AN ABSTRACT OF THE THESIS OF

Melinda T. Agapito for the degree of Master of Science in Marine Resource Management presented on June 26, 2008.

Title: Mapping and Lithologic Interpretation of the Territorial Sea, Oregon

Abstract approved:

Chris Goldfinger

Seafloor lithologic maps have been widely used to identify conservation sites. In this study, a lithologic interpretation of Oregon's territorial seafloor was created as an interim product in response to the need for a comprehensive lithologic map that will be used in the identification, evaluation and design of marine reserves in Oregon. While future multibeam mapping of the Oregon Territorial Sea will likely replace this product in the next few years, the ground truth data from which the map is constructed will continue in use in future efforts.

This mapping project utilized a classical geologic approach aided by GIS technology in which all relevant thematic geologic layers were applied to interpret patterns of seafloor lithology. The discovery of approximately 9,600 NOS bottom samples from the National Ocean Service (NOS) historic hydrographic smooth sheet archives has tremendously improved upon the original sample dataset (305 bottom samples) used in previous characterization of Oregon's territorial seabed. Supplementing the NOS bottom samples, other existing datasets including historic kelp distribution (used as proxy for rock), a triangulated irregular network (TIN) surface model derived from bathymetric soundings, rock outcrops digitized from 0.5 meter aerial photos, subsurface structure, and the adjacent onshore Oregon digital geologic map were used. While the collection of smooth sheet data from historic surveys utilized leadline sampling techniques and traditional navigation methods such as three-point sextant positioning, it was observed that the typical positional error averaged ~28 meters relative to contemporary aerial photography

where comparison was possible. GIS software was used for simultaneous display of varied thematic layers, qualitative interpretation, quantitative accuracy assessment, and density mapping processes in this project.

This current mapping effort showed that the NOS "smooth sheet" data collected from 1858 to 1958 compares well with modern data and that the NOS datasets and methods are able to capture the general outlines of rocky outcrops particularly in shallow areas. The territorial lithologic map shows a reasonable overall accuracy of 64 % relative to existing habitat interpretation of rocky reefs based on high-resolution multibeam data. Furthermore, the NOS bottom samples provide an opportunity to map additional sediment types that are not represented in the existing Surficial Geologic Habitat (SGH) map of the territorial sea. Finally, a companion product to the maps, a composite density map was created from the underlying datasets (kelp, bathymetry and bottom samples) to represent the spatial variation in data quality and quantity used in the interpretation of seafloor lithology.

It is anticipated that the data obtained from this study will serve as a useful tool for scientific investigation and management efforts such as the ocean zoning in the nearshore region of the Oregon coast, which includes the upcoming designation and evaluation of marine reserves.

Mapping and Lithologic Interpretation of the Territorial Sea, Oregon

by

Melinda T. Agapito

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APPROVED:

Major Professor, representing Marine Resource Management

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Dean of the Graduate School

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.

Melinda T. Agapito, Author

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Mapping and Lithologic Interpretation of the Territorial Sea, Oregon

1. Introduction

In 2000, the Active Tectonics and Seafloor Mapping Lab (ATSML) was engaged in mapping the Oregon's seafloor in response to the urgent need for seafloor data that was required for policy making. The first regional surficial geological habitat (SGH) map of the Oregon's continental margin was generated by Romsos et al., 2007 in response to the essential fish habitat (EFH) Bayesian habitat suitability modeling efforts of the Pacific Fishery Management Council (PFMC) and National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS).

Currently, the ATSML is initiating a mapping effort for the territorial sea in response to the process of establishing marine reserves in the state of Oregon as major endeavor to support the West coast governors' agreement on ocean health. In view of this, the Oregon's Policy Advisory Committee (OPAC), which is tasked to make recommendations to the governor, put forward a proposal recommending that seafloor mapping be conducted as part of establishing marine reserves. This is due to the fact that only five percent of the Oregon's territorial seabed has been mapped using multibeam bathymetry (Fox et al., 1999, Fox et al, 2000; Merems and Romsos, 2004). In addition, while a regional surficial geological map (SGH) for the territorial sea is available, (Romsos et al., 2007) there is the need to have it updated using additional data.

Seafloor mapping vis-à-vis marine reserves

Seabed geological mapping has evolved with time from characterizing surface sediments and defining its units or formations. For instance, in Oregon, Kulm et al. (1975) described the sedimentary facies (mud, sand, mixed sand and mud) of the Oregon's continental shelf in relation to sedimentary processes impacting its transport and distributions. This type of early study of substrates has propelled benthic habitat mapping of seabed by characterizing its topography and sediment texture (Fox, 1999; Cochrane and Lafferty, 2002, Freitas et al., 2003; Merems and Romsos, 2004, Lanier et al, 2006, Romsos et al, 2007).

Currently, it is apparent that the conduct of sediment mapping is being increasingly used to describe benthic habitats (Greene et al., 1999; Valentine et al., 2003). A number of studies have correlated sediment types to the habitats and its influence on the spread and abundance of marine organisms (Williams and Bax et al., 2001; Kostylev et al., 2001 Anderson et al., 2002;Pickrill et al., 2005). It has been reported that the seafloor characteristics of Heceta Bank in Oregon can be associated with certain types of macro-invertebrates and groundfish assemblages (Tissot et al., 2007). In Oregon, Fox et al. (2004) demonstrated some patterns of fish abundance, distribution, and species composition relative to the size of reef patches at Cape Perpetua. Also, Fox et al. (1999) has developed methods to characterize bottom types and establish its relationship to fish abundance and distribution.

Benthic Habitats vs. marine reserves

Sediment characterization and habitat classification have become important tools for research, monitoring, and management of national marine sanctuaries (Barr, 2003). Studies by Jones (1994) and Ticco (1995) suggested that habitat diversity is essential for the design of marine reserves. In California, the concept of benthic habitat mapping has been instrumental in the identification and design of marine reserves (Cochrane and Lafferty, 2002 and Airame et al, 2003). Lindholm et al. (2001) demonstrated that fish responses to variations of seafloor habitats (flat sand, pebble-cobble, and boulder) must be considered in the designation of habitat-specific marine protected areas (MPAs). Jordan et al. (2005) demonstrated that seabed habitat mapping is capable of defining the boundary and size of potential MPAs in the Kent Group of Islands, Australia. It was observed in their study that seabed habitat mapping is required for the process of determining whether the MPAs are comprehensive, representative and adequate. Therefore, lithologic map in the context of MPA process has increasingly been recognized to serve as an effective tool that can help integrate biological and physical data (species and habitats) that are essential in spatial planning involving marine reserves.

Goals

In view of the marine reserves effort and the limited seafloor data for the territorial sea, the ATSML initiated a coastwide mapping project for Oregon with the following goals and questions.

1. Pool all existing data necessary for the territorial sea and make them available for mapping the Oregon's territorial seabed.
2. Generate a comprehensive lithologic map which can be used to update the existing SGH map of the territorial sea in future.

The following questions are addressed as new datasets are being used in the mapping and interpretation process.

a) What are the issues and limitations of datasets and to what extent are they consistent with each other?
b) What lithologic interpretation techniques are most suitable for capturing seafloor rocks and rocky reefs?
c) What level of detail in terms of mapping scale and mapping unit can the available datasets provide?

2. Methods

2.1. Study Area

Complementing the focus area for the state of Oregon's marine reserve process, this study covers Oregon's territorial sea spanning three nautical miles (3.45 statute miles) from the coast. The Territorial Sea boundary line is measured 3 nautical miles from a coastal baseline which is defined using Mean Lower Low Water (MLLW) and extends to another three nautical miles from offshore islands found within the first three nautical miles (e.g. the offshore rocky islands of Orford and Rogue Reefs). The entire Territorial Sea comprises an area of approximately 1000 square nautical miles and has a mean depth of 35.5 meters. Several mapping efforts have been initiated for the territorial sea such as the regional mapping approach (Kulm, 1975; Romsos et al. 2007) and the localized approach with the use of high-resolution multibeam in specific rocky reefs (Fox et al., 1999, Fox et al., 2000; Amend et al., 2001; Merems and Romsos., 2004). Oregon's Territorial Sea is a management area encompassing the seabed, the water, and life within the area described above.

2.1.1. Nearshore Geologic Setting

2.1.1.1. Territorial sea Morphology/Physiography

Oregon's Territorial sea occupies the easternmost or landward part of Oregon's continental shelf with its widest width off Cape Blanco. The Territorial Seafloor is relatively flat with a mean slope of about 1 degree with a topography covered mostly by sediment (Maloney, 1965). A series of interconnecting subsurface synclines occurs between the shore and the outer banks off southern Washington as well as northern and central Oregon. The largest of these synclines are filled with sediment, and mostly outside the territorial sea (Kulm, 1978, McNeil et al, 2000).

The coastline of Oregon is relatively straight except where there are protruding headlands and estuaries extending westward and eastward from the coastline. Resistant headlands are mostly made up of volcanic rocks while the rest of the coastline is composed of crystalline and sedimentary rocks (Kulm 1978). Byrne (1964) has demonstrated that erosion is prevalent along the Oregon coast. Steep cliffs that are vulnerable to erosion characterize much of the coast. In the southern portion (Cape Perpetua extending to North of Florence), tertiary mudstones and siltstones are easily eroded from the cliffs when attacked by waves (Komar, 1994). It has been reported that less than 13 percent of Oregon's shoreline is critically eroding (Bernd-Cohen and Gordon, 1999). Another report estimates 180 miles of Oregon's beach representing about 50 percent of the coastline is undergoing erosion and approximately 120 miles of it is without dry sand at high tide (Oregon Ocean-Coastal Management Program, 2006). The vulnerability of the Oregon coast to erosion is attributed to major storm events in Oregon that tend to generate waves ranging from 20-50 ft in height. This is coupled with high water levels resulting from the water that washes up on shore following incoming waves enabling subsequent waves to reach much higher elevations (Komar and Allan, 2000)

Territorial sea sediment

Most of the sediments in the Oregon territorial sea are found to come from major rivers on the Oregon coast such as the Columbia River which serves as the main source of sediments. The Umpqua, Rogue and the Klamath Rivers of northern California provide additional sources of sediments in the southern part of the coast. Coastal erosion and landslides have been suggested by previous studies (Kulm, 1978, Byrne, 1963) as another sediment source along the coastline when wave action dispersed the sediments from cliffs and headlands. It is predicted that 595,000 m^3 of coastal sands could be added to the continental shelf every year (Runge, 1966).

Kulm (1975) has demonstrated that sand facies have occupied most of Oregon's near shore seabed since the Holocene transgression. This sand facies extends from the shore to depths of 90 to 100 meters between the Columbia and Siuslaw Rivers and to a depth of 50 meters from the Siuslaw River to the southern end of the Oregon coast. This sediment is continuously supplemented with new sands coming from erosion related sedimentary materials redistributed by wave action. Recently, it was observed that a systematic variation of beach sand sizes from Lincoln City to south of Siletz Spit is caused by sea-cliff erosion around Gleneden Beach (Komar et. al., 1994).

2.2. Datasets Sources and Data Distribution

2.2.1. Historic hydrographic Surveying (1878-1958)

The survey methods employed by U.S. Coast and Geodetic Surveys between 1878 and 1942 in the collection of sounding and bottom sample data recorded on "smooth sheets" are briefly described in this section. It is important to note that instruments and methods for hydrographic survey have progressively evolved. Three aspects of hydrographic data collection are emphasized in this documentation. These include the description of the hydrographic smooth sheets, datums for measuring the depths and position of soundings and the process on how the bottom sample labels on the smooth sheets were collected and identified.

Smooth sheets

Beginning in the 1850's a comprehensive recording of hydrographic data collected by the Coast and Geodetic Survey (now National Ocean Service, NOS) yielded a series of hydrographic smooth sheets" (see Figure 2.1). The first quality drawing paper, the "smooth-sheet paper" was mounted on muslin. The preferred standard paper for smooth sheets was the media also refered to as the Whatman's paper with dimensions of 31 x 53 inches (Hawley, 1931). However, a paper with a dimension of 36 X 42 inches (in continuous rolls of 20 yards) was preferred in offshore surveys (Adams, 1942). Smooth sheets were commonly constructed in 1:20,000 scales during the period between 1858 and 1958. Greater scaling was set as successive multiples of 1:20,000, with each scale being 2-fold greater than the preceding scale (i.e., 1:10,000, 1:5,000, and 1:2,500). The level of detail required on the hydrographic sheet served as basis for the choice of scale. For instance, a plot on a scale of 1:10,000 or more (Adams, 1942) was utilized in harbors, anchorages, channels, and other parts of the coast where there was higher chance of experiencing a catastrophe or navigation difficulty.

Datums

Two types of datums, the vertical datum (also called the sounding datum, chart datum or tidal plane) and the horizontal datum (also called geodetic or geographic datum) were used in hydrographic surveying. The former served as the reference for depths and elevations, while the latter was referred to for latitude and longitude to determine position of depth points and bottom samples.

