model (DEM) of the survey area using ArcGIS 9.3. The output raster was projected using the WGS84 Zone 10N projection. This bathymetry DEM raster layer was used to derive the hillshade layer and the other derivative layer used in the BTM classified layer such slope and bathymetric position index (BPI). Similar ascii file was also used to create and visualize a 3D image using IVS 3D software Fledermaus and Dmagic.

Hillshade layer. A hillshade layer was created using the hillshade tool of the Spatial Analyst toolbox of ArcGIS 9.3. The hillshade function obtains the hypothetical illumination of a surface by determining illumination values for each cell in a raster. It does this by setting a position for a hypothetical light source and calculating the illumination values of each cell in relation to neighboring cells.

BTM classified layer. BTM classified layer was created using the Benthic Terrain Modeler extension tool of ArcGIS 9.3. The tool calculates BPI using a neighborhood algorithm, creates slope layer, and combines this information to produce a classified map according to its topographic structures. A detailed description of BTM process is explicitly explained in Lundblad et al. (2006).

This study uses broad scale factor of BPI of 50 with inner annulus of 5and outer radius of 2, whereas, it uses fine scale factor of BPI of 6 which was found to capture the variation of the reef seafloor. Several broad scale factor were also tried such as 70, 100 and 150, however, the latter scale was observed to better show the complexity of the seafloor. The resulting BPI grid was then classified using the habitat zone and structures based on the classification used by Lundblad et al. (2006).

Creating the backscatter mosaic. In a multibeam system, apart from the depth ranges being recorded, most systems also collect the backscatter intensity as affected by the system at the time of the acquisition. These intensity values at each beam will be assembled to create the backscatter mosaic. The backscatter mosaic was created using IVS 3D FM Geocoder Version 7 software. Geocoder performed numerous corrections to best estimate the backscatter intensity. First, it corrected all gains and time –varying gains applied during acquisition. Then, corrected for the terms of sonar equation e.i. transmission loss, actual area of insonification, source level and transmit and receive beam pattern. In addition, it corrects for the seafloor bathymetric slope. Details of the processes involved in the numerous are more fully described in recent reports (Fonseca et al. 2009; Rosa 2007; Fonseca and Calder 2005). Geocoder also allows the user to apply corrections such as Angle Varying Gain (AVG) correction across swath and feathering between lines to minimize artifacts in the resultant backscatter image. Fonseca et al.

(2009) compares the difference between the mosaic without AVG correction and the final corrected mosaic as shown in Figure 5.

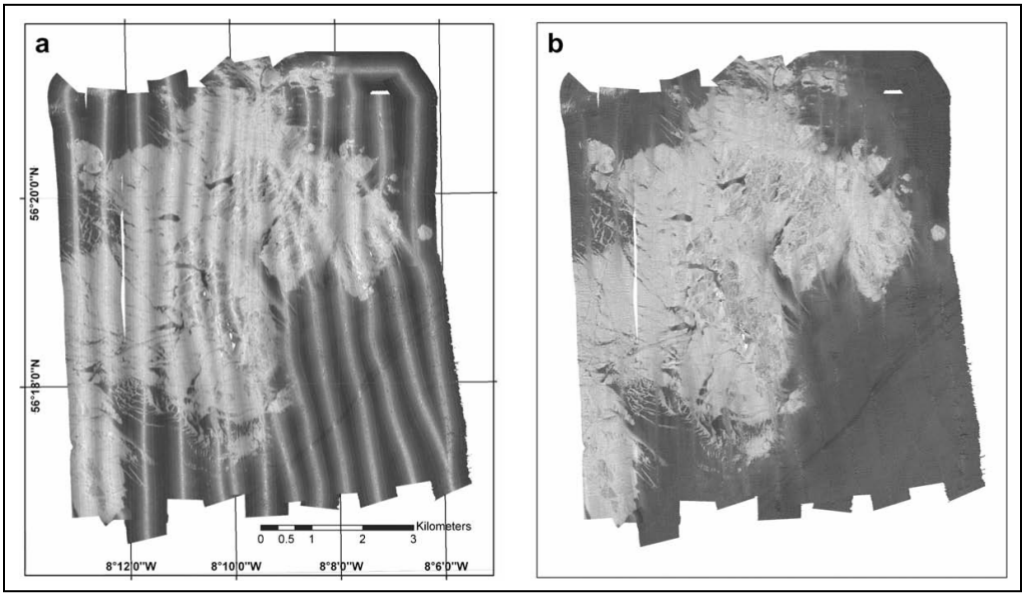


Figure 5. Difference between backscatter mosaic with no AVG correction (a) and with AVG correction and feathering between adjacent lines (Fonseca et al. 2009).

A total of 51 survey lines from both July 2008 and May 2009 multibeam survey were used to create the mosaic. AVG correction was applied at 30º to the mosaic using the average algorithm. Histogram corrections were also made to improve contrast within the image. The resulting image was then exported as Georeferenced Tagged Image File Format (GeoTIFF) file so it can be overlaid within ArcGIS 9.3 for further analysis and manual digitizing. A step by step procedure in creating the backscatter mosaic is attached in Appendix A.

Angular Response Analysis (ARA). The variation of backscatter strength with the angle of incidence is an intrinsic property of the seafloor (Hughes et al. 1996). It can be utilized for more robust methods for acoustic seafloor characterization (Fonseca et al. 2009). This method has the background concept used in ARA in Geocoder, backscatter analysis software developed by Luciano Fonseca and its colleagues of University of New Hampshire.

During the creation of the backscatter mosaic, Angular Response Analysis was also performed in IVS 3D FM Geocoder. Results of the analysis includes grain size, sediment classification and location (X,Y). An ASCII file was exported to ArcGIS. This point type data represent a sediment classification based on the angular response of the seafloor can be utilized to perform for a GIS-based analysis. The file was imported to ArcGIS and plotted using a Thiessen polygon to provide better spatial representation of the information such as grain size across half-width of the swath. The resulting polygon was then used to train the backscatter image using Maximum Likelihood cluster analysis. This layer was used to help in the manual interpretation. A step by step procedure in creating the backscatter mosaic along with the ARA analysis is attached in Appendix A.

Collection of ROV video. All video data were collected by ODFW using the Phantom HD2+2 ROV. An ROV survey was conducted on April and May 2008. The survey was part o ODFW effort to develop a fisheries-independent and non-extractive method for assessing reef fisheries in Oregon under its Marine Habitat Project. A total of 12 transect lines covering a total distance of 42,500 m, were surveyed. Details of the ROV specification and description, ROV operation and post survey processing were described in Donellan et al. (2008). Figure 5 shows the ROV survey tracks conducted in the Redfish Rocks.

A copy of the video provided by ODFW was used as ground truth information to verify lithologic classification during the manual interpretation and digitizing. The video was viewed using media player software (e.g Windows Media Player and VLC Media Player) and general the ROV path was plotted over the layers in ArcGIS to serve as guide in digitizing. ROV classified points were also used to train a classification of the backscatter mosaic but this was ultimately not used due to ROV positional issues. These caused a consequent misinterpretation, especially, in areas with image artifacts.

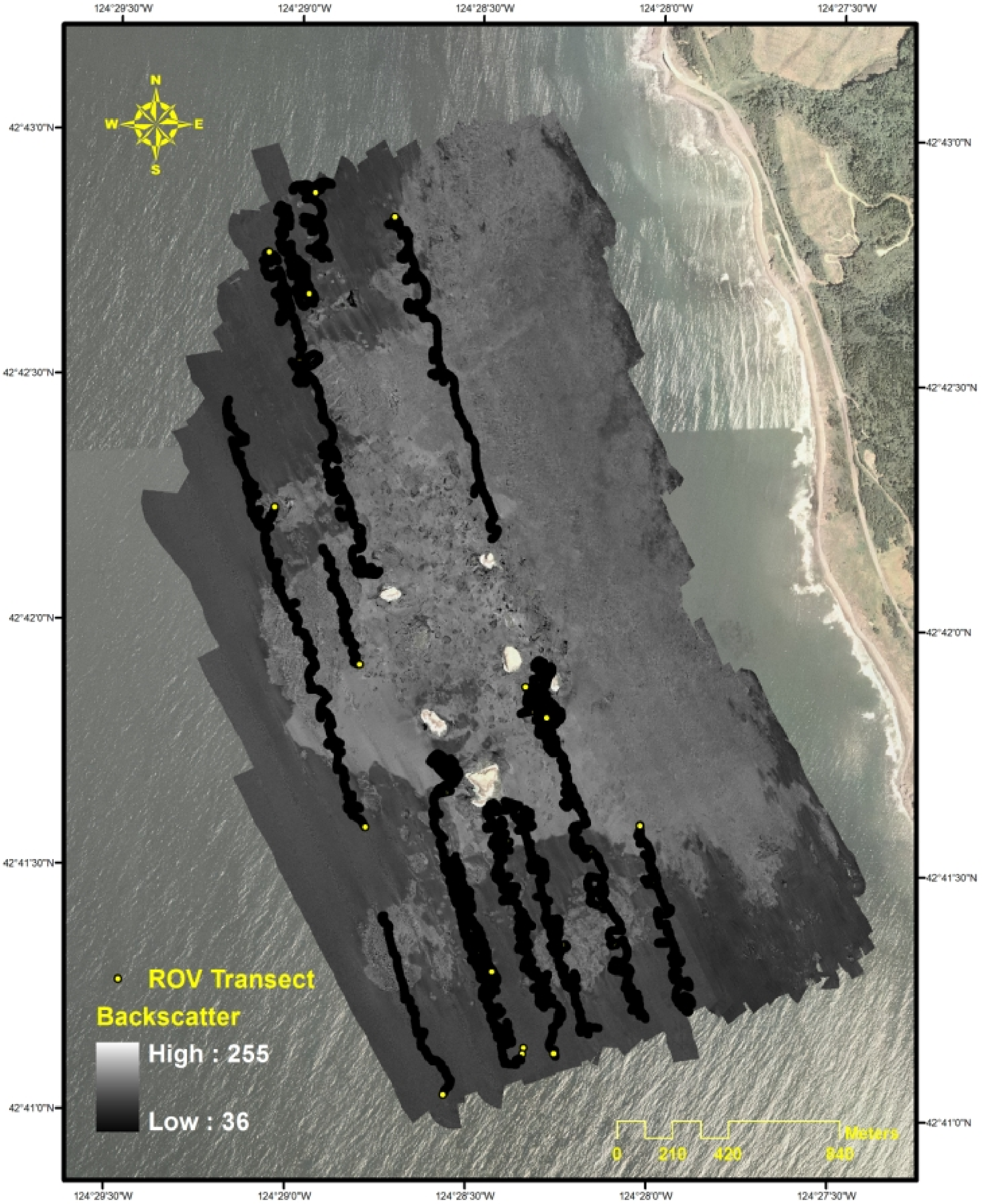


Figure 6. ROV video tracks overlain on backscatter mosaic.

Manual interpretation and map production

The benthic habitat map of Redfish Rocks Pilot Marine Reserve was created by visual interpretation from derived layers of bathymetric DEM and backscatter imagery. The DEM, hillshade, BTM classified raster, backscatter mosaic, ARA classified layer and ROV tracks were loaded into ArcGIS 9.3. All layers were georeferenced using WGS84. At first, boundary delineation was done by digitizing large features such as flat fine sand areas. These can be easily distinguished from the video, backscatter and BTM layers. Rocky outcrops boundaries were also drawn based on the Hillshade layer. Digitizing scale at was 1:2000 where boundaries are just discernable. Boundaries are then adjusted using the backscatter mosaic with finer 0.5m resolution with a scale of 1:1000 to 1:300. Primarily, polygon boundaries were created in the general process as shown in Figure 6. Additional zoom will be made to improve line placement of the individual classification. By alternating, between the backscatter mosaic, derive bathymetric layers and ground truth video, the boundaries of each benthic habitat could easily be interpreted. Each polygon is attributed with its appropriate habitat classification. Additional, adjustments were also made using the ARA classified layer, especially in transition areas between fine sand to gravel and gravel/cobble to boulders. Previous, surfacial lithologic maps created by the Active Tectonic and Seafloor Mapping Lab were also incorporated into the new benthic habitat maps, especially in the shallow water gap not covered by the multi-beam survey.

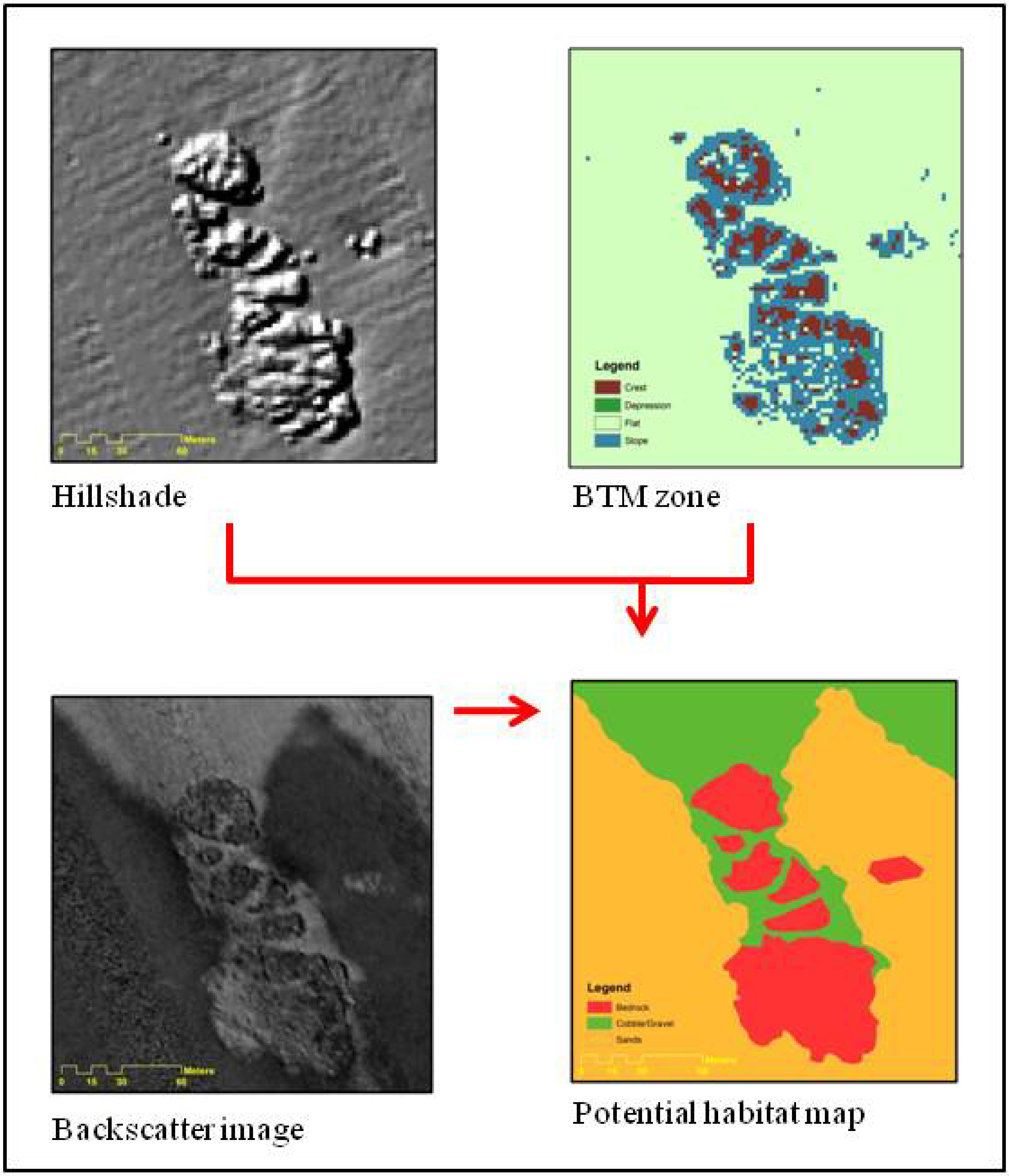


Figure 7. Polygon boundaries were drawn primarily based on the three mainly layer hillshaded relief; backscatter mosaic; and (c) potential habitat map.