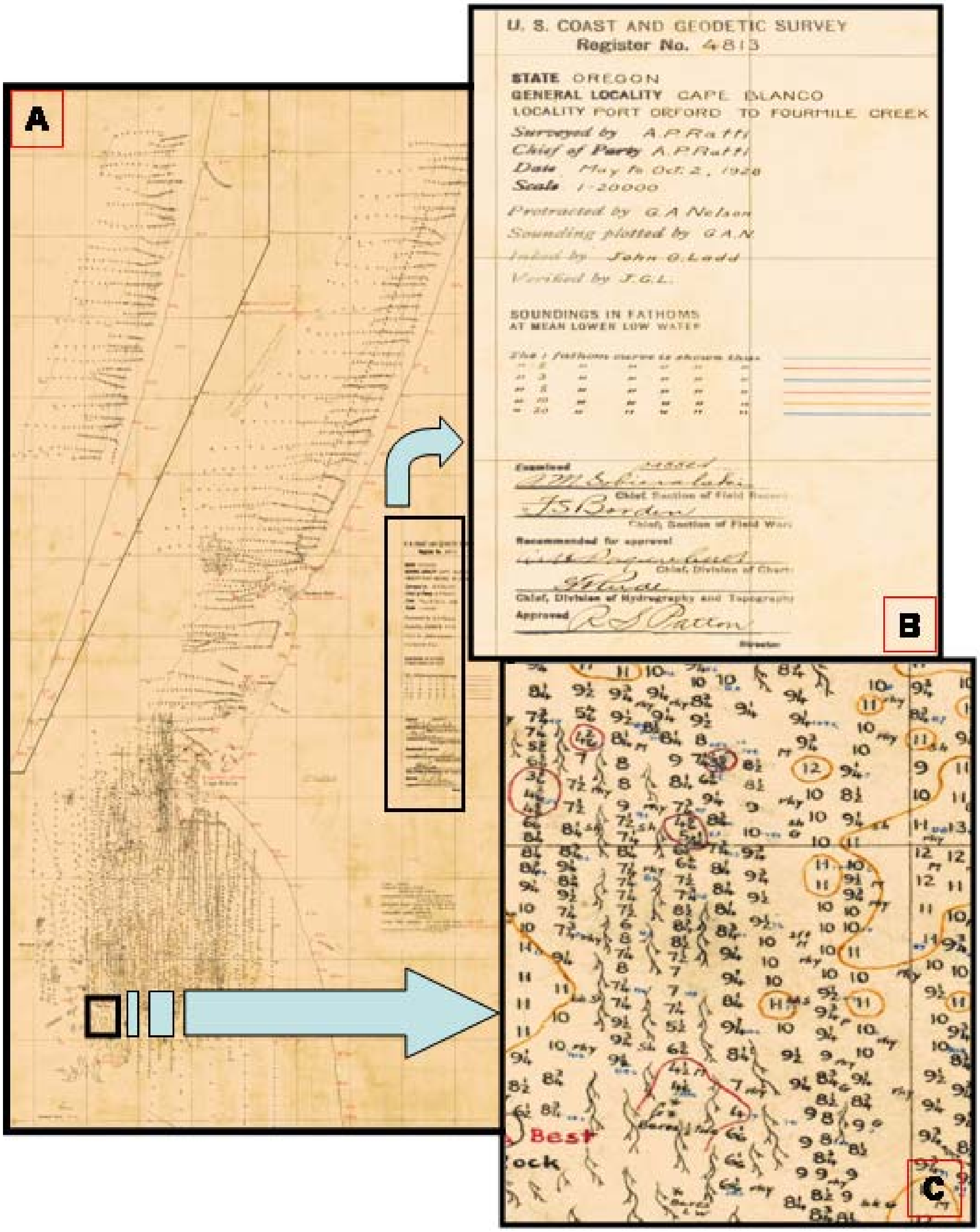

Figure 2.1 Smooth sheet for Cape Blanco surveyed in 1945 by U. S. Coast and Geodetic Survey

Depth Measurement: Tide gage and benchmark

The mean lower low water (MLLW) was the tidal datum utilized in all hydrographic surveys that were conducted by U.S. Coast and Geodetic Survey and in these early surveys, MLLW tidal data were generated from at least one lunar month's observation (U.S. Coast and Geodetic Survey, 1878).

In order to establish the sounding datum, tide-gauges and permanent benchmarks were established close to the survey area and on land, respectively. Prior to the 1930s, surveys utilized non-registering gages for which an observer was required to document the heights of the tide. The simplest and best gauge in perfectly sheltered localities was a vertical tide staff graduated upward in feet and tenths. Also, it was required to orient the vertical tide to ensure that its zero lay below the lowest tides was critical. In situations where data identification was a challenge due to increased range of the tide, a box-gauge was used. Beginning 1931, two principal kinds of automatic tide gages for a graphical recording of the tide were employed by the Coast and Geodetic Survey. Where prolonged observations were conducted, the standard automatic tide gauge was designed for use at primary tide stations or control station while portable automatic tide gages were used at secondary tide stations for short term observations (Adams, 1942). In general, the gauges were situated in locations representative of the tidal cycle as expected at the survey location. It is important to note that Airy's rule was applied by the hydrographer to set the limit of distance at which a gauge may be positioned in order that no correction of the observations for difference in time of the tide is required. Benchmarks (from which the gauge position is referenced) were established on land with the plinth of a light-house, and the base of a monument or rock (USCGS, 1878).

2.2.1.1. Geographic Positioning: Control stations and Sextant positioning

The North American datum of 1927 for surveys that were conducted after 1927 represents the horizontal datum that was used (Adams, 1942). The principal geodetic control for all coastal hydrographic projects consists of stations located at approximately 5-mile intervals by second-order triangulation along the coast. This is supplemented by intermediate stations located at approximately 2-mile intervals along the coast with thirdorder accuracy. The principal geodetic control for hydrographic projects consisted of second-order traverse with stations set at 2-mile intervals along the coast in situations where the character of the terrain made triangulation impracticable (Adams, 1942). The routine method of fixing *position* for hydrographic surveys is known as the *three-point fix method*, which used onshore stations, benchmarks, rocks, or buoys, with the geographic positions established based on the control stations onshore. Sextant angles or theodolite angles on board the sounding vessel were used to determine position where two observers determine angles simultaneously (Adams, 1942).

Two observers were positioned at *shore-stations (*light-houses or temporary tripods) to measure angles aboard the vessel and to verify the angle at the vessel in situations where work was conducted in deep parts of harbors, or where strong currents could potentially affect the accuracy of obtaining the position of samples. The position of the vessel was subsequently plotted using a three-arm protractor to generate a graphic solution of the three-point problem.

A greater degree of accuracy from observations closer to the control station on shore was guaranteed with the use of a sextant for positioning. For example, the error margin associated with sextant positioning was estimated to be on the order of 0.6 to 2.6 arc seconds, representing an increment of 2 m error for every 0.5 mile from the control stations on shore. Therefore, the accuracy of the instrument was quite high in controlled conditions. However, this accuracy is strictly applicable to sounding points but not as strict when positioning each bottom sample. In addition, the error budget must also consider some errors from the use of the instrument in a small moving vessel. Position errors relative to modern survey data will be discussed in a subsequent section.

2.2.1.2. Soundings and Depth Finding Instruments

The USCGS had established different systems of running lines for the conduct of soundings and each system utilized depends upon the bottom surface characteristic and the requirement for details aimed at a certain survey (USCGS, 1878). Several factors such as currents, direction of the wind and types of the vessel were influential in setting the direction of the survey line.

Instruments

The use of a graduated *sounding pole* was necessary in cases where sounding was being conducted in shallow shoal water (fifteen feet or less), or in muddy bottom. A disk must be attached at the end of the pole to avoid sinking (Adams, 1942). A sounding lead attached to a leadline made of graduated line (fathom or foot marks) is used on depths greater than 15 feet. The leadsman must heave the lead at an appreciable distance before sounding ship comes close to the sounding point. Subsequently, the leadsman when hauling in must keep the line taut and make sure that the lead touches the bottom when, depth is read from the markings on the leadline. It was very critical to lift the lead and keep it in a vertical position if the line has to be straightened. Immediately the sounding was obtained that line must be hauled and coiled back to its original position in preparation for next sounding. The roughness and smoothness of the bottom guided surveyors in determining the frequency of the casts. In irregular bottom surface, surveyors must conduct more depth soundings. This method is only effective between 10 to 15 fathoms and various weights of lead were used in this type of soundings. For instance, a lead weighing at least 8 pounds was used for depths of up to 8 fathoms and a range of 10-12 pounds for greater depths.

In addition to hand-lead soundings, a *sounding machine* was used in surveys using leadline technique. A sounding wire was used in combination with the sounding machine to advance the lead in areas of depths ranging between 15 and 100 fathoms. This was accompanied by the installation of a sounding chair on the survey ship. The weight of lead can range between 14-30 pounds in this method and can be used for depths of up to 1,000 fathoms. See chapter four of the hydrographic manual (Hawley, 1931) for more descriptions of sounding wires and sounding machines.

The use of acoustic fathometer and many other sounding instruments as part of the echo sounding method in 1931 revolutionized depth soundings (Adams, 1942). In the echo-sounding method, depths were measured based on the time interval consumed when sound travel from the ocean bottom back (which reflects the sound, generating an echo) to the ship. The depth was calculated from the product of one-half of the recorded time intervals and the velocity of the sound waves. The method of echo sounding provided a more efficient and effective depth measurement at depths greater than 15 fathoms. A detailed description of fathometer can be seen in chapter 4 of the hydrographic manual (Hawley, 1931).

2.2.1.3. Bottom Sampling

Sampling of the bottom sediments at selected intervals was conducted as an ancillary activity in hydrographic survey to evaluate the configuration of the bottom (U.S. Coast and Geodetic survey, 1878). Reefs or shoals were carefully sampled to determine as much as possible its extent and was evaluated for projecting (awash) rocks. To determine the extent of rocks, buoys were positioned at the highest points of a suspected reef area, and create radial sounding patterns from the buoys and increase the soundings within the shoal area.

Sampling leads have different diameter size ranging from 1½ - 2 inches that should vary with the weight of the lead. Sampling leads were designed to specific types of bottom surface. Typically, a cup-shaped depression in the bottom of a lead was created to hold bees wax, tallow, soap, or other arming material used to trap the bottom samples. Sand, mud, shells, and pebbles that adhere to these materials were brought to the surface for inspection and a material description recorded in the Sounding Records. To obtain samples in deep water, a snapper-type device was generally useful without which the bottom material will be washed off the armed sounding lead during its ascent through the water.

Bottom samples were preserved and described in wet and dry conditions. One set of specimen (per bottom sample type) was randomly selected and considered for classification.

2.2.2. Bottom samples from Hydrographic survey smooth sheets

The Lithologic point layer was digitized from the National Ocean Service (NOS) "hydrographic smooth sheets" which are the final, neatly drafted, accurate plots of hydrographic surveys using verified or corrected data. Approximately 9,000 bottom samples were captured for the territorial sea by the Active Tectonics and Seafloor Mapping Lab (ATSML) from 71 smooth sheets which were georeferenced by the Oregon Department of Land Conservation and Development (DLCD), covering the period from 1858 to 1958.

Approximately 1,500 bottom samples that were originally captured from post 1958 smooth sheets by NOAA-NOS were downloaded from NGDC, but only 208 samples were new information not included in the older smooth sheets that we digitized. Smooth sheets served as the foundation for nautical charts in the United States in response to the Organic Act of 1807, which authorized the U.S. Coast Survey (now NOS) to construct and maintain the nation's nautical charts. The sounding data was processed by hand to correct for tide to the mean lower low water (MLLW) tidal datum. This was a labor-intensive and time-consuming process, but the results were relatively accurate.

The horizontal accuracy of sample positions cannot be directly tested outside of the known errors in angle measurement. However, comparison of features was possible in several locations where nearshore rocks and islands were surveyed and are still essentially the same in modern data. Where possible, such positions were checked using the 2005 half-meter orthoimagery accessible at the Oregon Explorer site (Oregon Imagery Explorer, 2008). When matching these early surveys with recent data such as the 2005 aerial photo of the Oregon coast, we found out that positional differences ranged from 9 to 64 meters, averaging 28 meters. Table 2.1 and figure 2.2 shows the offsets used for testing navigational accuracy at known locations.

Rocks	A	B	C	D	E	F	Average
Offsets (meters)	16	15	25	63	41	11	28.5

Table 2.1 Offsets for known points (awash rocks), see Figure 2.2 showing the awash rocks on the 2005 Oregon aerial photo relative to the position of of the same awash rock as depicted on the National Ocean Service (NOS) smooth sheet.

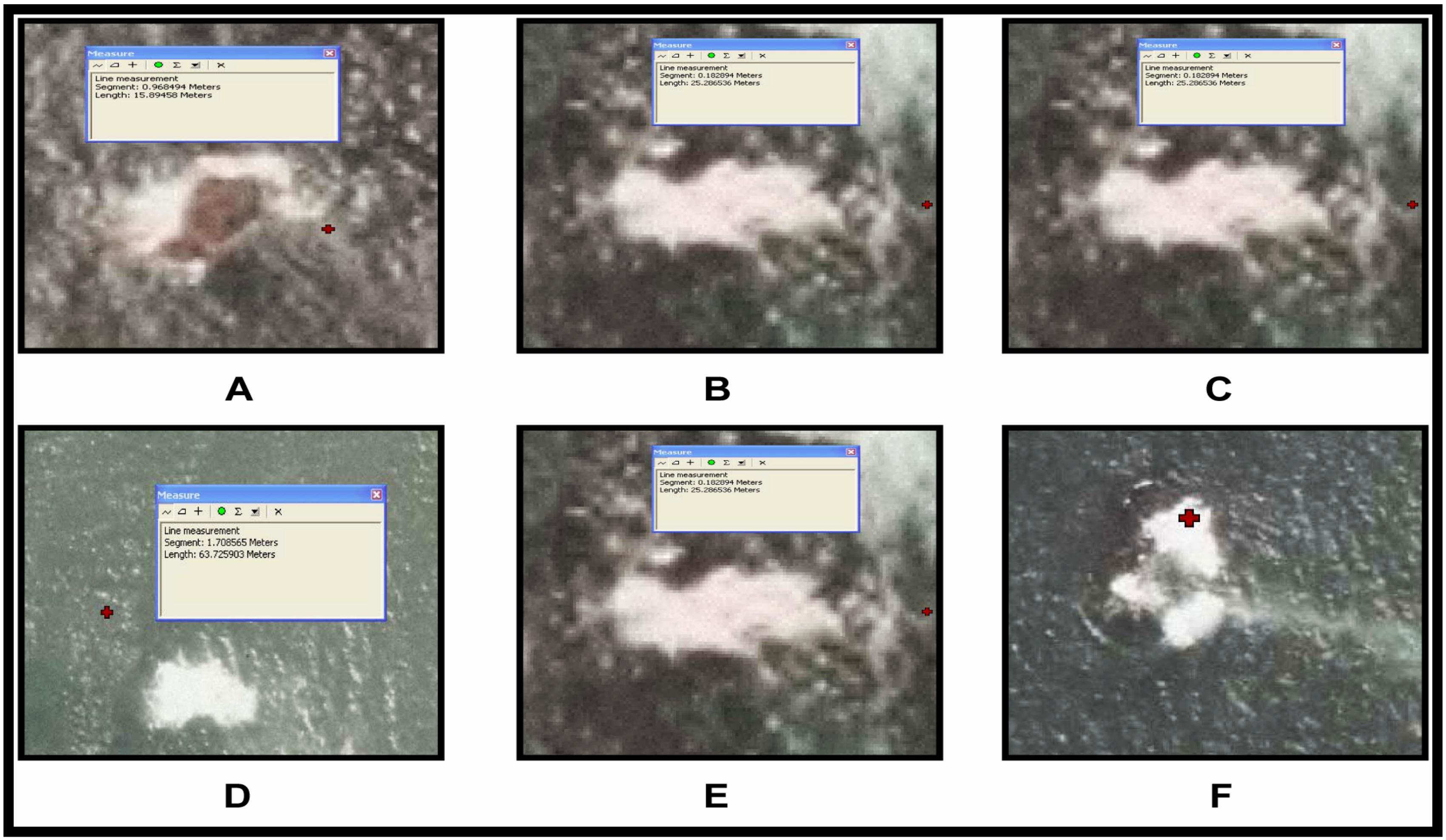

Figure 2.2 The screenshots of awash rocks from the 2005 one half meter spatial resolution of air photo of the Oregon coast, overlaid with NOS 089 (Red Cross) code for awash rock.