Four (4) main benthic habitat classes were identified and interpreted based on the following observations from the bathymetric raster, backscatter mosaic and derivative layers:

Interpreting bedrock. Bedrock covering 75% of the surface substrate describes this classification. This class is identified in the hillshade raster based on the geomorphology, often expressed as large rock outcrop with long ridges. Bedrock is also typically covered with joint patterns that help distinguish it from boulders. Rugosity alone cannot make this distinction. Similar ridges are also visible in the backscatter mosaic.

Interpreting boulders. Substrate in this classification more than 75% aerial cover of boulder (> 256mm) alone or in combination of bedrock. It also includes rubble, small and large boulders in several classification schemes (Madden et al. 2009). It can be distinguished in the hillshade layer, characterized by its numerous small ridges, high rugosity, and lack of joint patterns. Moreover it is commonly categorized as the crest zone in the BTM classified layer. Its sonar signature may be similar to bedrocks, though without joints.

Interpreting sand. Sand classification is described when greater than 50% of the unconsolidated particles is composed of sand (0.07 – 2mm in grain size) which maybe calcareous, terrigenous or may be derived from other sources. This sand is relatively flat to gradual changes in bathymetry and has a very homogenous backscatter signature. Large portions of the deeper area of the marine reserve are fine sand which is characterized by low (dark) backscatter.

Interpreting cobbles/gravel. This classification is determined when greater than 50% of the unconsolidated particles are composed of cobbles / gravel (2 – 256mm in grain size). Shell fragments, sand and silts often fill between the large particles. Stones and boulders may be found scattered in some cobble / gravel areas. Their sonar signatures clearly distinguishable in backscatter mosaic with a high reflectance value, especially when they are adjacent to large sand sediments.

Images of each substrate class taken from a snapshot of ROV video are shown in Figure 8.

Figure 8. Images of different substrate from ROV video: (a) bedrock, (b) boulder, (c) sand and (d) cobble/gravel.

Classification scheme used

This study uses the Coastal and Marine Ecological Classification Standard (CMECS) developed by the National Oceanic and Atmospheric Administration (NOAA) and Nature Serve. Classification is primarily under its Surface Geology Component (Madden et al. 2009). Under this component, substrate is classified as bedrock when the substrate it is covers is more than 75% bedrock, whereas substrate with less that 75% bedrock is classified as boulder. On the other hand, the bottom is classified Cobble/Gravel when substrate has unconsolidated particles greater than 50% smaller than boulders with grain size 2-256 mm. Shell fragments, sands and silt often fill the spaces between the larger particles. Substrate is classified sands when unconsolidated particles are greater than 50% sands (particles 0.07-2 mm).

For comparison purposes, this study will match classification schemes used in the other habitat mapping effort in the Redfish Rocks and Oregon state waters. These efforts includes: Surficial Geologic Habitat mapping spearheaded by the Active Tectonic and Seafloor Mapping Laboratory of Oregon State University, and ODFW ROV video substrate classification (Donelllan et al. 2008) and the 1995 bottom habitat type created from sidescan sonar survey (Fox et al. 1998) . This classification is shown in Table 4. It should be noted that classification of substrate is based on its primary habitat. Bedrock class is similar to both ODFW and 1995 sidescan survey however this class was convert to rock. Small and large boulder where lump to a boulder class.

Table 4. Comparison of Redfish Rock Habitat classification and other classification.

Redfish Rock Habitat Map *(based from CMECS)*	Surficial Geologic Habitat Map *(primary habitat)*	ODFW *(substrate classification)*	1995 Sidescan SONAR Survey *(substrate classification)*
Bedrock	Rock	Bedrock	Bedrock
Boulder	Rock	Large boulder, Small boulder	Large boulder, Small boulder
Cobble/Gravel	Gravel, Cobble, Shell	Cobble, Gravel, Hash	Cobble, Gravel
Sand	Sand	Sand	Sand

Assessing accuracy

In order to assess comparability of the map to previous maps, an error matrix was created as described by Congalton and Green (1999). Comparison was made between the Redfish Rock habitat map to SGH, with ROV video classification and with bottom habitat type map from the 1995 sidescan survey. Generally, comparison was done by intersecting points between two compared maps using Analysis tools in ArcGIS. This point shapefile incorporates the substrate classification of the map being compared. Shapefile table is then exported to MS Excel for error matrix calculation. Classification is then matched, and each pair of classification calculated using a pivot table. Overall accuracy, commission and omission errors were calculated.

This study used the Redfish Rock habitat map to compare the ROV video collected by ODFW. Four dive transect videos (Dive 183, 182, 190 and 194) out of 12 transect were used for the accuracy assessment. Track points were plotted into ArcMap 9.3 and were inspected to scan and eliminate obvious erroneous points. Donnellan et al. (2008) reported that a considerable position error along these tracks due to glitches of instrument positioning during the survey. Points that don't have substrate classification due to poor visibility were also eliminated. The points were then intersected with the Redfish Rock habitat map to create a table with substrate classification (both from ROV video and habitat map) in each of the points from the ROV track. A total 791 points were used for the assessment. The dBASE table was then exported to MS Excel. Substrate classification of other habitat maps tracks were converted to CMES classification as shown in Table 4 for comparison with the habitat map.

Results

The primary result of the research is to be able to make an accurate description of the seafloor habitat of Redfish Rock Pilot Marine Reserve based on the information collected from the multibeam echo sounder survey. In order to provide the most accurate interpretation of habitats, various derive layers were created from the bathymetry and backscatter information. Details of these layers as well as the habitat interpretation will be presented in this portion of the study.

Bathymetry

The multibeam survey mapped was conducted in a depth range of 1.9m – 55m, with an average water depth of 24m. An area of over 667 ha was mapped using multibeam survey, which covers ~93% of the marine reserve. Almost 70% of the mapped area is deeper than 20m (Table 5). It should be noted that much of the remaining unmapped area is the shallow portion of the reef. One of the limitations of multibeam survey is shallow water gap wherein risk factor is too high when navigating in shallow water. The possibility of running aground with sonar head and or entangling with overlaying bottom features such kelp beds or other large sessile fauna makes some areas un-mappable.

Table 5. Area covered by depth range in Redfish Rock Pilot Marine Reserve.

Depth range *(m)*	**Est. Area** *(ha)*	**%**
0-10	44.5	6.7
10-20	164.9	24.7
20-30	258.8	38.8
30->50	199.5	29.9
Ave. depth	*24.2m*	**100.0**

Generally, the Redfish Rock Reef is characterized as gradually sloping areas with large high relief rock present in the central portion of the reef. Six (6) of these rock outcrops are visible in the water surface as shown in the hillshade raster overlaid with the bathymetry layer (Figure 9). Rugged terrain characterized the mid and the inshore portion of the reef whereas relatively flat terrain in the outer reef. Fault-like structures were also found in large bedrocks. A 3D view of the reef is shown in Figure 10.

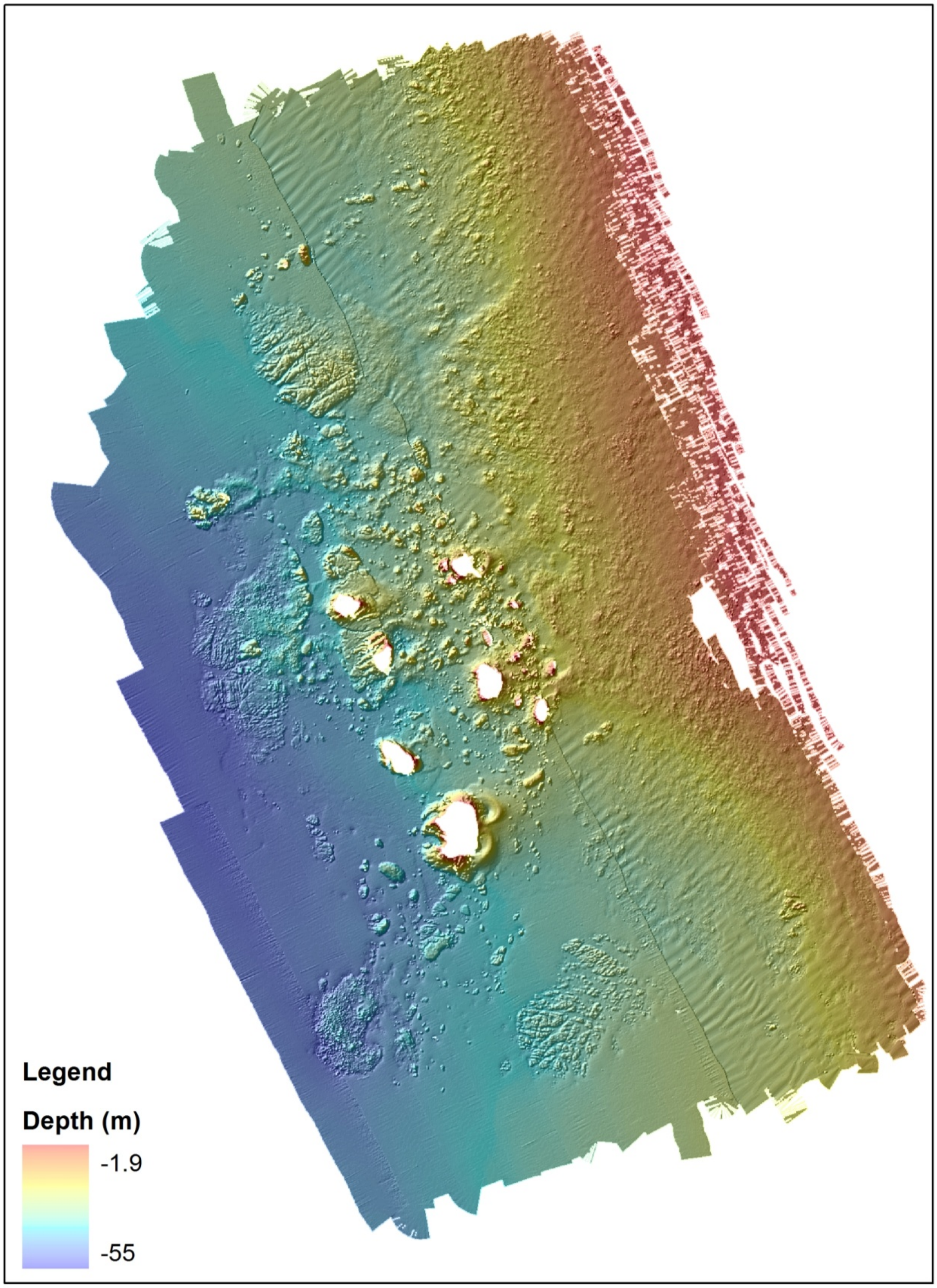


Figure 9. Hillshade bathymetry of Redfish Rock Pilot Marine Reserve.

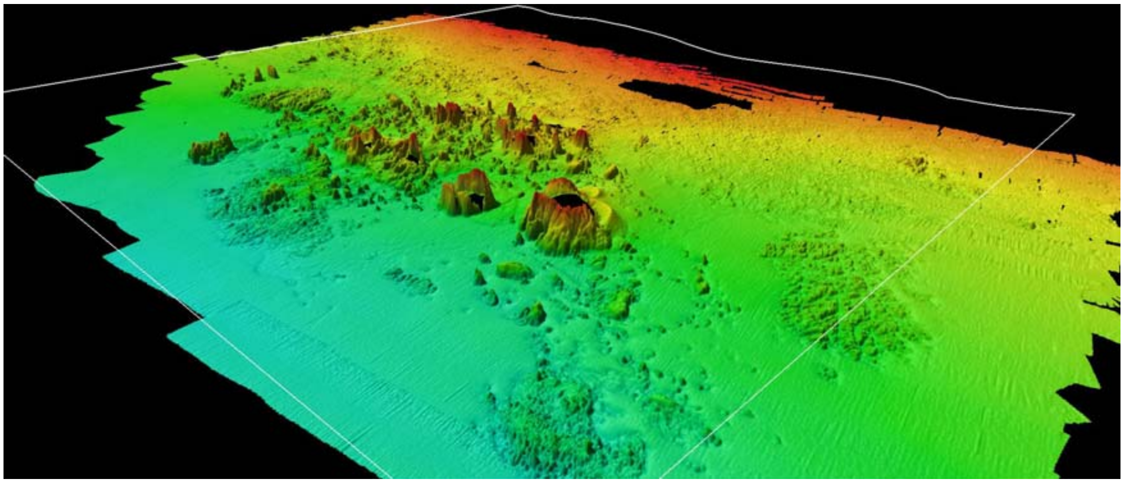


Figure 10. Three dimensional image of Redfish Rock Pilot Marine Reserve.

Reef zone was classified using the BTM which shows a relatively flat outer portion of the reef and a steep slope around the high relief rocks. Most of the reef is flat zones covering 73%. Crest and depression were located in the central portion of the reef covering 5.5% of the survey area (Table 6). Figure 11 shows the BTM habitat zones, showing broader classification of the reef topography. A more detailed classification of the seafloor structures as a result of the BTM classification is shown in Figure 12.

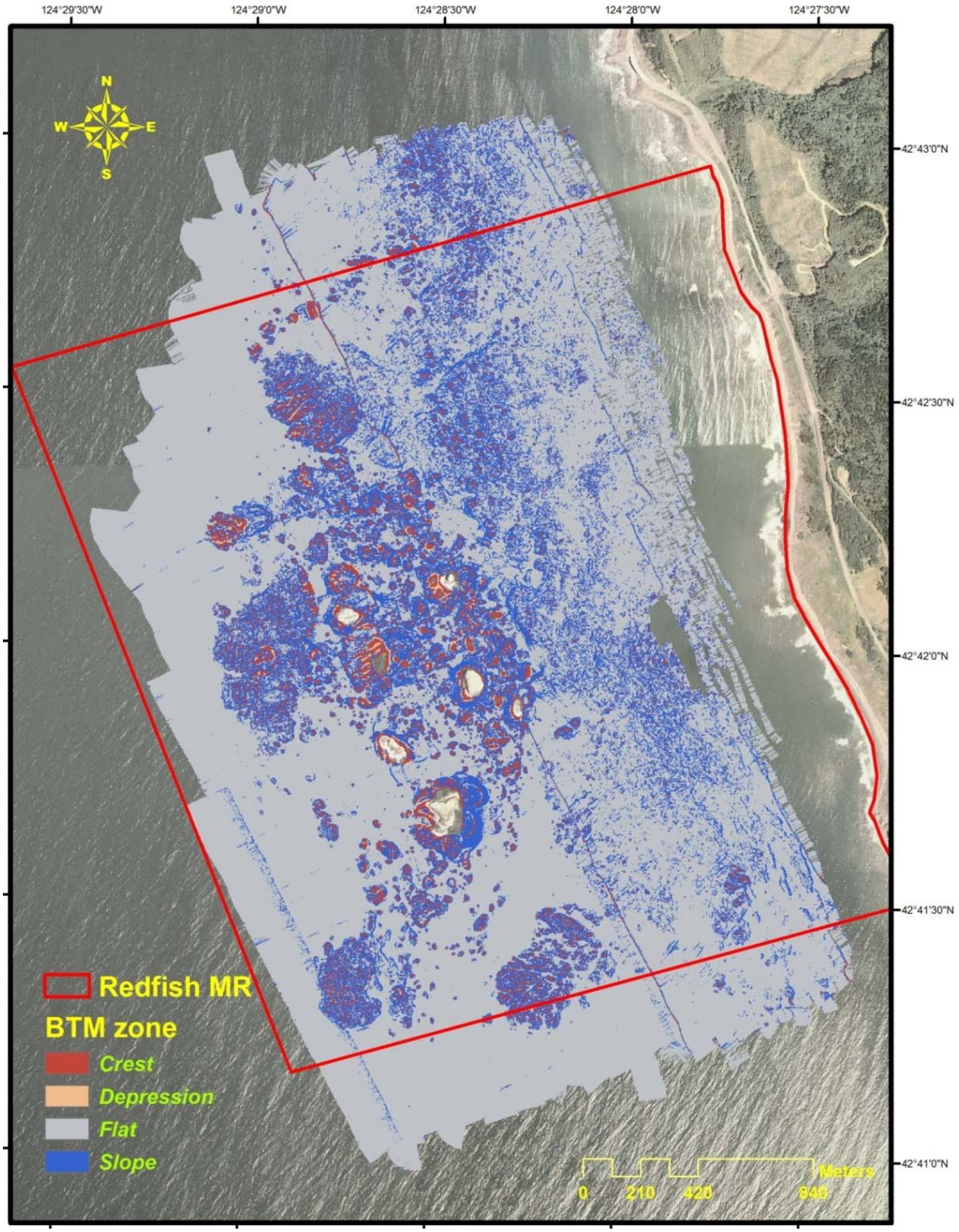


Figure 11. BTM zone layer.

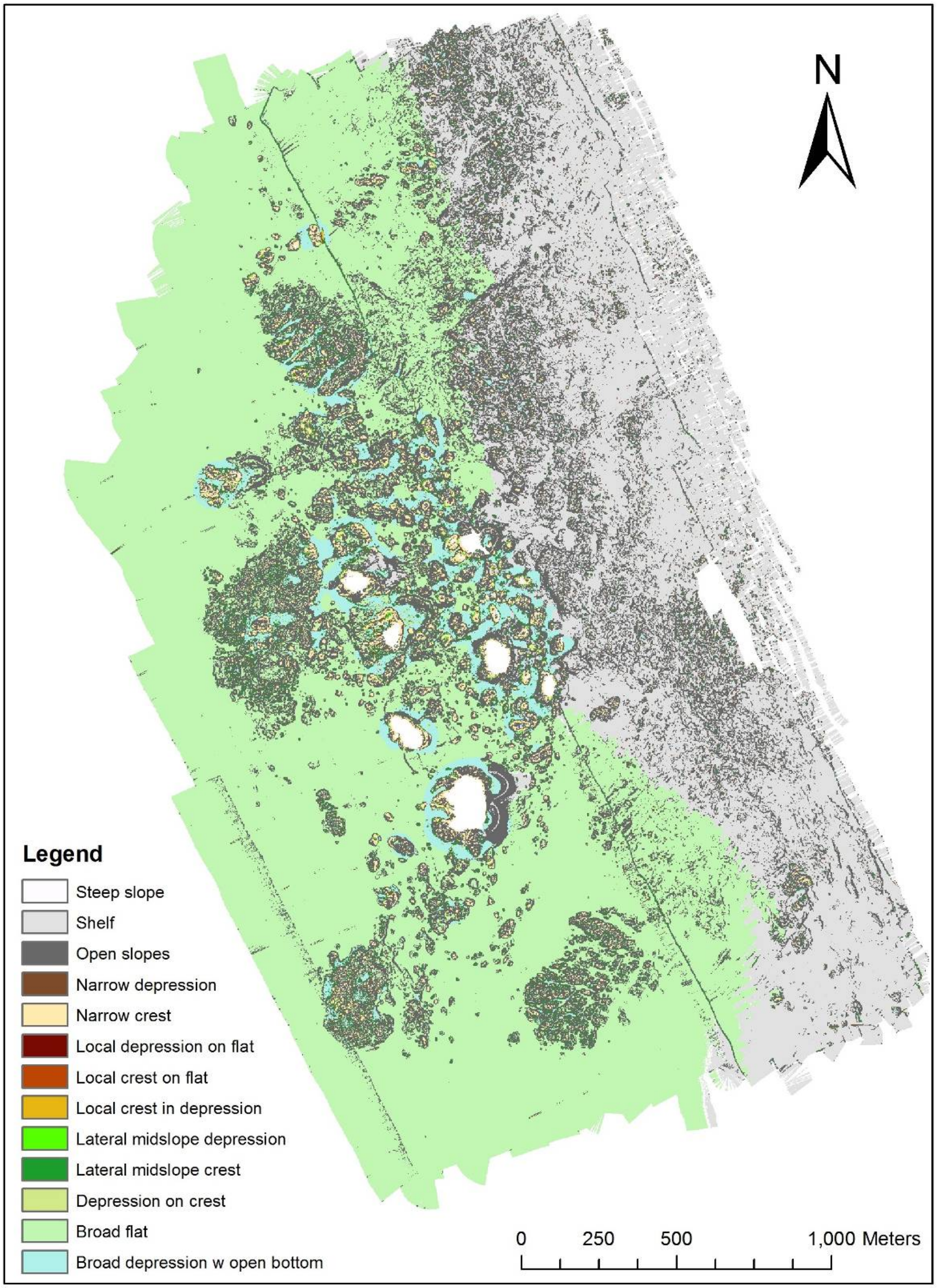


Figure 12. BTM habitat structures.

Table 6. BTM zone and estimated area covered.

Zone		**Area (ha)**	**%**
Crest		33.09	5.0
Depression		3.42	0.5
Flat	slope < 5°	488.37	73.1
Slope	slope > 5°	142.79	21.4
Total		**667.67**	**100.0**

Bottom features

Bedrock. Large bedrock areas were found mostly on the central portion of the reef. They are easily interpreted due to their distinct morphology. Typically, bedrock areas are distinguished by crevices or small ridge-like structure. These features are recognized in hill-shaded relief layer or through inspection of a 3D image of the bathymetry layer (Figure 13). Several videos showed that most the bedrocks were covered with thin layer of seaweed such as kelp especially in shallow water (less than 20m). Around these bedrocks are coarser sand, gravel and cobbles. Some which produce mound like feature as seen in Figure 13.

Figure 13. Bedrock features on the seafloor surrounded with coarser sand (red arrow).

Boulders. Shallow portions of the reef were mainly composed of small and large boulders. Large boulders where also observed scattered around bedrocks. Although, ROV video were able to classify small boulders (< 2m) and large boulders (>2m) this was difficult to categorize from bathymetric layers and backscatter mosaic. Both classifications were merged to a boulders class. It should also be noted that some large boulders may be misclassified as bedrock given that their backscatter information is very similar to bedrocks. Moreover, paths of boulders may also resemble smaller bedrock outcrops. Their similarity can be differentiated when verified with ROV video, however, limited groundtruth often entails some degree of subjective interpretation.

Cobbles / Gravel. Mixed sediments of cobble, gravel and shell hash was the main component of the center portion to the shallow portion of the reef. They are easily distinguished in backscatter mosaic especially in the area where they are adjacent to fine sand sediments. They often give higher backscatter reflectivity compared to sand. In Redfish Rock, the boundary of the two sediment classes is very distinct. Figure 14 show the backscatter mosaic and a snapshot of the boundaries of both sediment classes. Shell hash accumulation was also observed in some part of the reef as seen on a snapshot from ROV video (Figure 7).

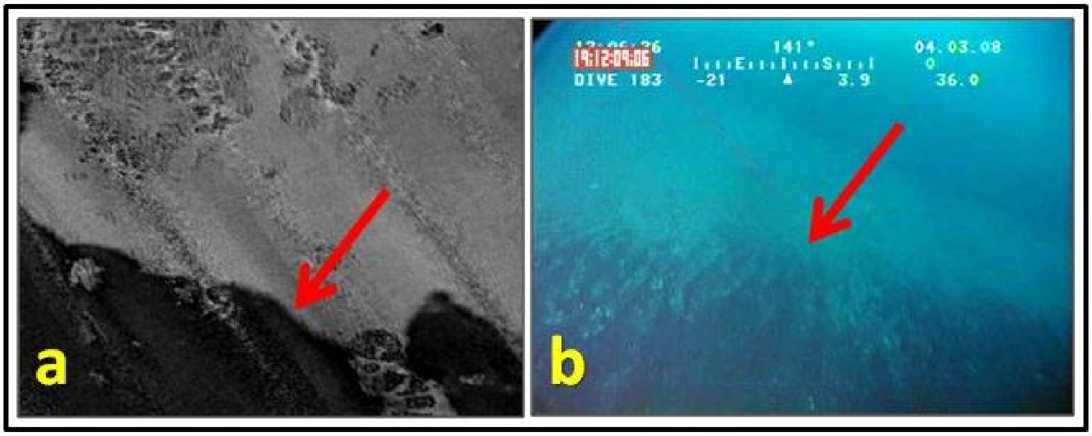


Figure 14. Backscatter image (a) and snapshot (b) showing the distinct boundary of sediments (red arrow).

Sand. A homogenous fine sand characterizes the deeper areas toward the southern shallow portions of the reef. Regular sand ripples were found in the deeper portions running along east-west axes. In the May 2009, shallow multibeam survey, relatively large sand waves were also observed in the shallow portion of the reef. This feature was observed in the 3D view of the bathymetry data. The feature was mainly composed of fine sand with regular ridges and ripples with estimated crest heights of 60 - 80cm. Figure 15 shows a sand waves feature. Although, the survey only covered depths < 15m, the changes in sand movement may also extend to deeper depths. This characteristic is evident to the dynamic nature of the sediment within the reef.

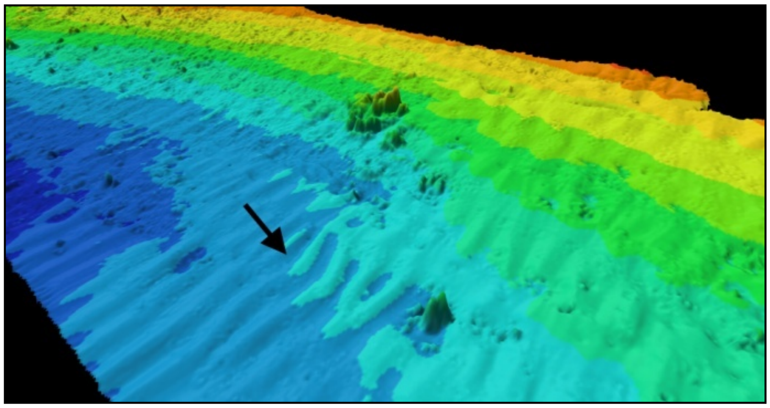


Figure 15. Sand waves features found during the survey.

Backscatter imagery

As previously mentioned, a backscatter image from a multibeam echo sounder shows the reflectivity of the seafloor from the SONAR. The lighter shade in the image indicates high reflectivity such as cobble/gravel, boulders or other hard substrates. Whereas darker shaded areas indicates absorption such as those in fine sand, mud and other soft sediment component.

The resulting backscatter mosaic is presented in 8-bit grayscale image wherein the strong backscatter signal is on the lighter shaded areas whereas lower signal is seen as darker shades (Figure 16). To improve contrast within the image, the resulting histogram of the image was adjusted thereby creating a more distinct difference between high and low backscatter values.

Several acoustic image artifacts were also observed. Among the prominent artifact is the stripping near the ships nadir. Using filters and blending tools applied during the image processing, much of it was corrected. Shadowing was also observed in some features especially in high relief area. These often are misclassified in many automated approach classification (Cochrane 2008). Notice also the results of combining two survey data to produce a single mosaic. A distinct difference along between the two survey lines from different survey time was observed. The variation of sonar setting such as gain and power produces variation in backscatter value thereby producing such artifact. There a need to recognize these artifacts prior to interpretation of bottom habitat.