2.2.3. Kelp from ODFW and NOS holdings

Kelp layers include point data from the NOS Hydrographic Data Base (NOSHDB) which were acquired from data collection beginning in 1965. In addition, both polygon and point layers were digitized from georeferenced hydrographic smooth sheets through the combined efforts of the Department of Land Conservation Development (DLCD) and the Active Tectonics and Seafloor Mapping Lab (ATSML). Another historical source of kelp data was the kelp paper map series obtained from surveys of kelp beds in Oregon in (Cameron, 1915), although these were very general and of limited value. The ATSML digitized kelp beds from these paper maps were georeferenced using modern control points from 2005 aerial photos of the Oregon coast (Oregon Imagery Explorer, 2008)

Primarily, kelp polygon layers were obtained from a coast wide inventory of the distribution and types of kelp canopy on the Oregon coast in 1990 as well as a series of surveys conducted by Oregon Department of Fish and Wildlife (ODFW) in 1996-1999 in five rocky reef sites including Rogue, Humbug, Orford, Redfish and Blanco Reefs (Fox, et al, 1996; Miller et al, 1997; Fox, et al, 1999). All surveys used aerial photographs to capture kelp beds, demonstrating the areal extent of kelp canopy. A total of 4.9 km^2 kelp canopy surface of genus Nereocystis were mapped in these series of surveys and were used in interpreting the extent of rocky reefs. Although, Macrocystis also exists (in limited quantity) along the Oregon coast, it was not included in the ODFW aerial surveys. Nereocystis is annual kelp and its canopy grows up to 2 meter diameter (Michael Graham, 2008, Moss Landing Marine laboratories, personal communication).

2.2.4. Depth Soundings from NOS and USACE

The bathymetry data were acquired from the NOS digital database and augmented by additional soundings digitized from nine smooth sheets which, previously were not captured by NOS. These soundings were georeferenced to NAD83 datum, an earth-centered datum based on the Geodetic Reference System of 1980. In general, data points are dense in the first 1.5 nautical mile from shore and become sparser moving offshore. This is because NOS bathymetric data used in this study were focused on safety of navigation, as are modern surveys. The labor intensive and time-consuming process of using lead line survey techniques to collect depth and sample points significantly limits the coverage between individual soundings (USCGS, 1878). Another source of depth points is the coastal bathymetric data of the US Army Corp of Engineers (USACE). This dataset provided high density soundings but in small patches along the Oregon coast. Most of them occur along the bays and chiefly coincide with the disposal sites of USACE. These sites include: Columbia River mouth approaches, Rogue River approaches, Port Orford nearshore disposal, Bandon boat basin at Coquille River approaches, Coos Bay approaches, Salmon harbor reach at Umpqua River, Siuslaw River in Florence, Yaquina Bay, Depoe Bay, Tillamook approaches, and the nearshore bar, entrance and turning basin at Chetco River.

2.2.4.1. Triangulated Irregular Network (TIN)

The Triangulated Irregular Network (TIN) model was the main bathymetric derivative obtained from depth soundings. It was created with ArcInfo using the default parameters of the Createtin command using ArcGIS 9.2®. Every node in the TIN model is joined with its nearest neighbors by edges to form triangles, which satisfy the Delaunay criterion. This model honors all input bathymetric points to form contiguous, non-overlapping triangular facets that depict the roughness of the seafloor, while avoiding interpolation and smoothing of the data from gridding.

2.2.5. Awash Rocks and Islets from Aerial Photos

A half meter resolution set of coastal aerial photos (taken in 2005) for the Oregon coast was used to digitize awash and some subtidal rocks that can be deduced from aerial photos through the white water surrounding them, as well as subsurface rocks visible on the imagery (Oregon Imagery Explorer, 2008). In this way, most of the small islets along the Oregon's coast, and limited subsurface rocky substrate were captured digitally. Additionally, aerial photos were used to track presence or absence of rocks that were documented in NOS hydrographic smooth sheets along the beach when possible.

2.2.6. Refuge boundary Layer from USFWS

This refuge boundary layer was the latest polygon layer updated in 2003 and it includes all the small islands on the Oregon coast that serves as refuge for wildlife. Most of these islands are close to the coastline (USFWS, 2003) and were also used to compare navigation between modern methods and the sextant methods used for most of the smooth sheets.

2.2.7. Disposal Sites from USACE

This is a thematic GIS layer produced by the US Army Corp of Engineers to show the location and extent of the dredge disposal sites of all the sediments collected from their dredging projects. This dataset is used to interpret the surficial lithology of the Oregon coast's disposal sites based on the recent physical assessment of the dredge materials.

2.3. Classification of Lithologies

This study assigns all rock types and sizes into a single category. The National Ocean Service (NOS) classifies "rock" bottom samples based on their position relative to Mean Lower Low Water (MLLW), such as being awash, and not by size or relief. Similarly, all types of "sand" (coarse, fine, black, white) and "mud" (black, gray, and green) bottom samples from NOS smooth sheets are classified as SAND or MUD. These are consistent with the SAND and MUD categories of the existing Oregon continental margin SGH maps by Romsos et al. 2007. In order to preserve the original nomenclature of the NOS bottom samples, a separate attribute for NOS lithology was added to the sample data point layer. The lithologic classes used in this study were based on the bottom samples noted on the smooth sheets, see Appendix A and B, which shows the Cartographic Code and the bottom characteristics represented on the smooth sheets, and its conversion into the lithologic classes used in this project.

Mixed classes were defined based on the combination of bottom samples found on the smooth sheets (see Appendix C) and a maximum of three sediment types were considered in the mixed classes.

Table 2.2 shows the interpretation of the smooth sheets bottom sample codes into broader classes of seafloor lithologies that were used in the lithologic interpretation of the territorial sea. There are two important things to note in our classification of lithologies. First, the dominant sediment is named first when naming mixed sediments. For instance in Mud/Sand category, mud is considered to be the dominant sediment in the class; however, it is important to note that there is no strict quantitative convention on the proportion of the sediments in the mixed class (Perugini, 2008, NOAA Coast of Geodetic Survey, personal communication). Secondly, lithologies are defined using range of grainsize.

Table 2.2 Lithologic interpretation of the classification codes used in U.S. Coast and Geodetic Survey (now NOS) smooth sheets.

Smooth sheet codes	Conversion to Territorial Seafloor lithologies
Blds	Boulder
St Blds	Cobble/Boulder
St	Cobble
G, P, Sn, fne G	Gravel
Gy S G,	Sand / Gravel
Oz, Cl, Silt,	Mud
rky, rky Sh, Rk (Island), Shale	Rock
rky S,	Rock / Sand
S, gy S, fne gy S, crs gy bk S, crs bk S, hrd S, fine gravel	Sand
gy S M Sh	Sand/Mud/Shell
M S	Mud/Sand
G bk Sh	Gravel/Shell
rky Sh	Rock/Shell
Sh	Shell
crs bk S Sh,	Sand/Shell

2.4. Mapping Data Density in the Territorial Seabed

This study utilizes varied GIS datasets to map seabed lithology. Therefore, a density map was created to assess the distribution of data and indirectly evaluate the quality of the interpretation. This method was originally used by Romsos et al. (2007) to standardize, assess and rank the quality of disparate datasets used in mapping the Surficial Geologic Habitats (SGH) of the continental margin of Oregon and Washington.

In this study, a density map is an indirect representation of confidence in the product derived from the lithologic polygon interpretation. Confidence, thus map accuracy, is based on the number and quality of data points available within an area. Grid density layers were created from bottom samples, bathymetry points, kelp and islet polygons and subsequently standardized or normalized which allowed for the creation of composite density map. Figure 2.3 shows the process in obtaining composite density maps.

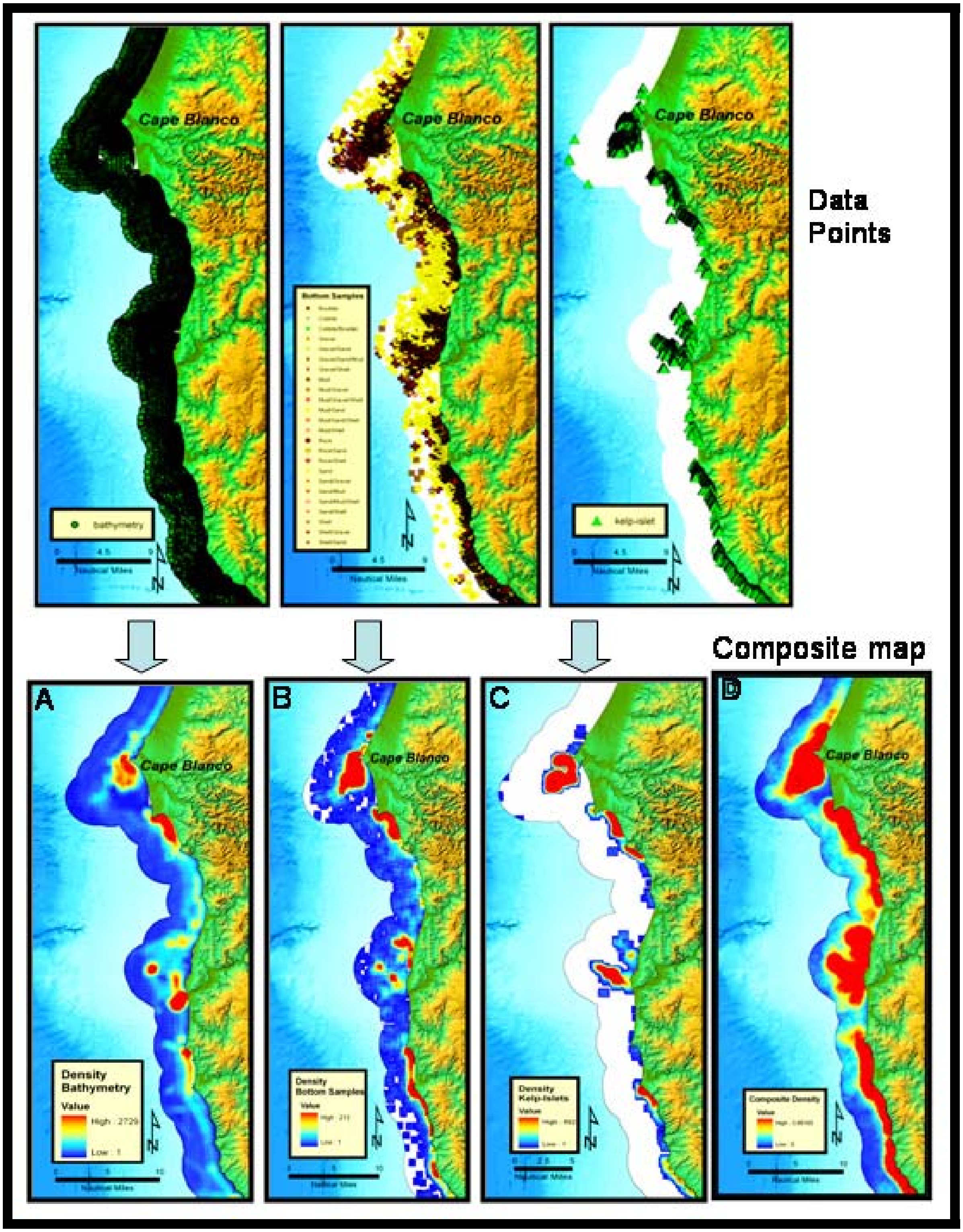

Figure 2.3 Process involved in creating density map. Top panels: Point data (bathymetry, bottom samples, kelp-islet) were used to produce the density data. Bottom panels: Density maps (A. bathymetry, B. bottom samples, C. kelp-islet), weights were applied to each density map to generate the additive composite map (A*1+ B*3+C*2 = D).

2.4.1. Density of Bottom Samples

The bottom sample density layers are composed of samples captured from the smooth sheets and the original samples for the territorial sea of approximately 300 points compiled from different sources (Romsos et al., 2007). Overall, there are approximately 9, 600 points used to generate the bottom sample density.