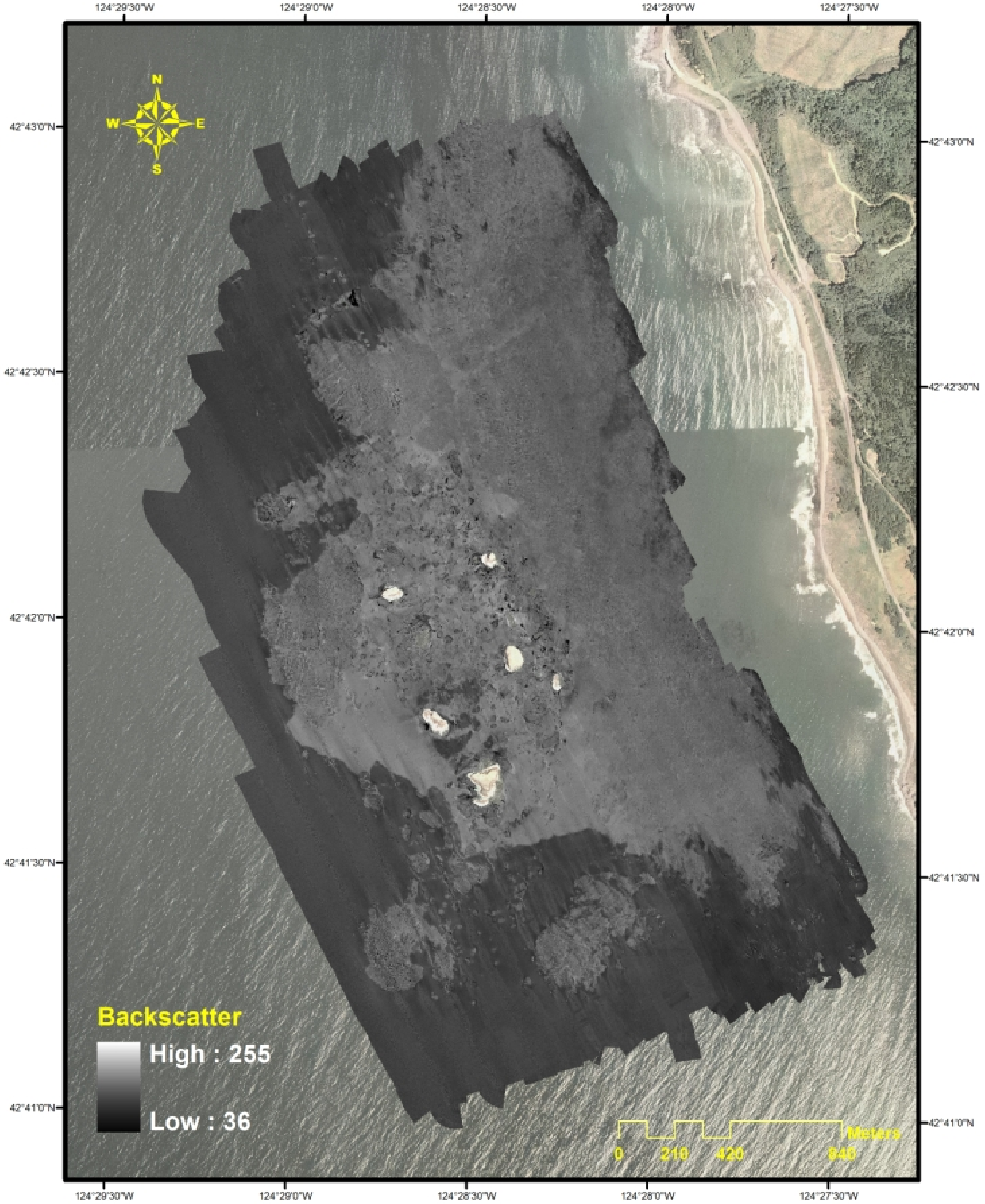


Figure 16. Resulting backscatter mosaic.

Results from the ARA analysis have been able to differentiate grain size variation over the survey area. This variation is plotted using the Thiessen polygon as shown in Figure 17. Variation indicates difference in outer reef with fine sand, with smaller grain size (i.e., blue) than in area with coarse grain size i.e cobble / gravel substrate (red polygons). However, high relief and highly heterogeneous area such as bedrock and boulder, most are misclassified. This limitation is inherent to the calculation within the ARA approach. This point is one of the flaws of the ARA (Fonseca et al. 2008; Rosa 2007). During the analysis, it assumes that the seafloor is homogenous in each port and starboard set of beams and calculates information such as grain size is estimated by variation of angular response across half-width of the swath of a homogenous seafloor. Therefore this approach may only be used in areas where the seafloor variability is low within the port or starboard swath

When using the Theissen polygons to classify the backscatter mosaic, it was able to differentiate subtle or gradual variation of grain size in the seafloor (Figure 17). An output layer using maximum likelihood classification is shown in Figure 18. More detail in differentiating sediment variation which can’t be clearly distinguished from the backscatter image is shown in Figure 19. However, it should again be noted that this can be accomplished in a homogenous type seafloor such as sand to coarse sediment grain size. In area with highly variability like shallow water environment, this limitation should be taken into account.

Moreover, grain size estimates are only limited to less than -0.7 phi value or 2mm grain size. Larger grain size will provide erroneous estimates. Thus, this approach can’t classify pebble or cobble type substrate.

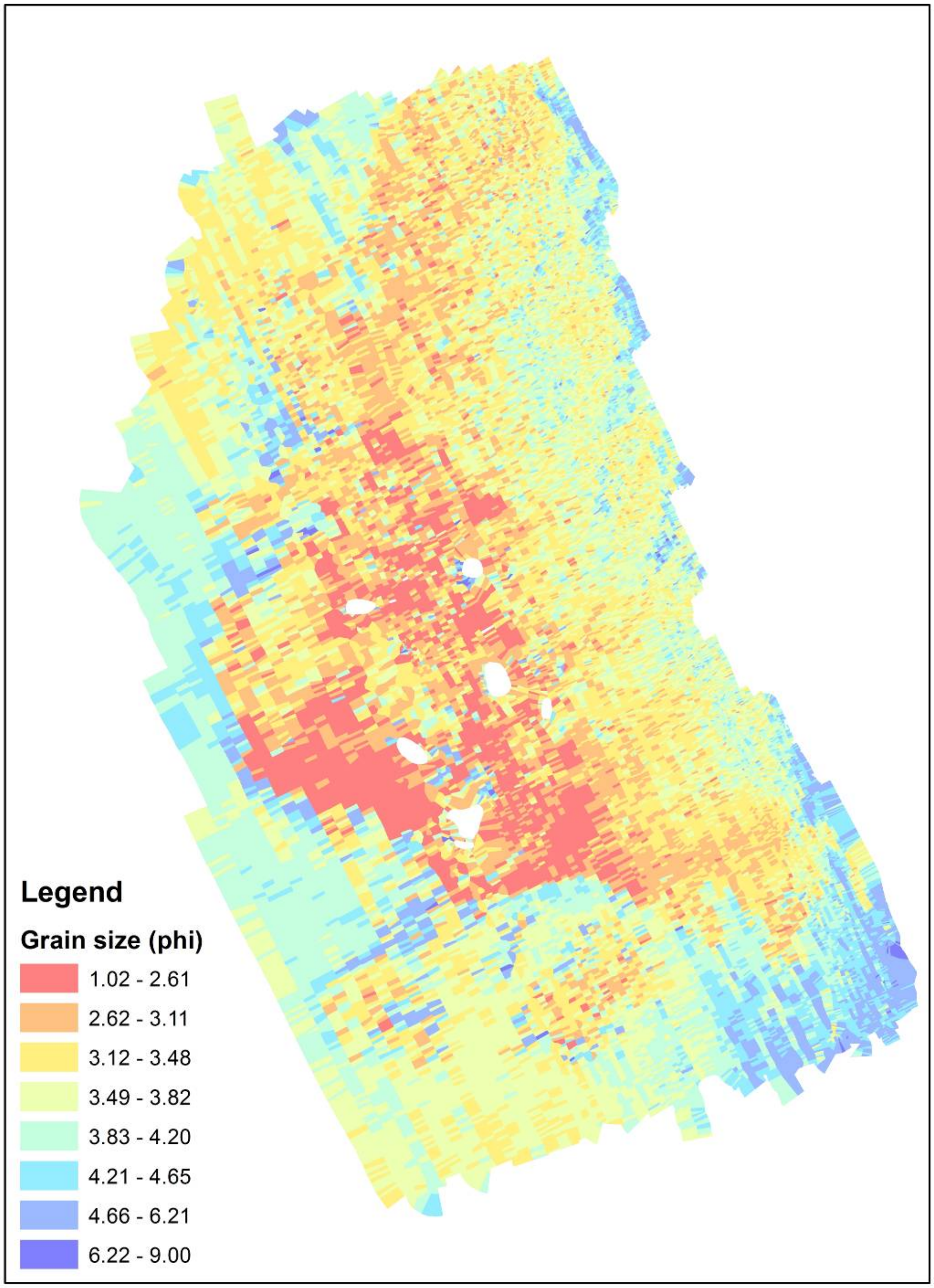


Figure 17. Thiessen polygons created to represent grain size information from ARA

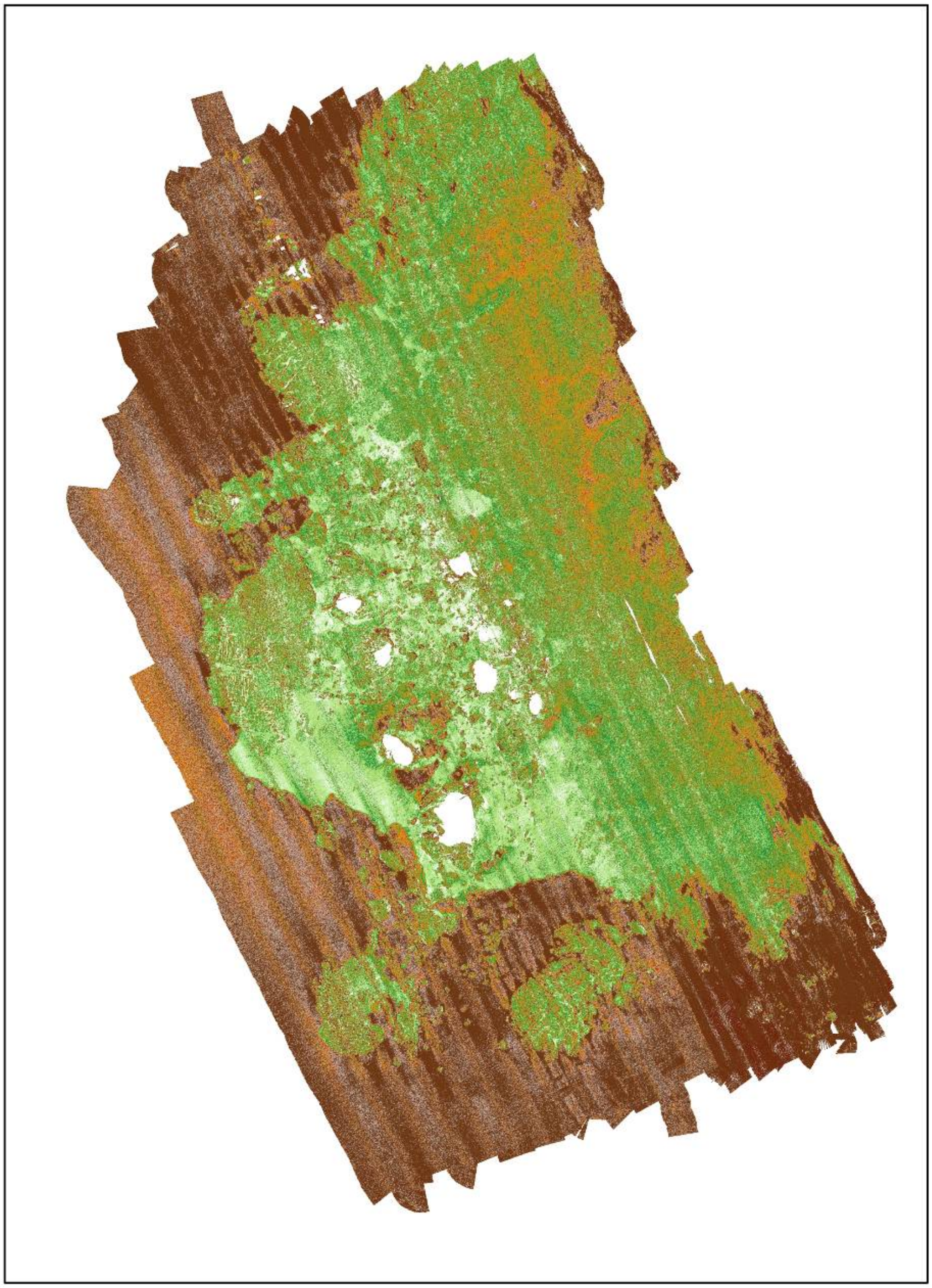


Figure 18. Backscatter image created from the grain size information using Maximum Likelihood classification.

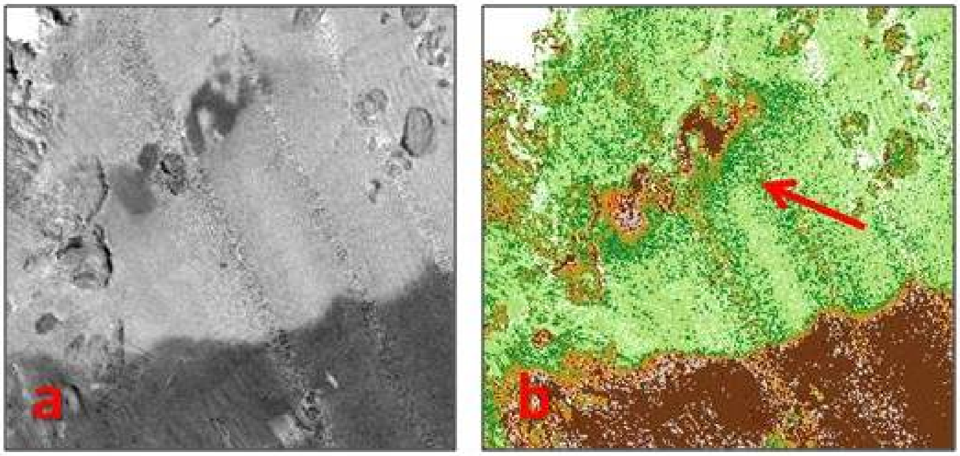


Figure 19. Comparison of backscatter image (a) and maximum likelihood classified layer (b) from ARA grain size estimate. Red arrow indicates gradual sediment grain size.

Habitat map

A total of 623 ha has been mapped covering the entire of Redfish Rock Pilot Marine Reserve (Table 7). Ninety – three percent interpreted from the acoustic data collected from multibeam survey whereas the remaining area was fill-in from the previous habitat map initiative. Four substrate classes have been identified namely: bedrock, boulder, cobble/gravel and fine sand. Sandy substrate dominates the entire marine reserve seafloor covering 43%. Breakdown of each substrate class is shown in Figure 20. Rock bottom substrate, both bedrock and boulder substrate cover 27%, unconsolidated substrate includes cobble /gravel and find sand, and composed 73% or the mapped area. The complete habitat map of the entire reserve is shown in Figure 21.

Table 7 Summary of the number and area of polygon for each classification.

Classification	No. of polygon	Area (ha)	%
Bedrock	535	68.3	10.8
Boulder	69	109.0	17.2
Cobble/Gravel	66	183.4	29.0
Sand	57	271.6	43.0
TOTAL	727	632.3	100.0

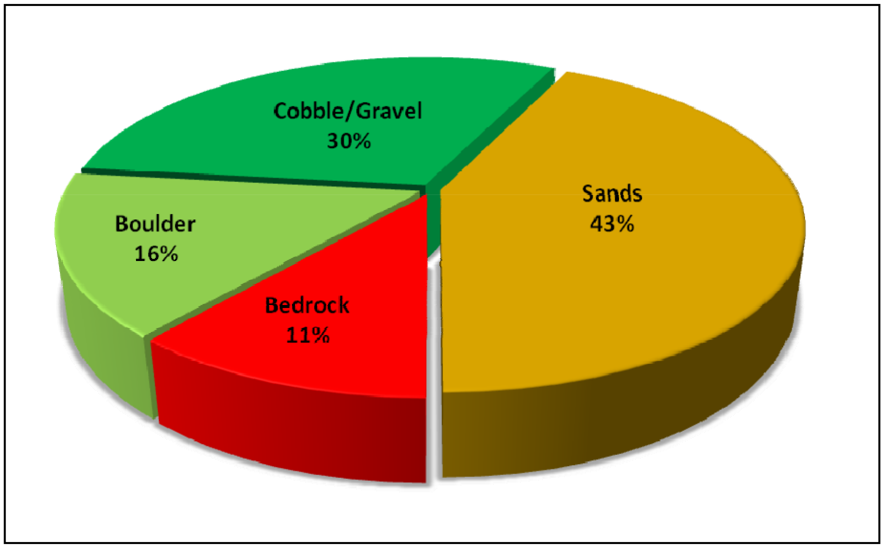


Figure 20. Breakdown of substrate class in the entire Redfish Rocks Pilot Marine Reserve.

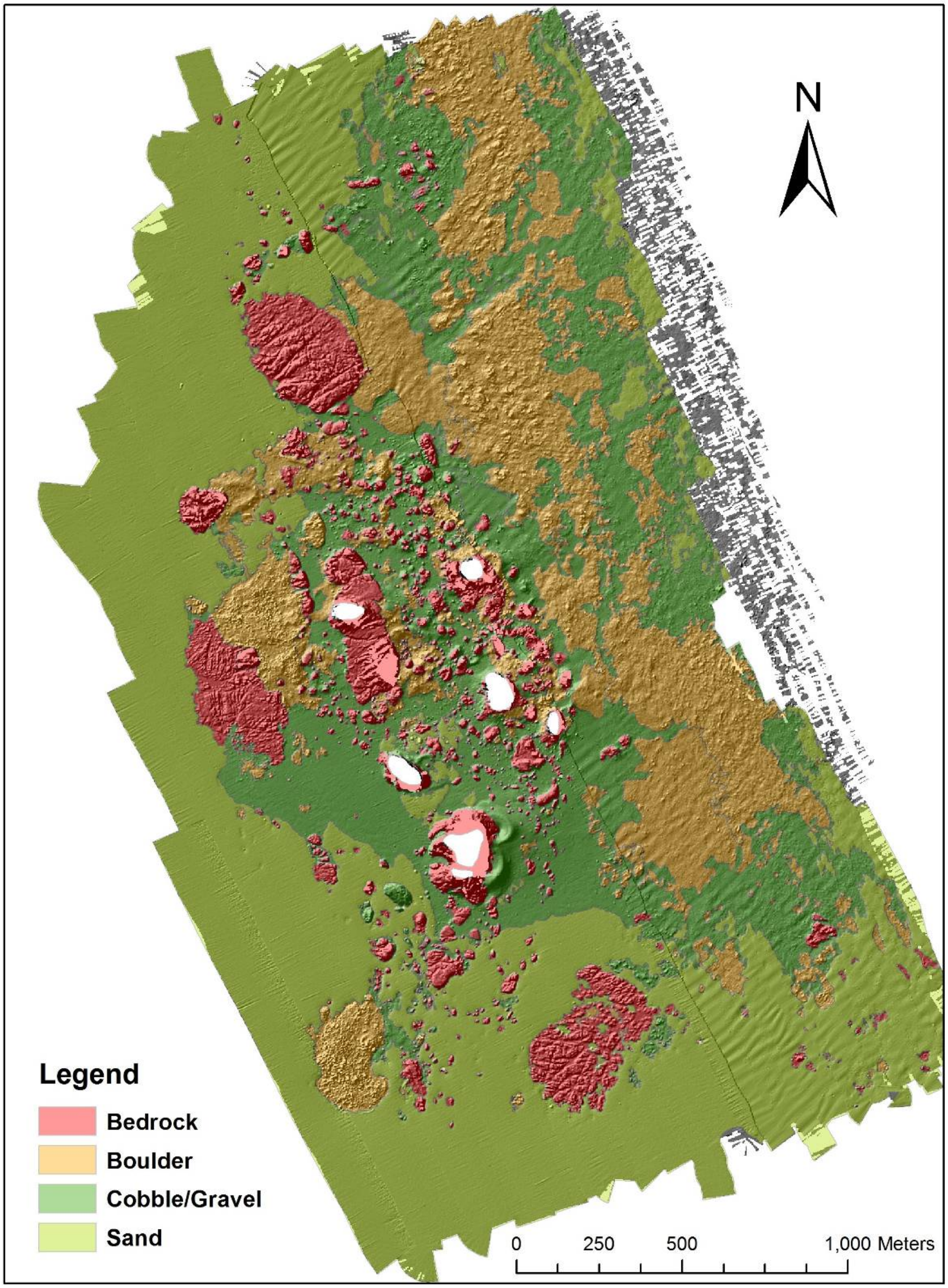


Figure 21. Habitat map showing four substrate class of Redfish Rock Pilot Marine Reserve.

Assessing map quality

For the purpose of comparing classification methodologies and it was compared to the three different classification i.e ROV video substrate classification, SGH map and the bottom type classification from sidescan survey conducted in 1995.

When compared to ROV classification, results shows that there is an overall accuracy of the 63.7% (Table 8). The modest accuracy value was due to several misclassified areas between two classifications especially on cobble/gravel type of substrate with commission error of 81.7% and omission error of 71.2. However, sand showed very minimal misclassified points.

Misclassification is attributed to several factors including difference of mapping scale between the two methods, poor positional accuracy and seafloor changes overtime. ROV had a finer scale of classification compared to the multibeam. It can identify seafloor classes with size less than 10m to sub meter, whereas, manual interpretation can discern substrate class with greater than 10m. This error occurs especially in highly complex reef such as Redfish Rocks. Poor positional accuracy of the ROV has been pointed out by Donellan et al 2008. Point along its track can be placed in area were it class do not match. Change in the seafloor overtime also contributes to the errors. Some of the ROV track used in the comparison (particularly Dive 194) occurs in the shallow portion of the reef wherein manual interpretation was based on the May 2009 multibeam survey. A survey conducted a year after the ROV survey.

Table 8. Error matrix comparing Redfish Rock habitat map with ROV video substrate classification.

	ROV substrate classification					
Habitat map	**Bedrock**	**Boulder**	**Cobble/ Gravel**	**Sands**	Total	**Commission error (%)**
Bedrock	65	19	43		127	48.8
Boulder	29	103	4	60	196	47.4
Cobble/Gravel	14	17	19	54	104	81.7
Sands	47			317	364	12.9
Total	155	139	66	431	791	
Omission error (%)	58.1	25.9	71.2	26.5	Overall	63.7

On the other hand, compared to previously created SGH map showed that there is an overall accuracy of 46.2% (Table 9) within must of the cobble/gravel substrate were misclassified to either rock or sandy substrate. The result is similar to Agapito 2008 when most of these SGH polygons were compared to multibeam created habitat maps.

Table 9. Error matrix comparing Redfish Rock habitat map with Suficial Geologic Habitat map primary lithologic classification.

	Cobble/ gravel	**Rock**	**Sand**	**Total**	**Commission error (%)**
Cobble/ gravel	23	89	62	174	86.8
Rock	6	97	72	175	44.6
Sand	8	32	111	151	26.5
	37	218	245	500	
Omission error	37.8	55.5	54.7	**Overall accuracy**	46.2

Compared to a habitat map created from visual interpretation of sidescan image, error matrix indicates an overall accuracy of 55% (Table 10). Large misclassified points were due to the misclassification of boulder and rock substrate.

Table 10. Error matrix comparing Redfish Rock habitat map with 1995 Side scan sonar survey substrate classification.

	Bedrock	**Boulder**	**Cobble/ Gravel**	**Sand**	**Total**	**Commission error**
Bedrock	35	59	2	10	106	67.0
Boulder	19	76	4	3	102	25.5
Cobble/ Gravel	12	160	30	14	216	86.1
Sand	8	16	6	241	271	86.1
	74	311	42	268	695	
Omission error	52.7	75.6	28.6	10.1	**Overall accuracy**	55.0

Discussion

The result of this studies shows that acoustic information from multibeam survey greatly improved the development of seafloor habitat map. The map produced is valuable for the management of marine resources. Map quality is dependent on the spatial resolution of the acoustic information. Although, acoustic data has its inherent limitations, managers and researchers should understand these limitations to provide a clearer picture of the seafloor.

Bottom features

This study describes the seafloor habitat of the Redfish Rock Pilot Marine Reserve by interpreting the information collected from multibeam survey and ground truth videos. Bathymetry profile and backscatter image were primarily utilized to identify seafloor features and define boundaries of substrate identified from the ROV videos. The use of bathymetry information enables researchers to show topographic structures and zones (i.e., flat, slope, crest, depression) using Hillshade and Benthic Terrain Model. It identifies the high relief areas and flat zones of the seafloor. Findings show that Redfish Rock Marine Reserve has high relief areas and complex rock outcrops found in the center portion toward the coast of the reserve and flat seafloor to seaward. Apart from the seafloor topography, backscatter information allows researchers to classify the hardness of the seafloor and provide inference on its composition. Both information are best verified through ground truth data which is useful to verify the map’s quality.

Automated vs manual interpretation

Interpretation of multibeam data can both be done automated or manually. Each approach has its own advantages and limitations. However, the combination of a wide array of automated classifications and a detailed manual interpretation can highly improve the habitat classification of the seafloor. Researchers should methodically understand the basic concept of automated methods and the output it can produce. Their output can greatly improve the manual interpretation and eventually the final map which is essential in resource management.

Different outputs of the automated approach classification can highlight specific seafloor features that are important in creating habitat map. Hillshade layer can be useful in spotting high relief areas or known structure for a particular seafloor habitat such as the ridge-like feature for bedrock. BTM classified layer is important to distinguish sloping, flat areas which are often associated with sand or unconsolidated substrate. ARA classified layer, on the other hand is important to identify sediment gradient.

When using the automated approach of classification one should also understand its inherent limitations. Since, most are calculated based in its pixel value, it should be recognized that erroneous values such as artifacts from both bathymetry and backscatter data is included in the calculations. Thus, these values are propagated in the process. Artifact created when acoustic information collected from different multibeam survey is an example in this study. This artifact is obvious in both bathymetric layer and backscatter imagery.

Understanding both the limitations and strong points of the automated approach will provided an easy interpretation of the habitat type, manually. These will minimize subjectivity in drawing boundaries of each bottom type.

Comparison to previous mapping efforts

When the habitat map was compared to ground truth observation, e.i. ROV video classification, its has a relatively higher degree of accuracy that comparison to older maps. This indicates that much of observed substrate type is confirmed in the produced habitat map. The higher commission on cobble/gravel substrate is mostly due to coarser sediment composed of hash, gravel in the video which was classified as sand rather than cobble/gravel. In this instance, the inaccuracy may be due to the inaccurate reference data from the ROV video. These inaccuracies may be due difference in mapping scale, ROV positional error, and change of seafloor overtime.

Compared to previous mapping efforts, the current habitat map provides a more detailed account of the topography and lithogic composition of the seafloor. Furthermore, SGH maps have shown the general outline of many rock outcrops especially in the shallow portion of the territorial sea which is crucial in the identification of special management areas such as marine reserve. Detailed mapping through multibeam survey is necessary to illustrate a more detailed picture of the seafloor.

On the other hand, when compared to habitat map created from visual interpreted sidescan sonar imagery, misclassification occurred between boulder and cobble/gravel substrate as well as boulder and bedrock. Although, sidescan can produce high resolution imagery, manual interpretation of the data will greatly affect the habitat map that is being classified. Fox et al. (YEAR?) also reported that the 1995 habitat map may have some degree of misclassification especially in bedrock with small and large boulders when compared to several SCUBA dive ground truth information. Without minimal ground truth information to verify substrate interpretation, it would be difficult to classify acoustic imagery.

CHAPTER 3 - IDENTIFYING SUITABLE HABITAT FOR DIFFERENT SPECIES IN REDFISH ROCKS PILOT MARINE RESERVE

Introduction

This study aims to identify areas habitat suitable for different species in Redfish Rock Pilot Marine Reserve. Specifically, only those species found within the HUD as well as the environmental variable within such as lifestage, depth and latitude. Although, characterizing the habitat of certain species considering different environmental factor is extremely difficult, identifying potential these marine organism would potentially to occur is practical exercise.

Probably, second to knowing what type of habitat in the marine reserve is to know what resource could be in these identified sites being protected. On the onset of both marine management and protection, it is crucial to assess the variety of resource that will be protected. Assessments are generally used to characterize the status of a population, relative to an idealized population size and to predict the response of a population to anthropogenic impact (Copps et al. 2007). Policy maker and resource manager, scientist and stakeholders needs to be aware if they are protecting critical resources and monitoring the response to protective efforts. Baseline survey and inventory is among the initial steps and subsequent monitoring is design to determine impact.

Habitat suitability modeling has become an initial step toward developing efficient technique for stock assessment of marine resources. This approach attempts describe marine resources and it distribution to known habitats. Although, there is still a vast need for scientific investigation to determine factors that affect the distribution of the marine organism in the complex marine environment, several efforts have attempted to model suitability of certain habitat as a proxy for the distribution of marine organism.