The spatial analyst *point statistic tool* (Spatial Analyst tools>Neighborhood>Point Statistics) was employed in creating the density layer with the output cell size of 100 m^2 and a search radius of 5 cells or 1500 m^2.

2.4.2. Kelp and Island Density

In order to obtain the density of the kelp and island polygon layers, a two-step process was carried out. First, kelp and island layers were merged and converted to raster layer with a small grid cell size of 25 m in order to accommodate the smallest polygon. Then, using the *raster to point* tool of ArcToolbox, the 25 m grid was converted to points using 50 m grid cell size. Similar parameters used in creating the bottom sample density were also untilised in producing the kelp-island density.

2.4.3. Bathymetry Density

Prior to creating the density layers, the sounding points were cleared of duplicates and a remaining total of approximately 183, 000 bathymetric points were used to generate the bathymetry density layer. The *point statistic tool* of Spatial Analyst was then used to generate the bathymetric density layer. A maximum of 2729 per grid cell recorded the highest number of points in a raster cell. For this purpose, we excluded the ODFW multibeam surveys from the density layer of bathymetry soundings.

2.4.4. Composite Density Maps

A two-step process was required to generate a composite density map. In the first phase, each of the density layers (kelp-islet, bathymetry, and bottom samples) generated by *point density tool* was normalized using the mathematical expression as shown below. This equation provides a raster with grid cells with a value between 0 to 1 and 0 to 100 percent when multiplied by 100. In the second phase, the density layers were weighted based on the level of confidence given to each data layer during the interpretation process. For instance, since bottom samples were assigned higher priority during the interpretation of the seafloor lithologies, it was given a weighting of 3 representing the highest weight as shown in the equation below. The weights assigned to the other layers were 2 for kelp-islet and 1 for bathymetry data.

Normalized grid density = (raster – min) / (max – min)
Raster represents the grid density layer (e.g. bathymetric density)
Max and *min* represent the maximum and minimum values of the grid cell.

Composite density map = (normalized bottom samples * 3) + (normalized kelp and island * 2) + (normalized bathymetric density)

2.5. Mapping the Territorial Seabed

2.5.1. Previous Mapping of the Territorial Sea

Beginning in 1858, the Coast and Geodetic Survey used lead line soundings and bottom sampling to map the territorial sea. This was followed by mapping the sediment facies as summarized by Kulm (1975). Recently, the Oregon Department of Fisheries and Wildlife (Fox et. al., 1999) embarked on collecting a series of high resolution bathymetric surveys using multibeam sonar on several rocky reefs inside the territorial sea. To date, this effort has mapped ~ five percent of the territorial sea. Following this, a regional surficial geologic habitat (SGH) mapping that included the territorial sea, was conducted by Romsos et al. (2007), although little data were available for the nearshore portion of this regional map which has much emphasis on federal waters.

2.5.1.1. ODFW Multibeam bathymetry Surveys

The Oregon Department of Fish and Wildlife (ODFW) initiated a multibeam mapping program on selected reefs which currently have completed about five percent coverage of the territorial sea. These multibeam surveys began in 1999 in southern Oregon around Cape Blanco to classify bottom surface topography and its relationships to rockfish populations. These reef sites include Orford Reef (southwest of Cape Blanco), Redfish Reef, and Humbug Reef (South of Cape Blanco). This was followed by a sidescan sonar survey of Perpetua Reef in 2000 and Siletz reef in 2003 (Fox, et al, 2000 and Merems and Romsos, 2004). All these mapping efforts involved the bottom characterization that was based primarily on examining the topographic relief of the bathymetric or that imaged with sidescan sonar data. Thus, habitat was primarily interpreted by discriminating large topographic features such as pinnacles, ridges and crevices as opposed to textural characteristics such as mud vs. sand vs. rock (Fox et. al., 1999). Overall, this multibeam mapping has significantly improved the previous mapping conducted by National Ocean Service on the same rocky reef sites.

2.5.1.2. Regional Mapping of the Territorial Sea

Depth soundings were conducted on the Oregon Coast starting in 1858 by the Coast and Geodetic Survey (now National Ocean Service) aimed at mapping navigational hazards. However, until 1942, most of the early soundings were limited to a maximum depth of 15 fathoms (Adams, 1942; Maloney, 1965). The introduction of echo soundings made it possible for more extensive soundings to be collected over the territorial sea particularly in shallow areas where navigational hazards are likely to occur. Based on these surveys, the bathymetric charts (5702, 5802, and 5902) for the Oregon coast were published by the U.S. Coast and Geodetic Survey (Maloney, 1965). Notwithstanding the availability of the bathymetry and bottom samples, there was still no regional lithologic mapping conducted for the territorial sea until the mid 1970’s when Kulm (1975) summarized the sedimentary facies of Oregon from several studies. The sediment facies were determined from the textural analysis of surface and subsurface samples. Following this historical account, the regional sedimentary facies map by Kulm (1975) can be considered as the first regional interpretation of Oregon’s seafloor lithology. However, Kulm’s mapping effort focused only on the distribution of three sediment facies: mud, sand and mixed facies (sand and mud) which meant that rocky reefs and any form of rock outcrops were excluded.

Recently, a regional mapping of the territorial sea which included both the sediment facies and rocks were conducted by Romsos et al. (2007) by combining the sediment facies data and the ODFW habitat interpretation along with a habitat interpretation scheme utilizing additional sidescan sonar, submersible observations, and seismic reflection data.

2.5.2. GIS-based Interpretative mapping of the territorial sea

This study utilizes a qualitative interpretation of various thematic GIS layers through the visualization capabilities of GIS. In particular, ArcGIS was used to perform geoprocessing tasks, display geospatial data and digitize polygons of interpreted seafloor lithologies. The method uses a classical geologic mapping, where all available data are used to interpret the seafloor map pattern of lithologies. This qualitative approach in mapping avoids the use of algorithms which in most cases rely on uniform data coverage, and do not consider the artifacts and uncertainties associated with each data type that can lead to misinterpretation. Since uniform multibeam bathymetry, homogeneous sample coverage, and sidescan sonar data do not yet exist for the Oregon continental margin, a classical geologic mapping approach was used for this work, as it was for regional mapping of the Pacific Northwest continental margin (Romsos et al., 2007). A qualitative method allows for spatial variability of data quality, variability in the relative importance of each dataset, and the interpretation of artifacts in each dataset.

The following section illustrates the methods employed in interpreting seafloor lithologies using various GIS layers that directly or provides supplementary evidence in interpreting lithologic character the seafloor lithology. Lithologic sample points are always given priority in situations where other layers are showing conflicting information. The process for interpreting each polygon doesn’t always involve all five layers presented below due to the varying density of the datasets.

The primary method used to create the interpretation polygon layer is through digitizing polygons of seafloor lithologies in ArcMap using the editing toolbar. The interpretation layer is overlaid on top of all other data layers which are displayed in 50% transparency in order to visualize the spatial distribution of each dataset. The critical part of digitizing interpreted polygons is drawing the extent of lithologies through qualitative and visual interpretation of multiple GIS layers (see Figure 2.4). Generally, the TIN model, kelp layer (as a proxy for rock) and aerial photos were used to substantiate the extent of hard substrates indicated by bottom sample points.

2.5.2.1. Interpreting lithology using the TIN model

Displaying the TIN using color-shaded relief can depict bottom features such as ridges, valleys and rock outcrops particularly in areas where points are relatively dense (see figure 2.5). In most cases, the TIN surface was used to determine the extent of rock outcrops supported by lithologic samples. Ideally, bottom samples, kelp, and geologic structural map are used to validate the TIN roughness as an indicator of rocky outcrops.

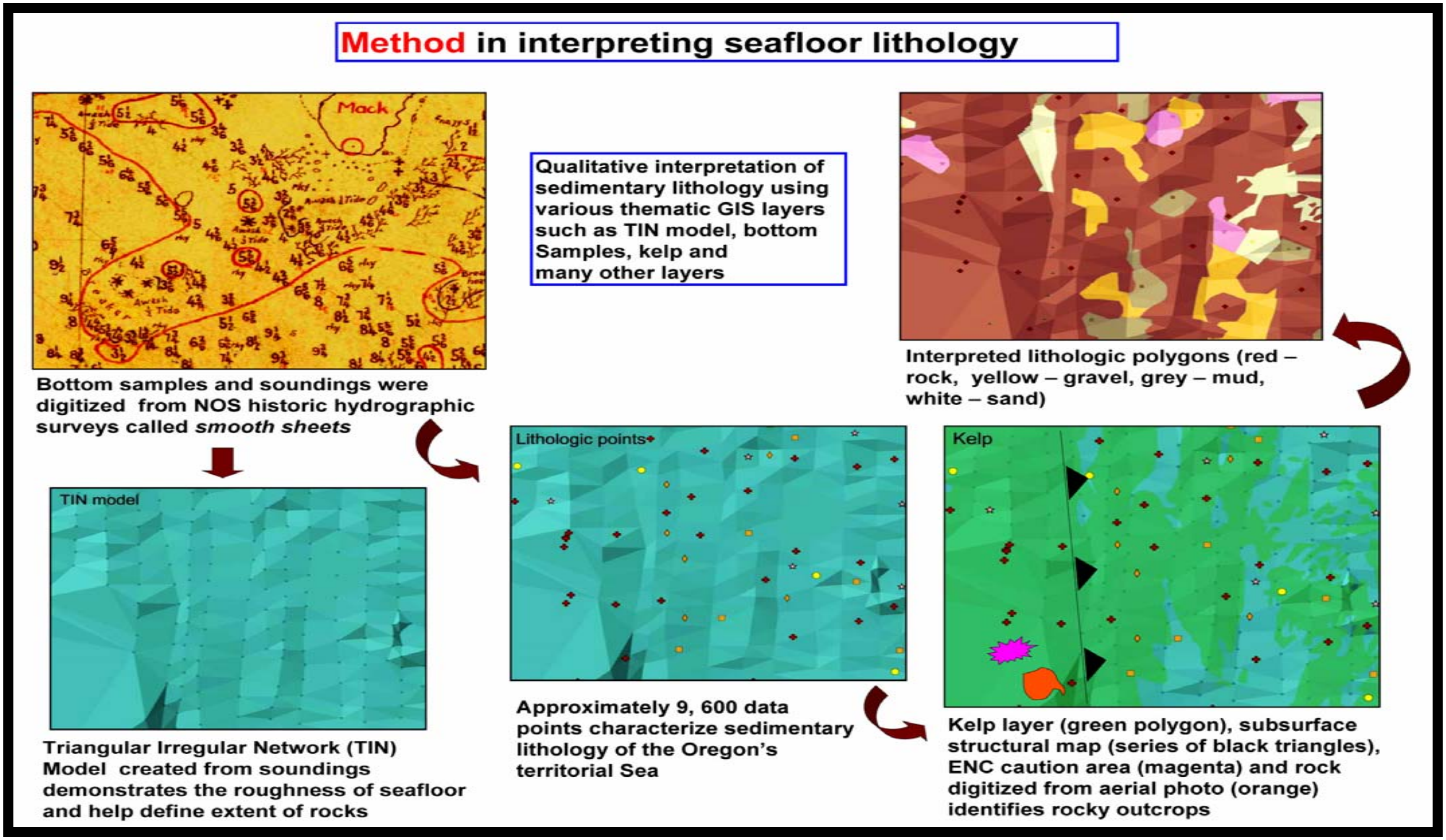

Figure 2.4 Qualitative interpretation processes involving the four major datasets (NOS bottom samples, triangulated irregular network (TIN) model, kelp, and subsurface structural map). Information from smooth sheet data such as the bottom samples and soundings are the main datasets used in the lithologic interpretation

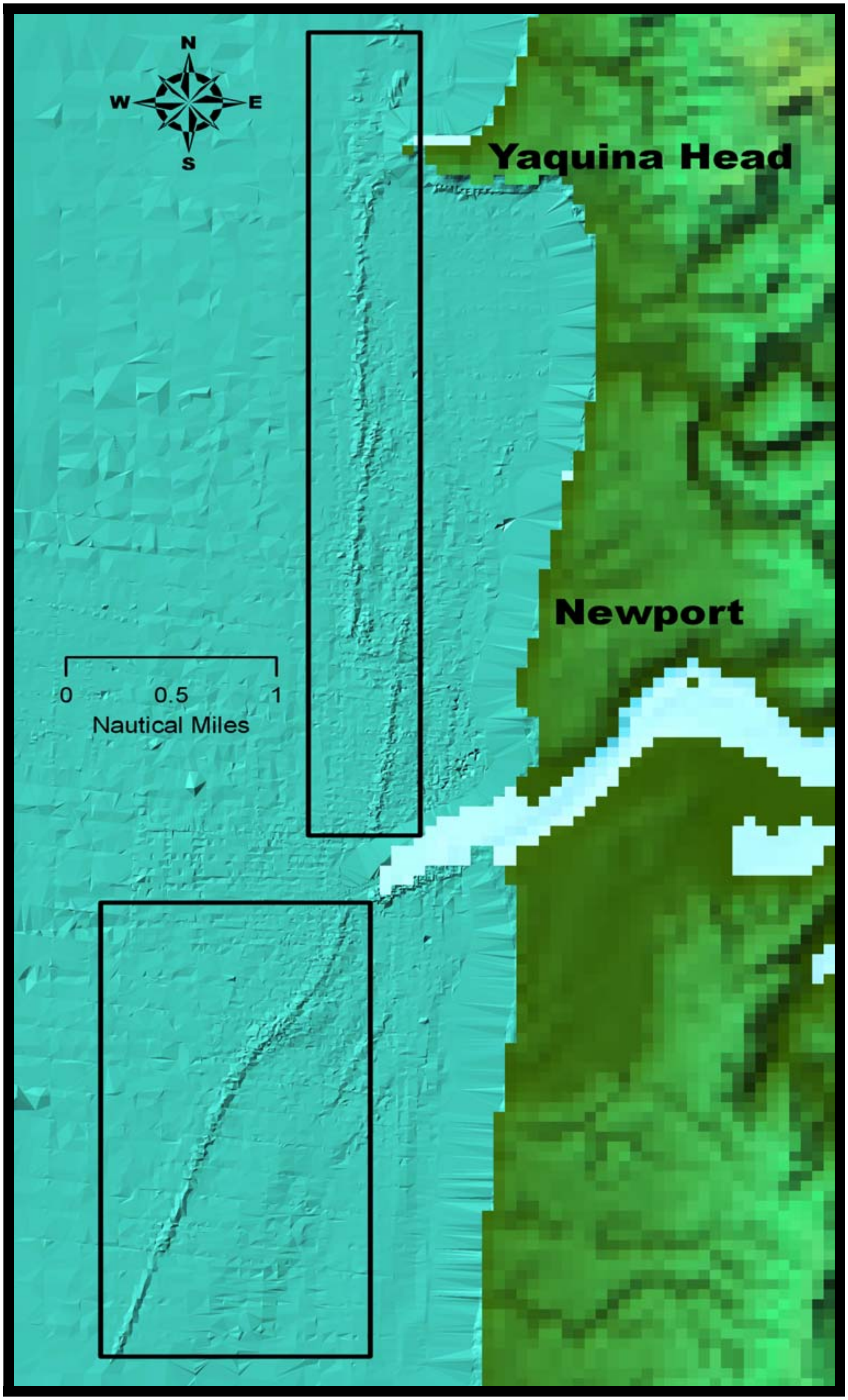

Figure 2.5 The TIN model (turquoise) created from soundings depict ridges from Yaquina Head to south of Newport.