There have been a wide array of predictive habitat models and statistical tools developed to address problems in various fields. A more common approach to predictive habitat modeling is relating spatio-temporal observation of species to environmental condition using statistics and other qualitative techniques, then predicts the distribution of species across a region, timeframe, and range of environmental conditions. Several of these approaches have been reviewed and compared in (Guisan and Zimmermann 2000; Austin 2002). Statistical techniques such as ordinary regression and its generalized

(GLM) form are popular and others also include neural network, ordination and classification method, Bayesian belief network (Marcot et al. 2001), Generalized Additive Model (GAM) or a combination of these models. Oftentimes, the investigator utilized several codes to come up with the projected output of the model like maps. More recently, Duke University has developed the Marine Geospatial Ecology Tools, integrating ArcGIS, Python, R statistical software, MATLAB and C++, for ecological modeling in marine ecology studies and conservation projects (Robert et al. 2010, MGET). Various type of these models should be tested for its suitable application. The quality of the models depends primarily on the goals of the study, defining the qualification criteria and the usability of the models rather than the statistics alone. (Guisan and Zimmerman 2000).

Several habitat suitability modeling studies have been conducted focusing much on estimating population of certain fish group or invertebrates utilizing the best useful information and tools available. Nasby-Lucas et al. (2002) provide habitat-based stock assessment of groundfish species using sonar and submersible data. Iampietro et al. (2008) utilizes habitat maps and density estimates of fishes to generate a best estimate stock in the absence of one. Bryan and Metaxas (2007) developed habitat suitability maps of deep sea gorgonian coral from coral observation and comparison of environmental variables (depth, slope, temperature, current speed and chl a concentration). In most cases, this approach is highly dependent data quality and suitable application.

Output of this habitat suitability models has become an important tool in implementing various marine resource management endeavors. Species distribution maps generated from models was used in a wider marine spatial planning in UK waters (Maxell et al. 2009). It should be noted that habitat suitability model maps add value to survey data and by using them in conjunction with other information sources such as stock assessment results, tagging studies and stakeholder knowledge during the marine management process (Maxell et al. 2009).

In the United States, identifying marine habitat through habitat suitability model has been used extensively particularly in the identifying Essential Fish Habitat (EFH) to be included in Fishery Management Plan. Information such a sea surface temperature, salinity, depth, bottom type along with fishery production data were used to delineate

Essential Fish Habitat (EFH) in Florida as an approach to sustain fisheries (Rubec et al. 1999). A similar research was conducted to model density of juvenile brown shrimp in Galveston Bay, Texas and it result has become an vital to refining the delineation EFH areas (Clark 2004).

In 1998, the Pacific Fishery Management Council described 83 species life histories along with habitat association as part of the Pacific Coast Ground fish Fishery Management Plan. These data where collected from published report, gray literature, GIS map and other sources. Over the years, this information has been review and updated to support the plans amendments. Moreover, the information detailed data gaps that need to be filled. To provide a flexible and logical structure of the information, the Habitat Use Database was developed, within which habitat uses by species and life stages is stored, summarized and analyze. It has become a vital input to various EFH analyses, identifying habitats of particular concern and fishing impact (Pacific Fishery Management Council, 2005).

Methods

This portion describes how species were identified and a potential species occurrence map was created using the habitat map created in the previous chapter and a species inventory data, NMFS Habitat Use Data.

Habitat Use Database

In an effort of compile information of on the uses of habitat by species and life stage particularly on the species list in the Pacific Groundfish Fishery Management Plan, the Habitat Use Database was created. HUD is currently maintained National Marine Fisheries Services (NMFS). Primarily, the database was used to identify groundfish Essential Fisheries Habitat (Copps et al. 2008). The ATMS lab and NOAA NWFSC updated the databasefrom 82 groundfish species to currently 323 species by incorporating information for non-FMP species found in nearshore environments identified through Oregon’s Nearshore Strategy (HUD meeting report). Most of the database information can be viewed and downloaded online at: http://pacoos.coas.oregonstate.edu/.

Mainly, the HUD contains habitat preference and occurrence information for each species. Habitat preferences data include bottom type habitat preference of each species in different life stage i.e eggs, juvenile adult stage. Moreover, it also includes a level of habitat affinity of each species. Occurrence information includes occurrence of each species i.e latitude (absolute and preferred), and depth (absolute and preferred). Species information was mostly collected from an in-depth literature review of each species, trawl data and NMFS survey data. Typical information in the HUD is shown in Appendix C.

Efforts have been made to improve the use of HUD among various potential users. In May 2009, a meeting was held to gather expert opinion from the scientific and fishing community. The meeting was primarily aimed to check and identify gaps and examine the validity of the species-habitat relationship within the database. Among the gaps included the need to verify HUD information to actual survey information, the need to incorporate more species, clarify species range criteria i.e preferred and absolute latitude and depth. To address to some of the concern, there is a need to test HUD information with actual survey information. This will be done in Redfish Rock Marine Reserve utilizing the habitat map being created. Thus, this part of the study was conducted.

Reconciling HUD habitat and Redfish Rock Habitat map

Bottom types within the HUD database include different types of mega habitat such as canyon, ridge, continental shelf and slope, nearshore and estuaries. To reconcile HUD habitat and Redfish Rocks Habitat map, there is a need to convert CMECS classification to its HUD habitat counterpart. HUD habitat classification was also translated to compare it to the SGH map. This was used to identify EFH as part recommendation to the Pacific Coast Groundfish Fishery Management Plan. Details in the transformation of the HUD and SGH are discussed in PFMC (2005). Table 11 shows the conversion of CMECS classification with the HUD and SGH habitat classification. Each polygon the Redfish Rocks habitat maps were then classified based on its SGH and HUD classification.

Table 11. Agreement of substrate classification between HUD, SGH and CMECS.

CMECS	HUD habitat Code	SGH habitat code
Bedrock	Sbhr	Sh/rock
Boulder	Sbhb	Sh/boulder
Cobble/Gravel	Sbhq Sbhg	Sh/cobble Ss/gravel
Sand	Sbus	Ss/sand

Extracting information from the HUD

One the objective this study is to identify potential species that could be found in different substrate classes in the habitat map. Using the substrate class, a query was made to extract information from the HUD based on the substrate data from each polygon. As previously mentioned, the HUD contains information of species at different life stages and in different habitat types and its and absolute/preferred depth range and absolute/preferred latitude range along the west coast. The query reports the species found in each polygon based on its substrate type, depth and latitude. A Python script was made to make the query and output a text file.

The input file was created in ArcMap and generating a text file from each polygon with habitat code, depth, latitude and polygon number. A point of each polygon was created using Feature to Point Tools. Each polygon has one point is located inside the polygon along with its polygon ID number. Using this point, depth values were then extracted from the bathymetry layer using Extract value to Points Tools in. Latitude information was added to the polygon attributes using Add XY coordinates Tool. Dbase file of the shapefile is then exported to MS Excel and converted it to a text file. This text file provides the input to the Python script to run the query to the database. Details of the Python script are attached in the appendix (Appendix C). Output text file includes polygon number, list of species, life stage and its habitat association.

Mapping the potential habitat

To map the information extracted from the HUD, output text file was compiled in MS Excel. Using Pivot table, a table was created with columns of polygon ID number and name of different species. The table was joined to the original habitat map using the polygon ID as link column in ArcMap.

To verify if the predicted species occurrence map, points with observed fish taken from ROV survey was overlay to its corresponding map.

Result

A total of 89 species have been predicted to occur within Redfish Rocks Pilot Marine Reserve (Appendix D). These are species for which the HUD finds highly suitable habitats available, which likely will differ from the species actually present. Most of the species are groundfish (76 species) and the rest are invertebrates (12 species) and plant (1 species). Groundfish species include black rockfish, blue rockfish, Canary rockfish, China rockfish, Copper rockfish, Kelp greenling and lingcod. This species were also observed during the ROV video survey conducted by ODFW (Donellan et al. 2009).

Results also shows that there are more species found on cobble / gravel type of substrate (Table12). The highest number of species (63 species) was found in cobble/gravel substrate whereas, lowest number of species is found in sandy substrate. Detailed list of these species is shown in Appendix E.

Table 12. Number of species found in different substrate class.

Substrate	**# species**
Bedrock	57
Boulder	50
Cobble/Gravel	63
Sand	49

Predicted species occurrence map versus observed

To show where these species can be found within the marine reserve, a potential species occurrence map can be created per individual species. Generally, many of the groundfish were found within rocky (bedrock and boulder) and unconsolidated substrate (e.g., cobble/gravel). Invertebrate such as Dungeness crabs were also identified and were found to exclusively to occur in sandy substrate.

Most of the species predicted to occur are found across the depth range of the marine reserve except black abalone (*Haliotis cracherodii*) which was only found at depth below 6m. HUD information indicates that this species occur at an absolute maximum depth of 6 m an error in the HUD database

The potential species occurrence map was then overlaid with the observed ROV point. Observed species mostly match with those predicted for that type of habitat. Among the species observed and mapped includes: blue rockfish, black rockfish, canary rockfish, China rockfish, Kelp greenling and Lingcod. Figure 22 - 24 shows the predicted species occurrence map and observed-species.

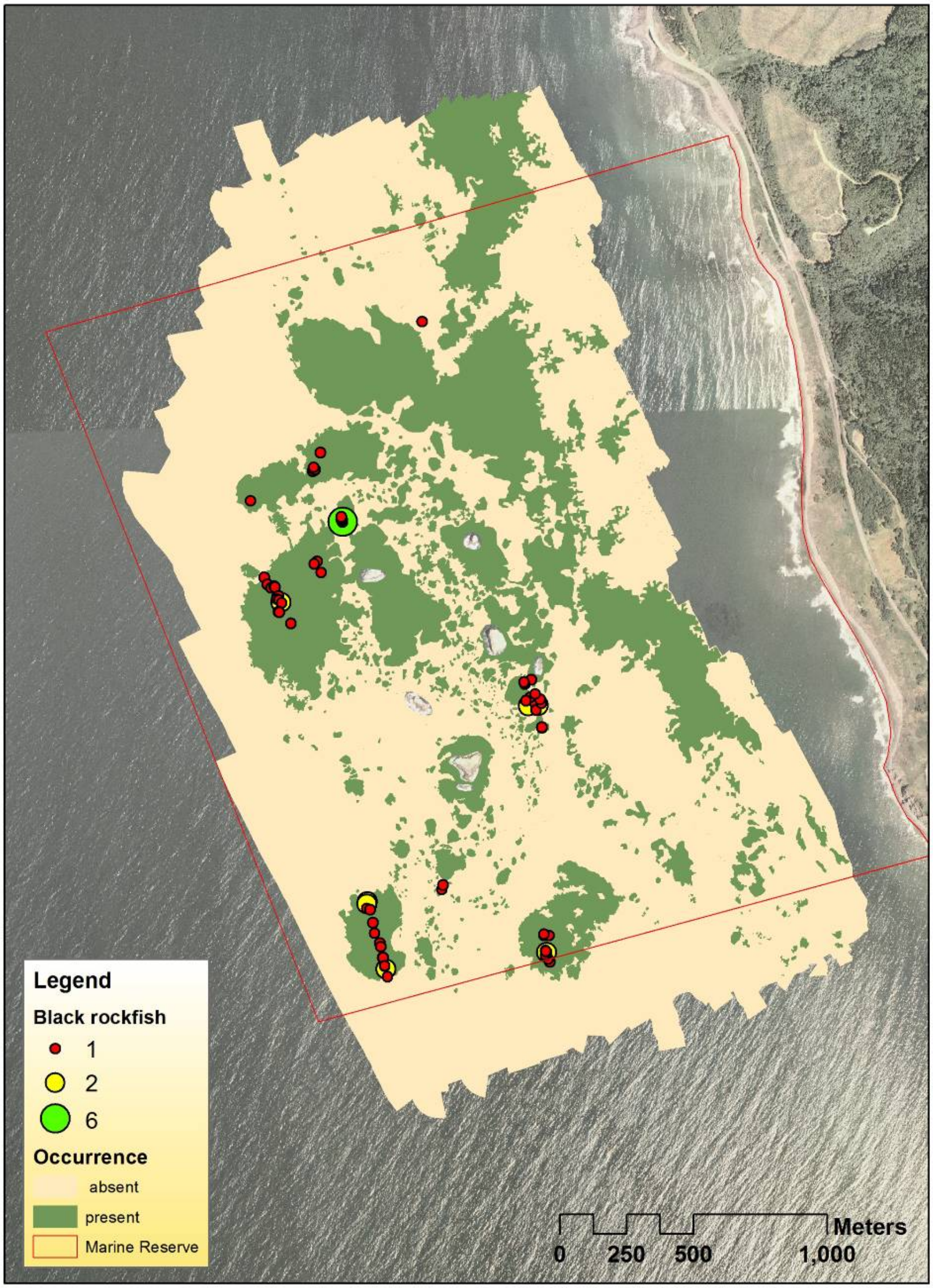


Figure 22. Predicted species occurrence map overlaid with the point where black rockfish was observed from the ROV.

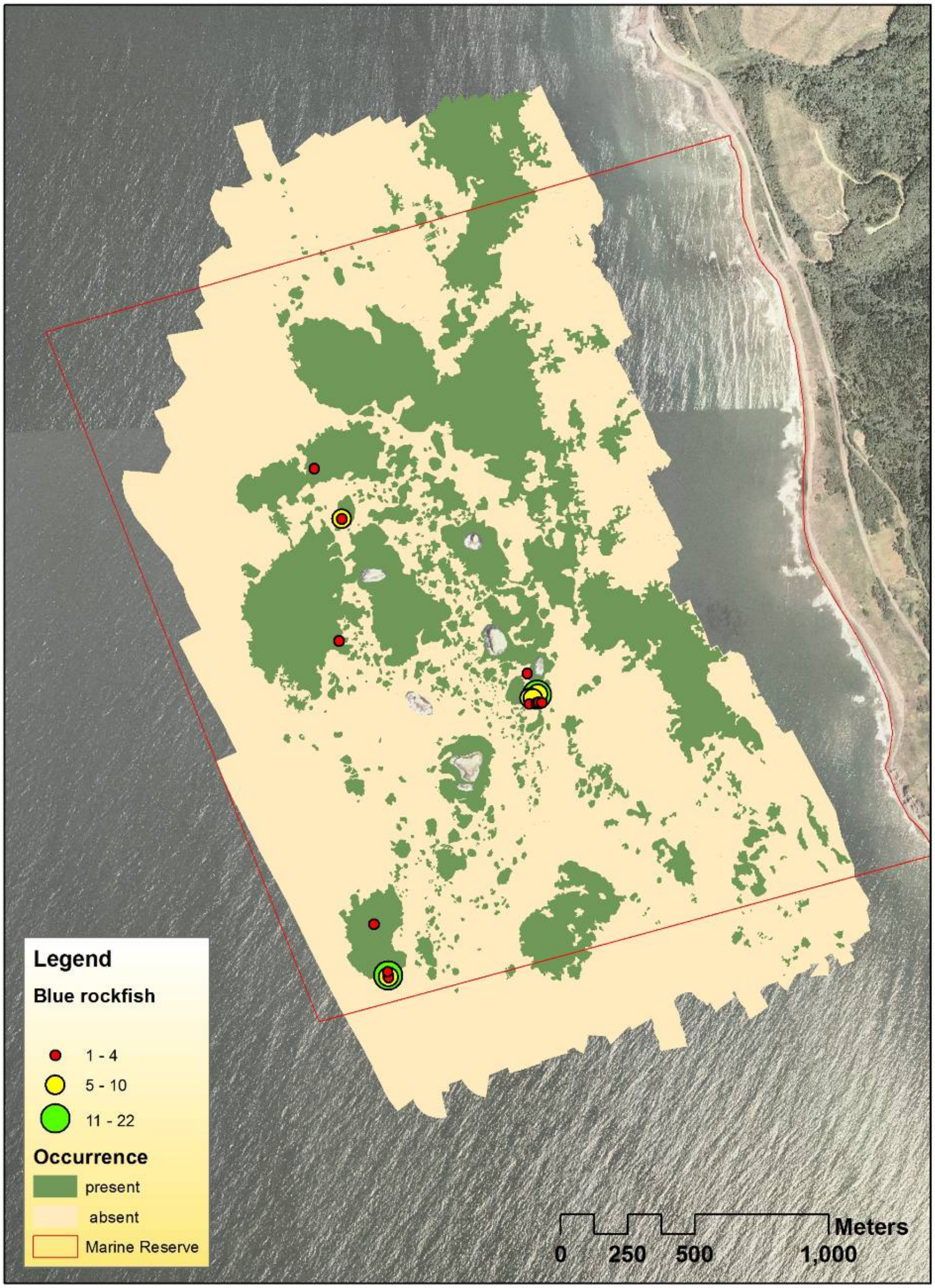


Figure 23. Predicted species occurrence map overlaid with the point where blue rockfish was observed from the ROV.

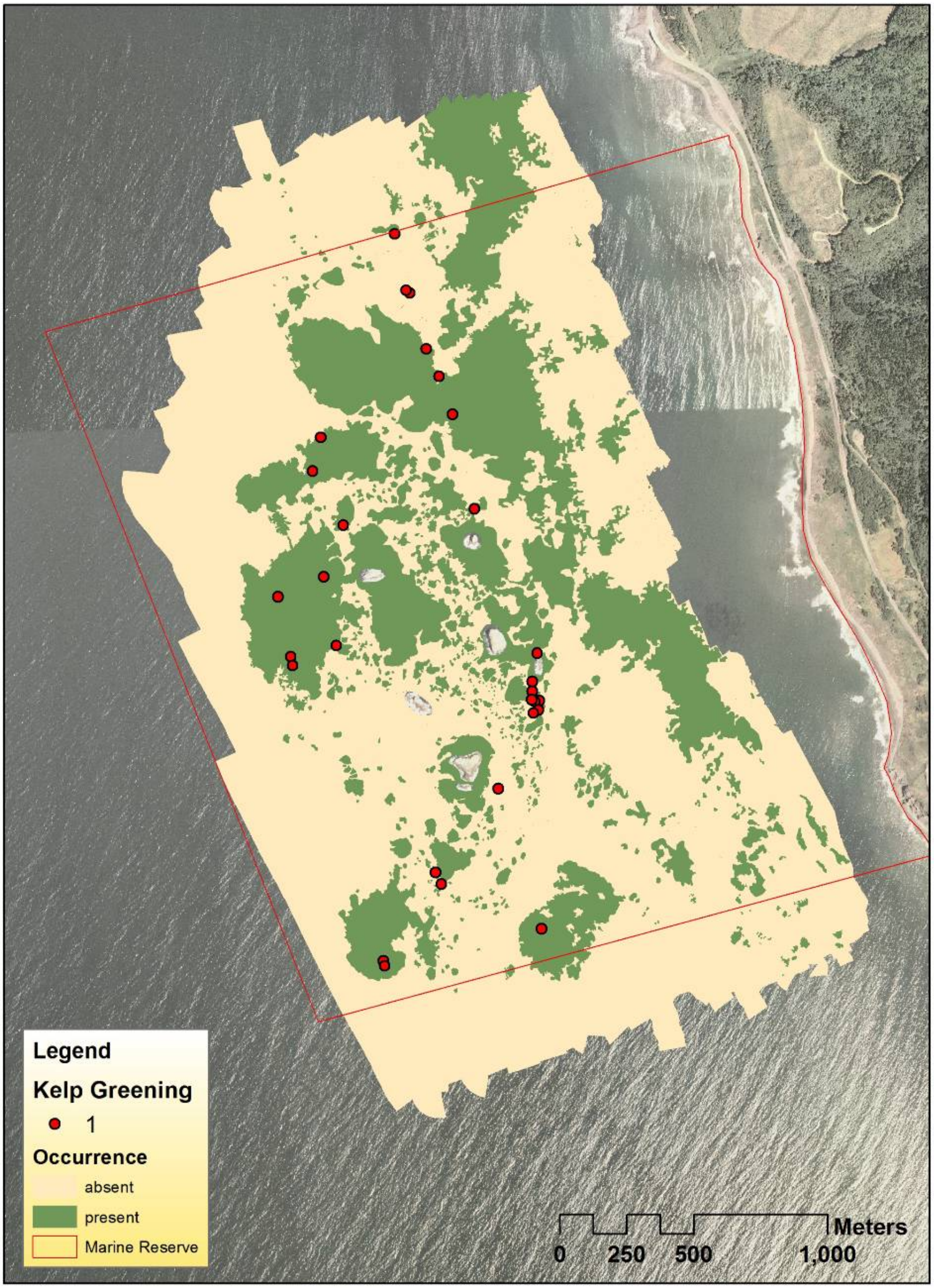


Figure 24. Predicted species occurrence map overlaid with the point where kelp greenling was observed from the ROV.

Discussion

This study describes a basic approach for identifying areas that have the potential for a habitat of certain species by combining a habitat map interpreted from a multibeam survey and other ancillary data and an existing species inventory database for the Pacific Northwest.

The species being identified are essential species that marine protected area managers need to monitor. Most of these species were part of the groundfish species data previously identified for specific groundfish fishery management. This was one of the purposes for which the HUD was created. Many of the 82 groundfish species managed in the Pacific Coast Fishery Management plan can be found in the Redfish Rocks Marine Reserve. Thus, it is also essential that these species be protected using appropriate marine protected area management strategies. Knowing the occurrence of these species is essential to attain the goal of protecting diverse species within Oregon's marine reserves.

To compare the potential occurrence map with actual survey results, points from the ROV survey where identified species were observed was overlaid on the map. Most of the observed points match the results found in the map. However, it should be noted that these are just points where these species were present. The predicted species occurrence maps tend to generalize all potential areas based on depth, latitude and bottom type. The map may not indicate the presence of an individual of each species, but indicates the potential to occur in such habitat. It should be noted that diversity of the species is due to the diversity of the habitat type, depth and latitude value in Redfish Rocks.

The map will provide important information to managers such as the potential species that may thrive in the marine reserve when properly protected. With the high diversity of the habitat types, i.e. sand, high relief rock and boulder, and extensive cobble/gravel substrate, there is greater potential for the reef to recover compared to areas with lower substrate diversity. Moreover, for monitoring purposes the map can be used to primarily identify sampling stations especially if one of its objectives is to check changing species composition and density over time.

The approach conducted in the study has designated potential areas for each species identified to occur in the marine reserve. However, it should be noted that the map was only based on the type of habitat, depth and latitude range of these species within the HUD. It should also take into consideration that species occurrence is a also dependent on numerous physico-chemical and ecological factors within the complex marine environment. Other factor such as temperature, fishing mortality may be included to refine this habitat suitability approach.

Currently, the HUD is one of the most complete inventories of marine species found in the Pacific Northwest. However, there is still a need to fill in the gaps in many species records. This study utilizes the depth range per species within HUD, particularly, absolute minimum depth and absolute maximum depth data of each species. Both depths will generate a much larger range thus more species will be included. HUD also has some information on the preferred minimum and maximum depth range. This information indicates at what depth each species preferred to occur. This information narrows down the location where these species can potentially occur. However, there is still very few species with preferred depth range data, which was not used in the analysis. Both absolute and preferred depth range is based on the numerous publish references indicating depth of the each species. Improvement of this data field can certainly improve predictability of species occurrence maps.

Despite the limitations of the potential species occurrence map this will still provide important information on the possible location of the 89 species being identified within Redfish Rock Pilot Marine Reserve. It is recognized that there is a need for the HUD to enhance the quality of the its information if it would be used in the similar exercise conducted in the study to other potential proposed marine reserve and evaluation sites. The map can also be utilized to other specific species researches within Redfish Rocks

CHAPTER 4 - IMPLICATION TO MARINE RESERVE MANAGEMENT AND POTENTIAL RESEARCH INITIATIVES.

Mapping habitat is an essential aspect in managing marine resources. Habitat maps play an important role in every phase of resource management, especially in the management process of marine protected areas. In selecting sites of marine protected areas, habitat maps allow managers to narrow down specific sites to protect. It is crucial that identified marine protected area sites cover significant percentages of habitat to protect biodiversity and enhance fisheries (Sala et al. 2002). In the process of selection, quality of habitat maps may vary depending on the data available to produce the map. However, detailed a mapping approach is necessary to produce an accurate map critical in the implementation and monitoring phase. Multibeam surveys are an effective tool to create a detailed map of the seafloor.

The habitat map created in this study is necessary in the management of Redfish Rock Pilot Marine Reserve. Habitat maps created from acoustic information have been useful in assessing ground occurrence. Bathymetry layers and backscatter imagery can differentiate seafloor hardness from surrounding soft sediments and estimate fisheries stock by extrapolation of data collected from submersible vessels (Nasby-Lucas et al. 2002). This habitat map can be used in estimating fisheries stock of the marine reserve. Fisheries data collected from ROV video can be utilized in the assessment. However, data quality is limited by the positional accuracy of the videos and should be given adequate consideration in the procedure. The information could be important as a baseline in the development of a quantitative method to assess the protected fisheries resources such as fish tagging and stock assessment.

Resource monitoring and evaluation activities are required to determine the efficiency of the management of marine protected areas. Development of monitoring protocols requires details this habitat maps to identify such sampling stations. The habitat map is useful to aid in the current undertaking of ODFW and local community to identify areas that need protection. Initial habitat characteristic of these sampling stations should be compatible to reference sites for comparability purposes. This habitat will provide a general idea of both monitoring and evaluation sites.

Apart from monitoring and evaluation, research and other scientific investigations will also be conducted in the Redfish Rocks Pilot Marine Reserve. Currently, research activities have been conducted including an investigation of rockfish species within the marine reserve. The habitat map has been a vital factor in the design of this research (Tom Calvenese, personal communication). One of the goals of the inquiry is to establish the relationship between movement of fish with the protection and other factors such as habitat (http://fishtracker.org).

Currently, discussions on physically delineating the marine reserve are conducted in the community level in collaboration with ODFW. A proposal was made to set up marker buoys along the boundaries of the marine reserve. Setting up these buoys requires preliminary knowledge of the seafloor features. Different substrate needs different anchoring designs for these buoys. Community members have been utilizing this habitat maps for such purpose.

Moreover, the habitat map in this study can provide essential input to information and education component of the marine protected area management. Information, Education, Communication (IEC) campaigns are an integral component in every phase of MPA management. The primary purpose is to constantly communicate numerous management strategies, monitoring and research outcome to stakeholders. The habitat map will become necessary information for various types of stakeholders. Fishers can use it as reference map for resources they often associate to substrate type. Ongoing discussion has been taken place at the community level to allow tourism activity such as SCUBA diving within the marine reserve. Planning this management strategy needs bathymetry maps to identify dive sites.

Out of the finding of the study, several researches were identified in the near future to further describe Redfish Rock Marine Reserve habitat. These researches can provide managers information for the management of the marine reserve. These includes: continuing seafloor characterization of the marine protected area and adjacent reefs, biological characterization of the seafloor, setting up of resource monitoring plan and sediment change pattern over time,.

Ongoing seafloor mapping using multibeam surveys has been already conducted in the marine protected area of Redfish Rocks by ATSML of Oregon State University in

July 2010. The acoustic information can be used to produce a similar habitat map of the surrounding area and a comparison area for Redfish Rocks. The survey covers all of MPA portion as well as the Humbug Reef. The data is useful especially in developing resource monitoring protocol for the marine reserve.

One of the goals of marine protection initiative of the State of Oregon is the protection of diverse marine habitat to sustain the abundance of marine organisms within these areas. The current study primarily characterizes the surficial lithology of the seafloor and provides a prediction of habitat suitability for relevant species. There is a need to characterize the actual biological resource within the marine reserve. Ongoing discussions are already conducted between ODFW and local communities to conduct baseline resource inventory within Redfish Rocks and other identified marine reserve sites in Oregon. The map will provide as essential basis in the conduct of such research. Biological characterization will provide an overall picture, including the seafloor lithology and the biological resource within.

Bottom features such as relatively large sand waves is evident of a highly dynamic seafloor. Redfish reef can be a representative site to research in investigation change of seafloor sediment over time.

CHAPTER 5 - CONCLUSION

Utilization of multibeam survey data in this study is useful in creating a habitat map of Redfish Rocks Pilot Marine Reserve. The approach has successfully delineated distinct benthic habitats important to the management of the marine reserve. A combination of both manual and automated interpretation of the seafloor can improve the accuracy of the habitat map while making use of the strengths of each data type, and minimizing the negative effect of data artifacts. Layers derived from the automated classification provide an outline of each substrate class while manual digitizing delineate a more detailed boundary of each class. Both approaches have advantages and disadvantages that need to be considered in the interpretation and production of the habitat map. Most automated approaches may misclassify bathymetry layers and backscatter mosaics according to the quality of the acoustic information, this can be corrected through a detailed manual approach. Knowledge of the SONAR principles and GIS as a tool is an integral part of the process.

Compared to previous mapping efforts, the habitat map produced in this study showed a more detailed characterization of the seafloor. The map quality and accuracy produced is sufficient to provide a basis for a more detailed investigation of the seafloor and serve as baseline for the marine reserve. Bottom features such as large rock outcrops, fine sand and cobble/gravel substrates have been identified. Classification of boulders can include error, such classifying them as bedrock especially in areas not covered by ground truth survey, though the biologic implication of this are not likely to be significant.

The habitat maps presented here can also be utilized in describing the fisheries resources of the marine reserve. It has successfully enumerated a list of species that could potentially be found in the marine reserve. Although, the predictive model is strictly limited to the availability of information from the HUD, this can be further evaluated and verified in other specific investigations for such purposes. The model only related potential species distribution based on depth, latitude and habitat affinity. Other factors such as spatio-temporal temperature variability and other ecological factors to distribution of the different species may be incorporated in future mapping endeavors..