2.5.2.1.1. Mapping (digitizing) Scale and Mapping Units

The digitizing scale varied according to the density of data captured from the smooth sheets. For instance, in areas where the density of data is higher and relatively patchier, a small digitizing scale ratio of up to 1:2000 was found more effective in order to draw a more detailed interpretation. Conversely, a scale of 1:20000 was set as the maximum digitizing scale used for areas where data is less dense and accuracy was unaffected by using a larger scale ratio. The mapping units used for interpretation also varied according to the data density, seafloor patchiness, z values (depth) of TIN vertices and the size of the triangle. The following summarizes the interpretation methods:

- If the TIN model indicated seabed roughness, and there were rocky bottom samples, it was interpreted as rock. The extent follows the limits of the TIN roughness unless limited by other bottom samples, affected by artifacts, or contradicted by other data (see figure 2.6).

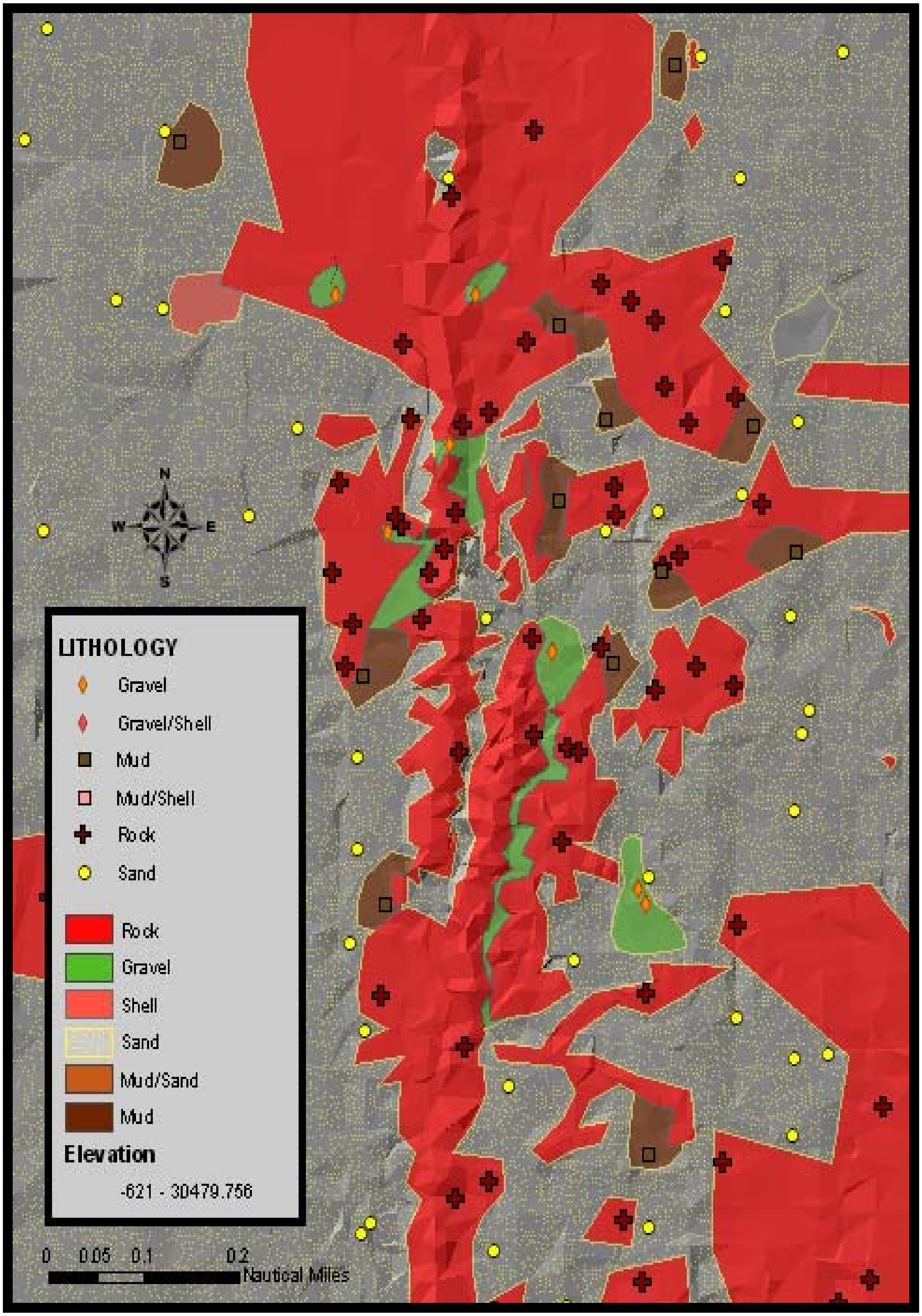

Figure 2.6 Image shows portion of Siletz reef where bottom samples and interpreted lithologies are overlaid (50% transparency) on the triangulated irregular network (TIN) model.

- The individual z values (depth) defining the vertices of the TIN model define the roughness variability used to map rock outcrops. For instance, in areas where the average local TIN roughness is significantly exceeded consistently by a patch of several TIN vertices, they were mapped as rock if they were unlikely to be artifacts and not contradicted by other data. The local value needed to exceed the average local roughness varied according to the local data quality and density, but was typically 5-7 m. The mapping of rock by this procedure generally required several crossing lines or random points, preferably during the same survey, to establish rock outcrops (see figure 2.7). The relatively high threshold for vertical roughness is conservative, that is few errors of commission are likely. The available data are not very sensitive to low lying rock outcrops, this we consider the rocky substrate coverage to most likely represent a minimum rock area in the Territorial Sea.

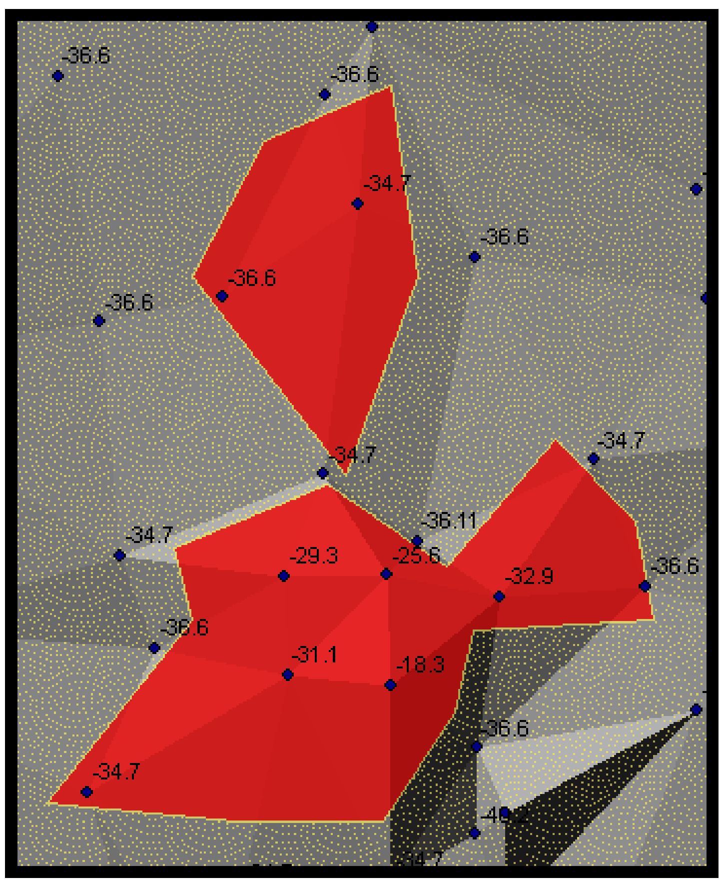

Figure 2.7 Random sounding points with varying depths (in meters) define some roughness on the triangulated irregular network (TIN) surface model and interpreted as rock outcrops (red polygon)

- Rock outcrops defined by TIN vertices that have limited surrounding data to define the outcrop, were drawn outward from the vertices 50% along the TIN facets to define the rock polygon (see figure 2.8).

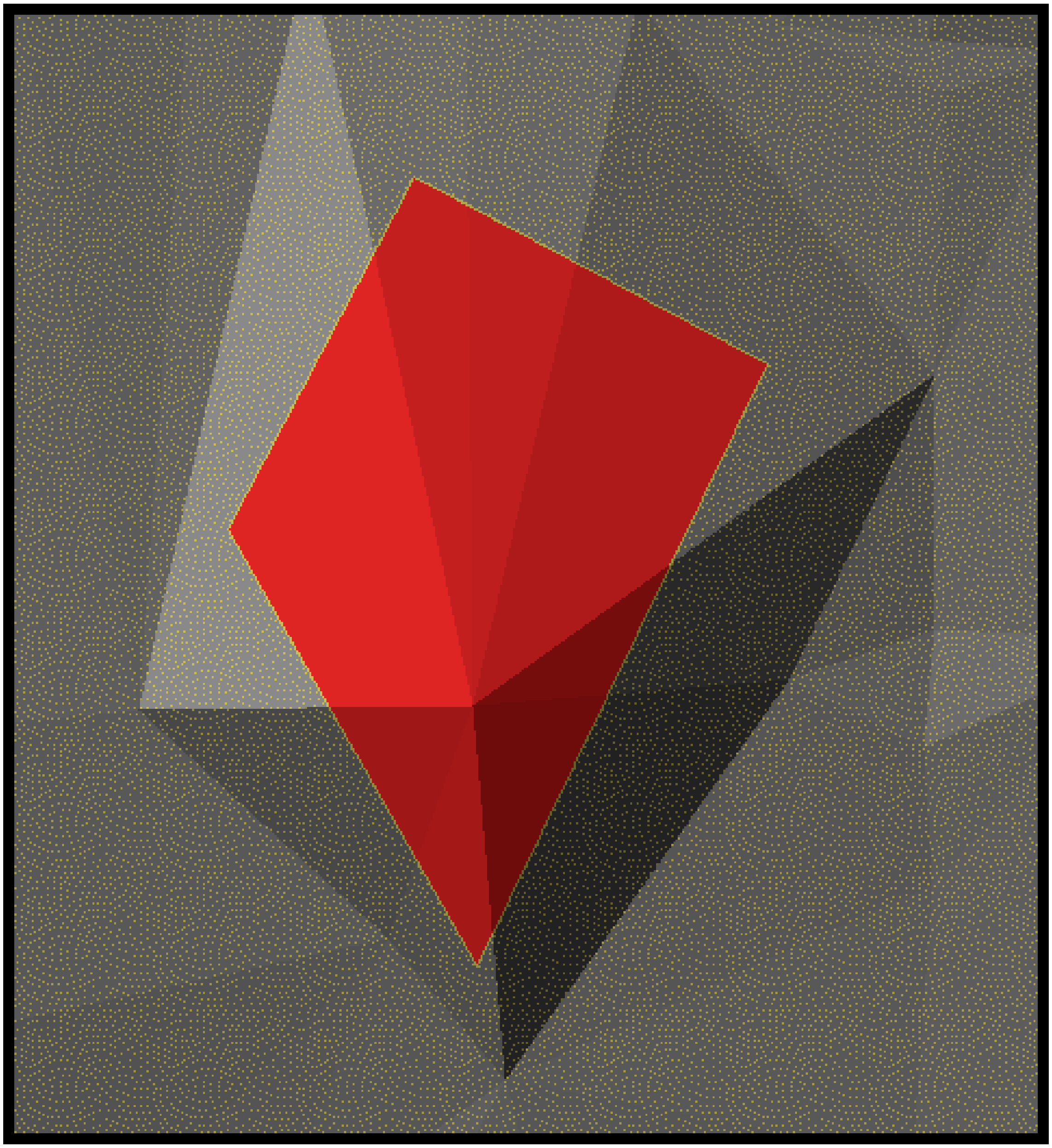

Figure 2.8 single triangles from triangulated irregular network (TIN) model representing rock pinnacle or rocky areas. Rock interpretation (red polygon) covers only 50 percent of the TIN triangle facet.

- If single or a few rocky (*rky*) bottom samples and other lithologic points define a rocky substrate that is not also supported by TIN roughness, a polygon was drawn with a diameter of ~ 150 meter. In contrast, a single awash rock (NOS code 089) bottom sample was assigned a 50 m diameter (see Figure 2.9).

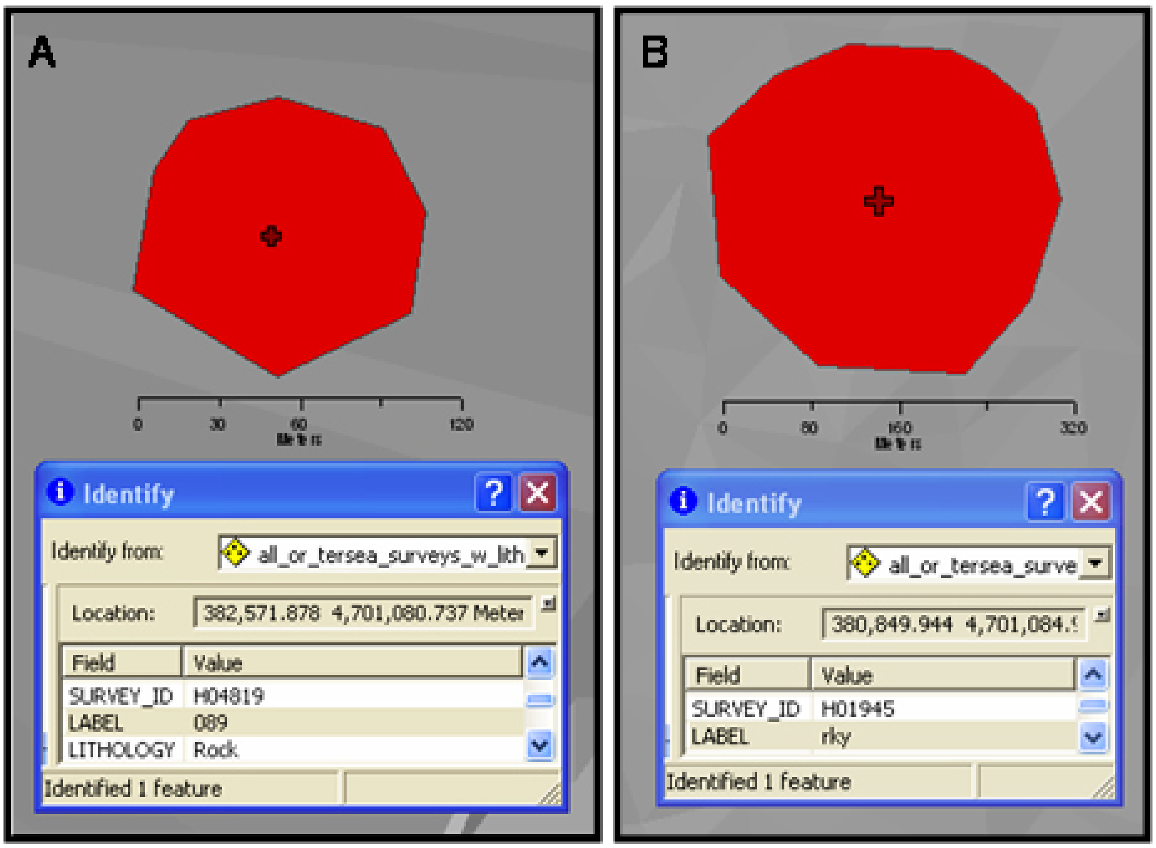

Figure 2.9 This "screenshot" of rock polygons (overlaid on TIN model) shows the standardized diameter used in determining the extent of single bottom samples where smooth or flat TIN surface model does not substantiate presence of rock. *A* is the single awash rock with the NOS code, 089 which can be composed of single rock and *B* represents NOS code, *rky*, which stands for patch of rocks.

- Because available data support a sand substrate in nearly all areas that do not have rocky substrates, we map areas with no available data as sand.

- In areas where conflicts arise, such as kelp mapped in areas of sandy bottom sample lithology, sample data takes precedence. Such cases were rare however.

2.5.2.2. Interpreting lithology using bottom samples

A total of approximately 9, 600 bottom samples from NOS and the usSeabed (Reid et al., 2006) were displayed in several point layers and visualized over other rock proxy data such as kelp and TIN model. The bottom sample layers were the primary datasets used to interpret the bottom character of territorial seabed. The bottom sample points are very dense in some areas (213 per 100m^2) and are capable of outlining the extent of seafloor lithology more clearly than the TIN model or kelp layers. The surveyors of the Coast and Geodetic survey focused on rocky areas as their mission was safety of navigation, as it remains today. This resulted in increased sample and sounding density near discovered rocky outcrops. In situations where the TIN model and kelp layer data do not show enough information to substantiate the bottom samples and define the outcrop extents, a mapping procedure (see section 2.5.2.1.1.) described above is used.

2.5.2.3. Interpreting lithology using aerial photos

A one-half meter resolution aerial photos taken in 2005 (Oregon Imagery Explorer, 2008) were used to digitize and create a polygon shapefile of awash rocks and islets on the Oregon coast. Figure 2.10 is an aerial photo showing the captured islets. This created the rock polygon shapefile that served as one of the GIS thematic layers used during the interpretation process.

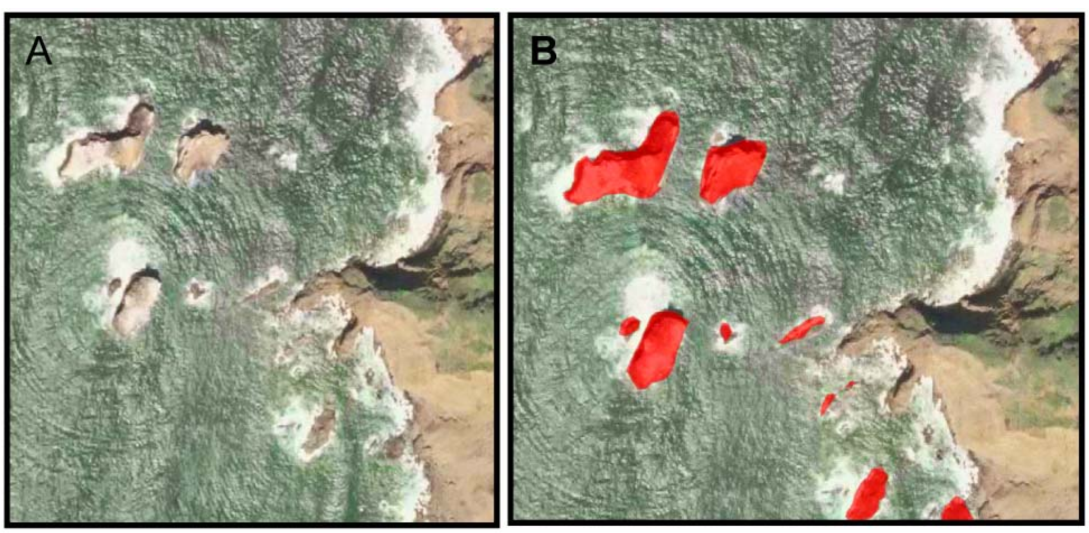

Figure 2.10 Oregon 0.5 meter aerial photos showing (a) wash rocks and (b) polygons of rocks (red) digitized from aerial photos which was also used in rock interpretation of the Oregon's seafloor. This aerial photo is also available online, *http://oregonexplorer.info/imagery/*

Aerial photos also provided clues about the extent of rocks particularly in areas close to the shoreline where bathymetric data and TIN model are not detailed, as well as in the shallow subsurface in cases where image quality allowed interpretation of rocky bottoms in shallow water (see figure 2.11).

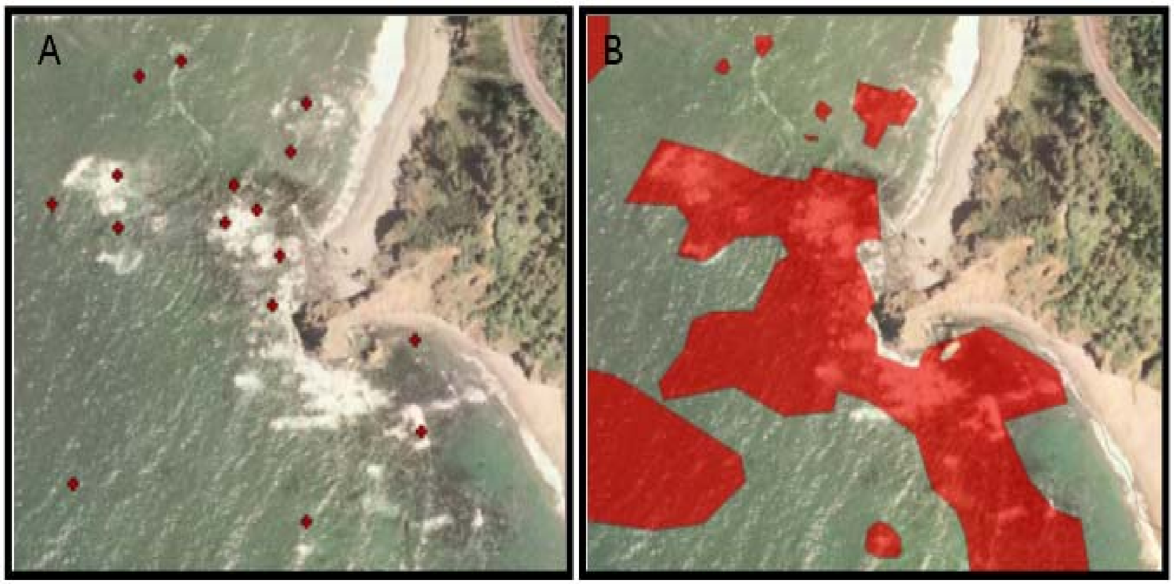

Figure 2.11 Oregon 0.5 meter aerial photo (south of Frankport) showing patch of rocks close to the shoreline. A - NOS rock bottom samples (red cross) corroborate to the rocks shown by aerial photo. B - Rock polygon digitized from rocks shown by the aerial photo and NOS rock samples

2.5.2.4. Interpreting lithology using kelp layers

Macrocystis and *Nereocystis* comprise two large species of kelp are commonly found on the U.S. west coast. They are monitored using aerial photography as their canopies on the water surface are still visible from a great distance (Britton-Simmons et al., 2008 and Fox et. al., 1994). On the Oregon coast, the genus Nereocystis is the most common kelp type while *Macrocystis integrifolia* is found in extremely limited ranges in North Cove (Simpson's reef) at Cape Arago (Yoshiyama and Sassaman, 1987; Fox et. al., 1994; Hansen, 1997)

Similar to TIN model, the kelp polygon and point data layers were utilized as rock proxy and were significantly considered in determining the extent of rock outcrops. The critical part of using this data is the fact that kelp polygons were digitized from an aerial extent of the kelp canopy which can be a potential source of error in itself. Knowing this potential source of error, a careful interpretation of kelp polygons was observed. For instance, it is disregarded in cases where it conflicts with the bottom samples, though this conflict could arise from change of the seabed over time. Figure 2.12 shows how other lithologies (gravel, shells, mud and sand) were interpreted amidst the kelp polygon. Michael Graham (2008, Moss Landing Marine Laboratories, personal communication) observed that the kelp canopy of genus Nereocystis expands to a maximum diameter of 1-2 meters in this annual species. Thus for this species, the chance of over-interpreting rock (by using kelp as proxy) is unlikely, particularly considering that most aerial photography errors represent a kelp canopy smaller than its true extent (Britton-Simmons et al., 2008).

2.5.2.5. Interpreting lithology using geologic structural maps

Geological structural maps were used as an additional supporting data, particularly in areas where the TIN roughness and sample points suggested a structural trend. The structure data used was the compilation of Goldfinger et al. (1992). The structural data includes depiction of geological structures such as faults, synclines and anticlines. Faults often create seafloor linear outcrops, while folds are generated from compressional stress resulting from crustal deformation processes. These structures may potentially expose rock outcrops on the seafloor, particularly anticlines which tend to create rock exposures at their crests, and faults which create high-angle scarps. Structural mapping was originally done using seismic reflection data and thus these structures were mapped in the shallow subsurface, with seafloor exposure indicated where apparent. Using these geological structures was carefully considered in conjunction with the degree and patterns of the TIN roughness and sample data. Figure 2.13 represents the geological structures complementing with the roughness of the TIN surface, hence, interpreted as rock outcrops.