The use of Bayesian Net could be an efficient tool in creating the model if considering these factors, and could allow for the uncertainties to be included in the model.

The Redfish Rock habitat maps will enhance the ongoing characterization of the seafloor of the Oregon territorial sea as well as the management of its marine reserve. It will be used to update current SGH map maintained by ATSML. Moreover, it is a vital tool in any scientific investigation and several management strategies to be implemented within the marine reserve.

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APPENDICES

APPENDIX A. Creating the backscatter mosaic and computing for Angular Response Analysis (ARA) using FM Geocoder

1. Setting up your session in FM Geocoder.
    a. Open FM Geo.
    b. Create new session. File > New session.
    c. Add lines. File > Add lines. Navigate to your folder where you place you're the .all files. Click Open. Choosen .all files will then be added in Geo input files for processing.
    d. Click on Session Setup. You have the option to let Geo determine the mosaic bounding coordinates for you by clicking Scan button on Prescan files bounds, however this may take a while if you have many lines. It is suggested that you have the bounding coordinate from ArcGIS or Caris and just directly input it to Mosaic bounds. Set Mosaic pixel size to 0.50m. Check on Compute ARA Analysis. Check Use Formal ARA Inversion and Check Compute Statistical Analysis. FM Geocoder will allocate the lines and setup you bounding coordinates.
    e. Edit Parameter. Processing > Edit parameter. Apply AVG Correction with AVG Algorithm at Adaptive. Choose Click Ok.
    f. Set up Mosaic parameter. Mosaic > Edit Parameter. Choose No nadir if possible. Click OK
    g. Save Session option. File > Save Session. Choose save session set up only. Click OK.
    h. Add bathymetric surface. Apply Bathymetric correction.
    i. Run the lines. Control option > Run Lines.
    j. If running line is complete.
    k. Adjust histogram, if desired.
    l. Save Mosaic as geotiff. Mosaic > Save As Geotiff.
2. Calculate for Angular response analysis
    a. ARA > Show ARA patch > Best Fit
    b. Build ARA.

c. Export ARA data as ASCII file.
d. Open ASCII file in MS Excel as txt file.
e. Converting grain size on phi scale to mm. In Excel, you can convert grain size phi scale to mm using the following formula: grain size (mm) = 1 / 2 ^ phi. Save file as csv.
f. Add csv file to ArcMap and display XY values.
g. Use the points to create the Thiessen polygon.

Appendix B. Typical species information in Habitat Use Database.

species id	Common name	Scientific name	Lifestage	Abs. min depth	Pref. min depth	Abs. max depth	Pref. max depth	Abs min latitude	Pref. min latitude	Abs. max latitude	Pref. max latitude	GIS Hab code	Habitat association
5	Sablefish	*Anoplopoma fimbria*	Adults	0	200	1900	1200	28	NULL	55	NULL	As/soft	Strong
6	Pacific Flatnose	*Antimora microlepis*	Adults	350	500	3050	950	23	NULL	55	NULL	As/soft	Strong
8	Arrowtooth Flounder	*Atheresthes stomias*	Adults	9	50	900	500	35.6	42.8	55	55	As/soft	Strong
17	Pacific Sanddab	*Citharichthys sordidus*	Adults	0	50	549	150	22.8	NULL	55	NULL	As/soft	Weak
41	Petrale Sole	*Eopsetta jordani*	Adults	0	50	550	300	30	38	60	49	Bs/mud	Medium
50	Pacific Cod	*Gadus macrocephalus*	Adults	40	50	875	300	34	NULL	65	NULL	As/soft	Medium
54	Rex Sole	*Glyptocephalus zachirus*	Adults	0	50	850	450	28	NULL	62	NULL	As/soft	Medium
55	Kelp Greenling	*Hexagrammos decagrammus*	Adults	0	0	52	20	33	34.5	55	55	Sh/boulder	Weak
56	Flathead Sole	*Hippoglossoides elassodon*	Adults	0	0	1050	366	36.5	NULL	65	NULL	As/soft	Strong

Appendix C. Phyton script code created to query HUD.

```
import os, pyodbc
of = open('Z:/cromsos/RedfishReefHUD_AbsoluteResults.txt','w')
def getSpeciesFromRangesHabitats(PolygonNumber, Z, Y, GeoHab):
    n = 1
    d=round(Z)*-1
    depth=int(d)
    selectSQL = "SELECT * FROM GIS_SPECIES_DET_V_SMW WHERE
ABSOLUTEMINDEPTH <= '"+repr(depth)+"' AND ABSOLUTEMAXDEPTH >=
'"+repr(depth)+"' AND ABSOLUTEMINLATTITUDE <= '"+repr(Y)+"' AND
ABSOLUTEMAXLATTITUDE >= '"+repr(Y)+"' AND GIS_HAB_CODE =
'"+GeoHab+"'"
#    print selectSQL
    SDconn=pyodbc.connect('DRIVER={SQL
Server};SERVER=tomcat;DATABASE=hud;UID=hud;PWD=gf1sh12')
    SDcursor=SDconn.cursor()
    SDcursor.execute(selectSQL)
    for row in SDcursor:
#        print row
        SpID = row.SPECIES_ID
        CommName = row.COMMONNAME
        SciName = row.SCIENTIFICNAME
        LifeStage = row.LIFESTAGE
        Association = row.HABITATASSOCIATION
       of.write(PolygonNumber+', '+repr(SpID)+', '+CommName+', '+SciName+',
'+LifeStage+', '+Association+', '+repr(n)+'\n')
        n+=1
#    print "number of records = "+ repr(n-1)
    SDcursor.close()
    SDconn.close()
```

```
os.chdir('Z:/cromsos')
f=open('Hab_pt_depth.txt','r')
line = f.readline() # skip the header line
line = f.readline() # read the first data line
while line:
    linesp = line.split('\t')
    PolygonNumber   = linesp[0]
    GeoHab              = linesp[4]
    Y                       = float(linesp[6])
    Z                       = float((linesp[7].split())[0])
#    print PolygonNumber, GeoHab, Y, Z
    getSpeciesFromRangesHabitats(PolygonNumber, Z, Y, GeoHab)
    line = f.readline()
f.close()
of.close()
```

Appendix D. List of potential species than can be found in Redfish Rocks Marine Reserve.

No.	Common Name	Scientific Name
Fishes		
1	Arrowtooth Flounder	Atheresthes stomias
2	Bank Rockfish	Sebastes rufus
3	Big Skate	Raja binoculata
4	Black abalone	Haliotis cracherodii
5	Black Rockfish	Sebastes melanops
6	Black-and-Yellow Rockfish	Sebastes chrysomelas
7	Blue Rockfish	Sebastes mystinus
8	Bocaccio	Sebastes paucispinis
9	Brown Irish lord	Hemilepidotus spinosus
10	Brown Rockfish	Sebastes auriculatus
11	Brown smoothhound	Mustelus henlei
12	Buffalo sculpin	Enophrys bison
13	Butter Sole	Isopsetta isolepis
14	Cabezon	Scorpaenichthys marmoratus
15	California halibut	Paralichthys californicus
16	Canary Rockfish	Sebastes pinniger
17	Chilipepper	Sebastes goodei
18	China Rockfish	Sebastes nebulosus
19	Copper Rockfish	Sebastes caurinus
20	Curlfin Sole	Pleuronichthys decurrens
21	Darkblotched Rockfish	Sebastes crameri
22	Dungeness crab	Cancer magister
23	English Sole	Parophrys vetulus
24	Flag Rockfish	Sebastes rubrivinctus
25	Flathead Sole	Hippoglossoides elassodon

No.	Common Name	Scientific Name
26	Giant wrymouth	Delolepis gigantea
27	Gopher Rockfish	Sebastes carnatus
28	Grass Rockfish	Sebastes rastrelliger
29	Green sturgeon	Acipenser medirostris
30	Halfbanded Rockfish	Sebastes semicinctus
31	Kelp Greenling	Hexagrammos decagrammus
32	Leopard Shark	Triakis semifasciata
33	Lingcod	Ophiodon elongatus
34	Longnose Skate	Raja rhina
35	Pacific angel shark	Squatina californica
36	Pacific Cod	Gadus macrocephalus
37	Pacific herring	Clupea pallasii
38	Pacific Ocean Perch	Sebastes alutus
39	Pacific sand lance	Ammodytes hexapterus
40	Pacific Sanddab	Citharichthys sordidus
41	Pacific sandfish	Trichodon trichodon
42	Pacific staghorn sculpin	Leptocottus armatus
43	Petrale Sole	Eopsetta jordani
44	Pile Perch	Rhacochilus vacca
45	Puget Sound Rockfish	Sebastes emphaeus
46	Pygmy Rockfish	Sebastes wilsoni
47	Quillback Rockfish	Sebastes maliger
48	Red Irish Lord	Hemilepidotus hemilepidotus
49	Red rock crab	Cancer productus
50	Redstripe Rockfish	Sebastes proriger
51	Rex Sole	Glyptocephalus zachirus
52	Rock greenling	Hexagrammos lagocephalus
53	Rock Sole	Lepidopsetta bilineata

No.	Common Name	Scientific Name
54	Rosethorn Rockfish	Sebastes helvomaculatus
55	Rosy Rockfish	Sebastes rosaceus
56	Rougheye Rockfish	Sebastes aleutianus
57	Sablefish	Anoplopoma fimbria
58	Sand Sole	Psettichthys melanostictus
59	Sharpchin Rockfish	Sebastes zacentrus
60	Shiner perch	Cymatogaster aggregata
61	Shortraker Rockfish	Sebastes borealis
62	Silvergray Rockfish	Sebastes brevispinis
63	Speckled Rockfish	Sebastes ovalis
64	Splitnose Rockfish	Sebastes diploproa
65	Spotted Ratfish	Hydrolagus colliei
66	Starry Flounder	Platichthys stellatus
67	Striped Surfperch	Embiotoca lateralis
68	Stripetail Rockfish	Sebastes saxicola
69	Tiger Rockfish	Sebastes nigrocinctus
70	Topsmelt	Atherinops affinis
71	Vermilion Rockfish	Sebastes miniatus
72	White sturgeon	Acipenser transmontanus
73	Widow Rockfish	Sebastes entomelas
74	Wolf-eel	Anarrhichthys ocellatus
75	Yelloweye Rockfish	Sebastes ruberrimus
76	Yellowtail Rockfish	Sebastes flavidus
Invertebrates		
77	California sea cucumber	Parastichopus californicus
78	Coonstripe or Dock shrimp	Pandalus danae
79	Flap-tipped piddock	Penitella penita
80	Flat abalone	Haliotis walallensis

No.	Common Name	Scientific Name
81	Giant octopus	Octopus dofleini
82	Ochre sea star	Pisaster ochraceus
83	Oregon triton	Fusitriton oregonensis
84	Purple sea urchin	Strongylocentrotus purpuratus
85	Razor clam	Siliqua patula
86	Red abalone	Haliotis rufescens
87	Red sea urchin	Strongylocentrotus franciscanus
88	Rock scallop	Hinnites giganteus
Plant		
89	Bull kelp	Nereocystis luetkeana

Appendix E. Habitat association of species at different lifestages.

Common Name	***Habitat association at different life stage***				
	Juvenile		***Adult***		
	Medium	**Strong**	**Weak**	**Medium**	**Strong**
Arrowtooth Flounder					✓
Bank Rockfish		✓			✓
Big Skate				✓	
Black abalone					✓
Black Rockfish		✓			✓
Black-and-Yellow Rockfish		✓			✓
Blue Rockfish		✓			✓
Bocaccio	✓	✓			
Brown Irish lord					✓
Brown Rockfish					✓
Brown smoothhound				✓	✓
Buffalo sculpin					✓
Bull kelp					✓
Butter Sole					✓
Cabezon					✓
California halibut					✓
California sea cucumber					✓
Canary Rockfish		✓			✓
Chilipepper		✓			✓
China Rockfish					✓
Coonstripe or Dock shrimp					✓
Copper Rockfish					✓
Curlfin Sole					✓

Common Name	***Habitat association at different life stage***				
	Juvenile		***Adult***		
	Medium	**Strong**	**Weak**	**Medium**	**Strong**
Darkblotched Rockfish					✓
Dungeness crab					✓
English Sole		✓			✓
Flag Rockfish	✓			✓	✓
Flap-tipped piddock					✓
Flat abalone					✓
Flathead Sole					✓
Giant octopus					✓
Giant wrymouth					✓
Gopher Rockfish		✓			✓
Grass Rockfish					✓
Green sturgeon					✓
Halfbanded Rockfish					✓
Kelp Greenling			✓		
Leopard Shark			✓	✓	
Lingcod					✓
Longnose Skate					✓
Ochre sea star					✓
Oregon triton				✓	✓
Pacific angel shark					✓
Pacific Cod		✓			
Pacific herring					✓
Pacific Ocean Perch		✓			✓
Pacific sand lance					✓
Pacific Sanddab					✓
Pacific sandfish					✓

Common Name	***Habitat association at different life stage***				
	Juvenile		***Adult***		
	Medium	**Strong**	**Weak**	**Medium**	**Strong**
Pacific staghorn sculpin			✓		✓
Petrale Sole					✓
Pile Perch					✓
Puget Sound Rockfish					✓
Purple sea urchin					✓
Pygmy Rockfish					✓
Quillback Rockfish					✓
Razor clam					✓
Red abalone					✓
Red Irish Lord					✓
Red rock crab					✓
Red sea urchin					✓
Redstripe Rockfish					✓
Rex Sole					✓
Rock greenling			✓		✓
Rock scallop					✓
Rock Sole					✓
Rosethorn Rockfish				✓	
Rosy Rockfish					✓
Rougheye Rockfish		✓			✓
Sablefish		✓			
Sand Sole		✓			✓
Sharpchin Rockfish	✓		✓		✓
Shiner perch					✓
Shortraker Rockfish				✓	✓
Silvergray Rockfish					✓

Common Name	***Habitat association at different life stage***				
	Juvenile		***Adult***		
	Medium	**Strong**	**Weak**	**Medium**	**Strong**
Speckled Rockfish			✓		✓
Splitnose Rockfish		✓			
Spotted Ratfish		✓			✓
Starry Flounder		✓			✓
Striped Surfperch					✓
Stripetail Rockfish		✓			✓
Tiger Rockfish				✓	✓
Topsmelt				✓	✓
Vermilion Rockfish					✓
White sturgeon			✓		
Widow Rockfish		✓			✓
Wolf-eel					✓
Yelloweye Rockfish					✓
Yellowtail Rockfish				✓	✓