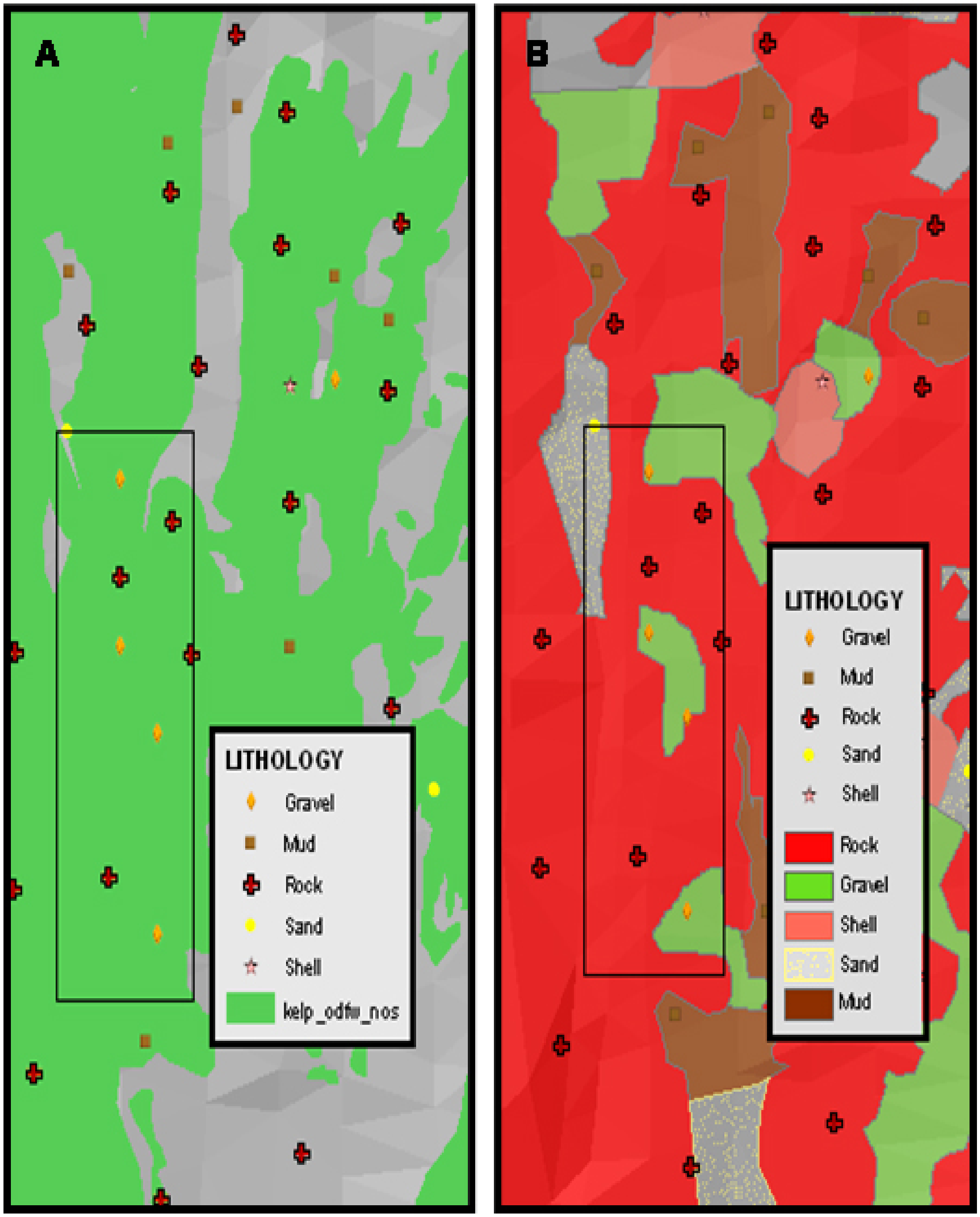

Figure 2.12 This portion of the map was taken around Orford Reef at Cape Blanco. A. Conflict between the bottom samples and kelp polygons, and B. the interpretation layer in which bottom samples takes precedence over the kelp data.

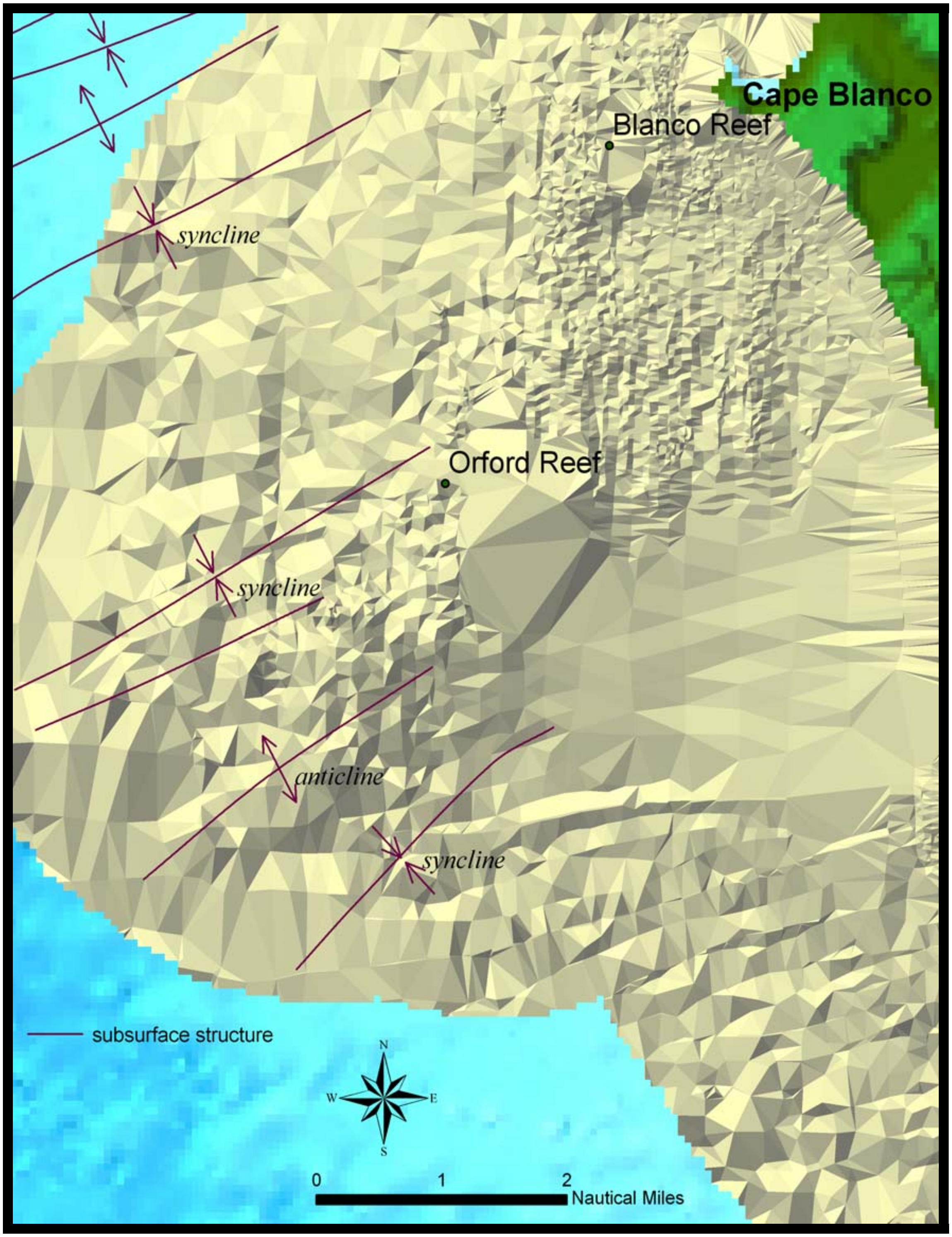

Figure 2.13 Triangulated irregular network (TIN) surface model overlaid by subsurface structural map depicting tectonic structures such as syncline, anticlines and faults. The geologic structural lines (magenta) substantiate the roughness of TIN at Orford reef around Cape Blanco.

2.5.2.6. *Interpreting lithology of dredge disposal sites of the US Army Corp of Engineers*

Dredge materials dumped in disposal sites have been examined on a regular basis as part of the USACE's sediment quality program that developed a sediment quality evaluation framework since 1986. This program includes sediment-related data storage to allow ready access of sediment quality information taken 10 to 15 years ago (Siipola and Carruba, 1998). Both physical and chemical analyses are conducted on materials proposed to be dredged and disposed on 11 disposal sites on the Oregon coast. To interpret the lithology of these disposal sites, the physical analyses of the recently disposed sediments were translated into the standardized lithologic classes used in this study. The translation of the physical composition reported for the dredged materials to the standard lithologic classes is as shown in Table 2.3.

Table 2.3 Physical composition of dredge material and its conversion into the lithologic classes used in territorial sea mapping. Sources: USACE, 1999, 2002a, 2002b, 2002c, 2003, 2005a, 2005b, 2006a, 2006b, 2006c.

Site	Sediment Composition	Lithologic Classification
Chetco	80% Sand	Sand
Columbia	>99% Sand	Sand
Coos	69.60% Sand, 28.8% Silt/Clay, 1.60% Gravel	Sand/Mud/Gravel
Coquille	97.2% Sand with Shell Hash	Sand/Shell
Rogue	54.48% Sand, 24.99% fines, 16.54% Gravel	Sand/Mud/Gravel
Siuslaw	97.1 Sand, 2.7% Silt/Clay, 0.2% Gravel with Shell Hash	Sand/Mud/Gravel
Umpqua	76% Sand, 23.70% Silt/Clay, 0.37% Gravel with Shell Hash	Sand/Mud/Gravel
Yaquina	91.60% Sand, 8.4% Silt/Clay, 0.2% Gravel	Sand/Mud/Gravel

2.5.2.7. *Interpreting lithology using other GIS layers*

Other secondary GIS thematic layers were used to provide additional clues to confirm the presence of rock outcrops. These include the *caution areas* and *breakers* from NOAA electronic nautical chart (ENC) and pinniped haulout sites which are data points that represent most of the rocky haulout areas of pinnipeds on the Oregon coast. These secondary datasets were used only cautiously where supported by other data.

2.6. Quantitative assessment and comparison with high-resolution surveys

One way to assess the quality of the map is to conduct an accuracy assessment (Congalton and Green, 1999) which requires reference data, usually groundtruth data, to which remotely sensed data can be compared. It is assumed that the reference data provides the highest level of accuracy. An accuracy assessment of this type was conducted using the ODFW multibeam and sidescan data and the Territorial Sea map (this work). The habitat interpretation of selected rocky reefs along the Oregon coast conducted by ODFW was considered as the reference data for the purpose of determining the quality of our lithologic interpretation relative to the habitat interpretation produced from the high-resolution bathymetric surveys. This comparison however cannot strictly compare the Territorial Sea Map to a reference dataset, because the ODFW habitat maps used here is also an interpretation, albeit from detailed sidescan/multibeam surveys. The ODFW habitat interpretations are for the most part not interpreted from groundtruth data, but rather are a product of qualitative interpretation techniques applied to high resolution bathymetry or sidescan data. Some of these surveys are multibeam, some are sidescan, and one had ROV transect video as groundtruth, while the others did not have groundtruth Merems and Romsos (2004). Nevertheless, a comparison was deemed valuable if not strictly quantitative. Table 2.4 shows the location of ODWF sites, instruments and the types of interpretation applied per site.

Table 2.4 Locations of Oregon Department of Fish and Wildlife (ODFW) sonar surveys, instrumentation and method of interpretation

ODFW Survey Sites	Survey Instruments	Method of Interpretation
Orford and McKenzie	Multibeam	Topographic relief characterization
Redfish	Multibeam	Topographic relief characterization
Humbug	Multibeam	Topographic relief characterization
Siletz	Multibeam	Topographic relief characterization
	sidescan	Backscatter interpretation
	ROV video	Groundtruthing with ROV video
Cape Perpetua	sidescan	Backscatter interpretation
Bandon	Multibeam	No interpretation

Four major reef areas were considered in the assessment process, including, Orford, Redfish, Humbug and Siletz Reefs. Perpetua Reef, ephemeral low-lying reef, was not captured in the lithologic interpretation of the territorial sea (this work). While this may be considered a failure of the method to identify a rocky outcrop, perhaps due to sparse data, or to low relief, it may equally well be due to temporal change. As the data used here cover the period 1858 to present, it could be that sand covered low-lying Perpetua reef earlier during the last century. Since potential causes for the failure to map Perpetua Reef cannot be distinguished, we omit it from the error analysis.

2.6.1. Simplifying the lithologic classification

Since the ODFW interpretation was mainly focused on characterizing the topographic relief (flat vs. rough) of the seafloor, it was necessary to simplify the ODFW rock classification for the purposes of comparison. For instance, ODFW habitat interpretation defined rock relative to particle size and approximate vertical relief. On the other hand, the lithologic interpretation of the territorial sea in this current study uses leadline samples, and does not include rock "size". Smooth sheet data defined rocks as awash rocks (NOS code 089), patchy rocks (NOS code *rky*, and single rocks (NOS *Rk*) into one category of Rock (see Appendix C). Table 2.5 shows that shell and its mixed classes were included in the Gravel/Cobble lithologic class and mud excluded from the assessment classification based on the fact that mud was not part of the ODFW habitat interpretation.

Table 2.5 Simplified classes of seafloor lithology considering the lithologic interpretation of the territorial sea (in this study) and the habitat classification of the sonar survey sites by the Oregon Department of Fish and Wildlife

Sites (Reef)	**ODFW habitat classification**	**Territorial sea lithologic classification**	**Simplified lithologic Classes**
Orford	Boulders >2m	Rock	Rock
Redfish	Boulders <2m		
Humbug	Bedrock 1 and 2		
	Gravel/Cobble	Gravel, Sand/Shell, Shell, Shell/Gravel	Gravel/Cobble
	Sand	Sand	
Siletz	Boulder, high rock, flat rock	Rock	Rock
	Sand	Sand	Sand

2.6.2. Sampling Scheme and Sample size

A simple random sampling scheme was used to generate the reference points based on the Hawth's Analysis (Beyer, 2004) available for ArcGIS™ as an extension tool. The Siletz overall accuracy remains constant from 970 samples and above. For this reason, we used 970 samples for Siletz. Following Siletz Reef samples plot, the sample sizes for other areas were estimated based on the proportion between the total area and the number of points chosen for Siletz.

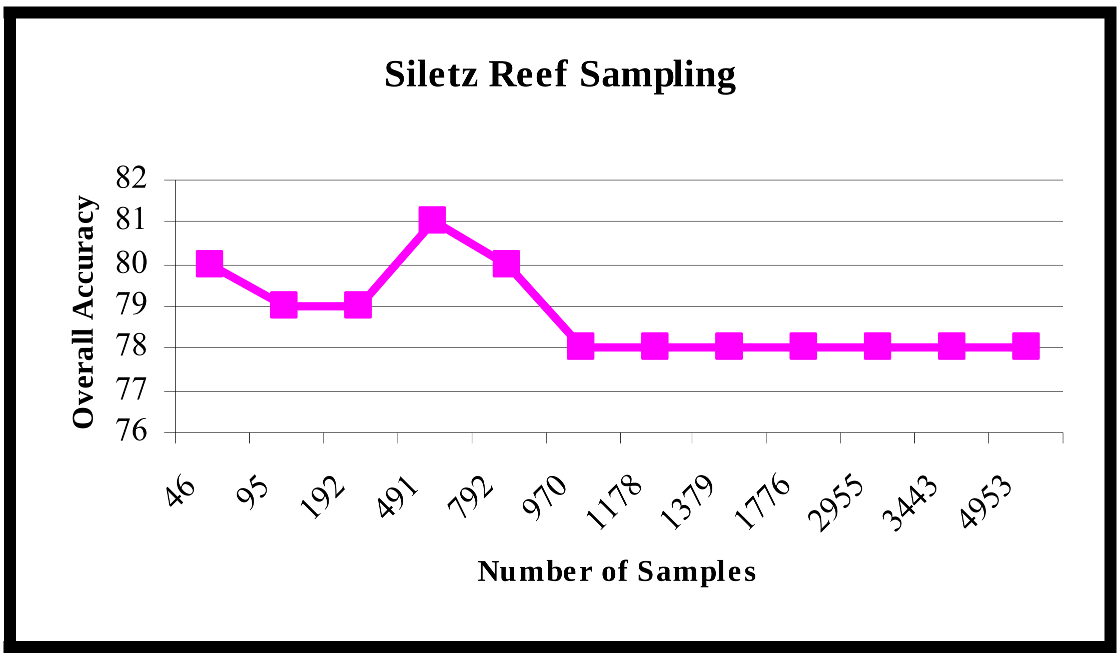

Figure 2.14 Siletz Reef Samples plot. The overall accuracy of 78 percent remains constant from samples 970 and above.

2.6.3. Quantitative Comparison of Territorial Sea and ODFW lithologic Interpretation Using Error Matrix

The error matrix columns and rows are valuable in demonstrating the overall and the individual conformity of classes between the two map interpretations. Individual conformity is calculated and referred to as the producer's and user's accuracy (Story and Congalton., 1986). Producer's accuracy is simply the number of observations correctly identified for each class or category in the classified data relative to the reference map. The user's accuracy represents the number of observations correctly identified versus the unspecified points for a given class within the classified data. Congalton and Green (1999) demonstrated that the user's accuracy represents the ground area estimates for each class. In addition, individual class can also be reported based on errors of inclusion (commission errors) and errors of exclusion (omission errors).

The generation of the values for the error matrix entails a five-step process. 1) Random points are generated using the *Generate random points tool* from Hawth's extension. 2) Random points are intersected with each of the polygon interpretation layers (ODFW habitat interpretation; territorial sea lithologic interpretation). 3) With the aid of the SQL capability of ArcGIS, the habitat and lithologic interpretation of territorial sea and ODFW are simplified into a separate attribute column. 4) The simplified classification in step 3 is queried to fill in the error matrix. 5) Conformity of data is calculated using the producer's and user's accuracy equation (see Appendix D).

3. Results

The territorial sea mapping project produced a detailed lithologic map capturing rock outcrops and other unique types of lithology not mapped in previous mapping studies in the territorial sea (Kulm, 1975; Romsos et al., 2007; Fox et al, 1999, Merems and Romsos, 2004).

3.1. Lithologic Mapping of the Territorial Sea

3.1.1. Rock Outcrops

This current mapping of the territorial sea includes approximately 155 km^2 of rock outcrops. Although this is less than half of the rock interpretation for the Territorial Sea in the existing regional map by Romsos et al. (2007), it provides a more detailed representation of the distribution of rock outcrops on the Oregon coast. For example, in the lower portion of southern Oregon, the current territorial sea interpretation revealed rock patches of Rogue reef and some rock outcrops at Nesika Beach. Additional patches of rocks were mapped in shallow areas between Hunters Cove and south of Chetco Cove (see Figure 3.1). On the northern portion, additional rocky outcrops are also found from Cascade Head down to Newport. Also, some patches of additional rocks were mapped around Cape Arago and Bandon (see figure 3.2)

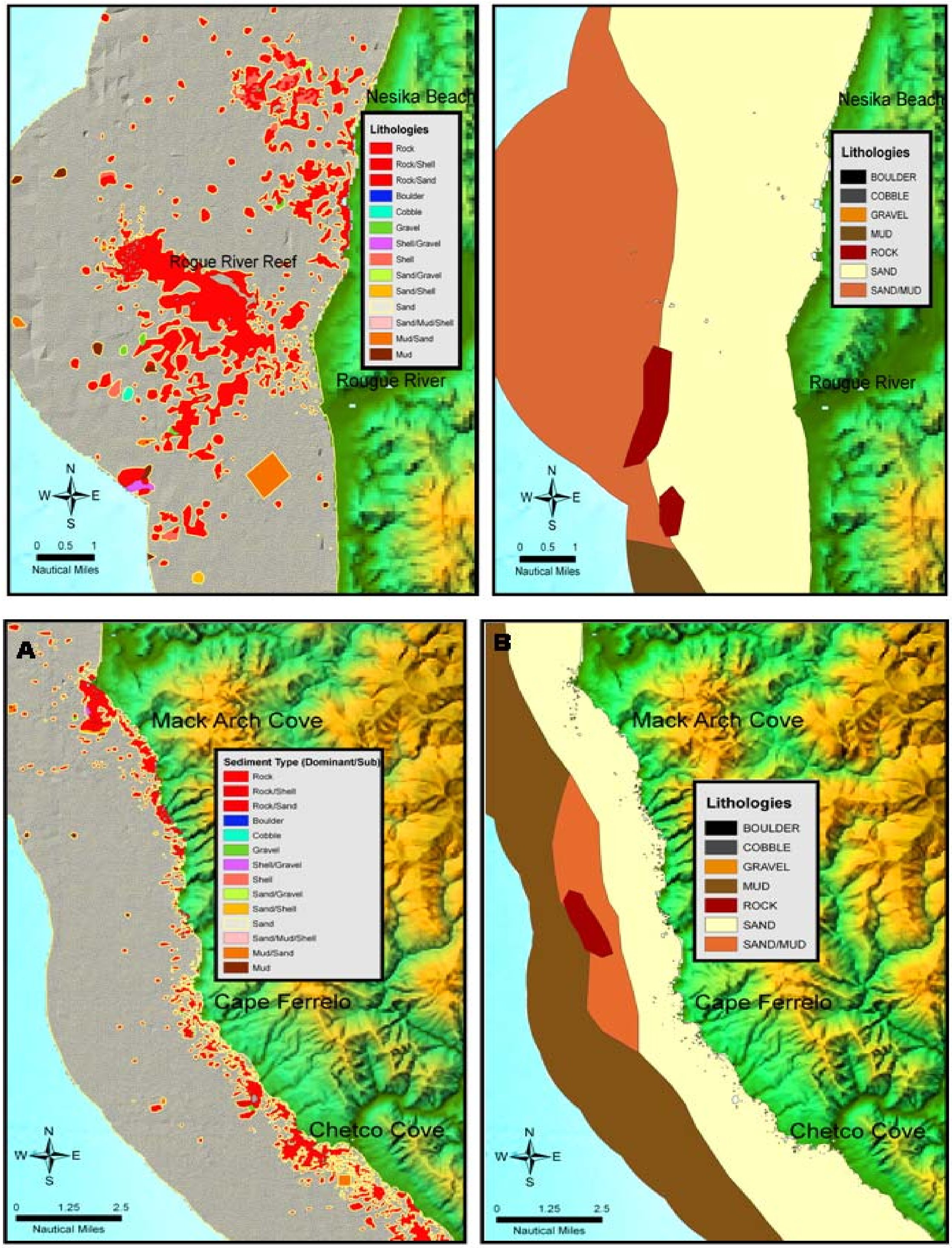

Figure 3.1 Additional rock mapped in southern Oregon. Top panels – Rogue Reef and rocky reefs at Nesika Beach. Bottom panels – rocky outcrops in the shallow portion of the territorial sea from Mack Arch Cove down to south of Chetco Cove. Left panels show the additional rock depicted in the territorial sea map. Right panels show the same area of the territorial sea as depicted in the surficial geologic map (SGH) map by Romsos et al., 2007.

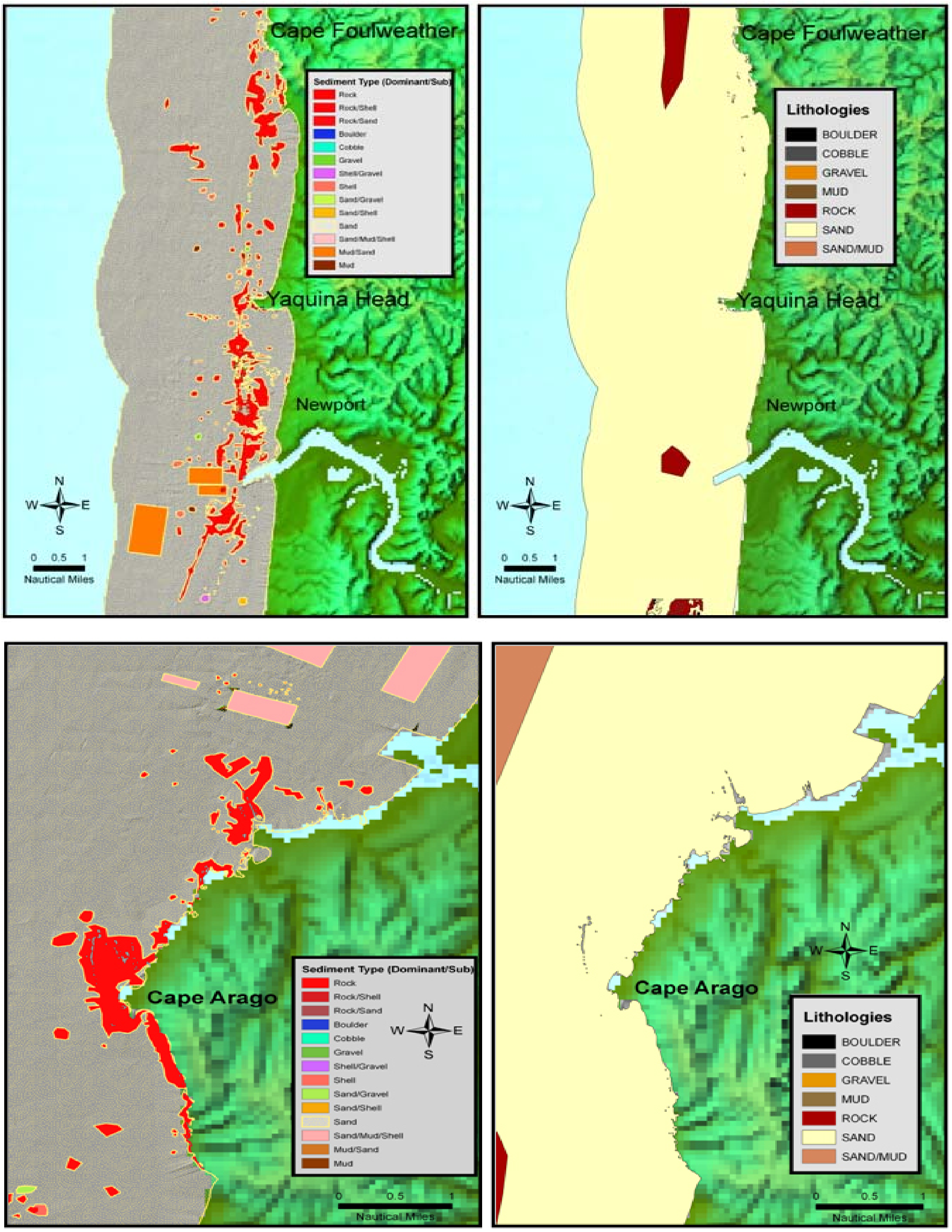

Figure 3.2 Additional rock map in northern Oregon. Top panels–ridges between Cape Foulweather and south of Newport. Bottom panels–rock outcrops around Cape Arago. Left panels show the additional rock depicted in the territorial sea map. Right panels show the same area of the territorial sea as depicted in the surficial geologic map (SGH) map by Romsos et al., 2007.

3.1.2. Sand

Sand interpretation dominates the territorial sea and consists of approximately 3058 km^2 comprising about 90 percent of the total area. This quantity of sand was interpreted from approximately 4,000 sand bottom samples. This sand interpretation of the territorial sea was also demonstrated by previous regional mapping conducted by Kulm (1975) and Romsos et al. (2007).

3.1.3. Mud

Mud comprises a small amount of interpreted lithology and small patches of mud are usually found in areas close to river mouths or at depths of more than 20 meters off the Columbia River, deeper than 45 meters around Tillamook Head or 65 meters at Cape Meares. In southernmost Oregon, mud is usually found in areas deeper than 60 meters (see figure 3.3). A number of studies demonstrated that mud is more likely to be found in deeper parts of the shelf because of wave action that transports this lightweight sediment further offshore (Kulm, 1975; Kulm, 1978) implying that, the presence of mud in shallow parts of the territorial sea is uncommon. However, in Oregon's territorial sea, patches of mud were also found in shallow areas where high relief boulders occur such as Orford and Siletz reefs (see figure 3.4). In addition, it is apparent that the distribution of mud patches corresponds to the extent of mapped rocky reefs or large fields of rock outcrops in the lower portion of northern Oregon. There was no evidence of mud in Central Oregon (Waldport to Coos Bay), which is consistent with the previous discussions of mud sediment distribution in the territorial sea by Kulm (1975).

3.1.4. Other Classes of Lithology

Appendix C shows other classes of lithologies including shells, and mixed classes (Sand/Mud/Shell, Gravel/ Shell, Rock/Shell, Sand/Shell) comprising a total of 401 bottom samples. These lithologies were not included in previous mapping of the territorial sea although a more recent survey observation confirmed that shell hash filled the gaps of the boulders observed in reefs off Cape Blanco (Fox et al., 1994).

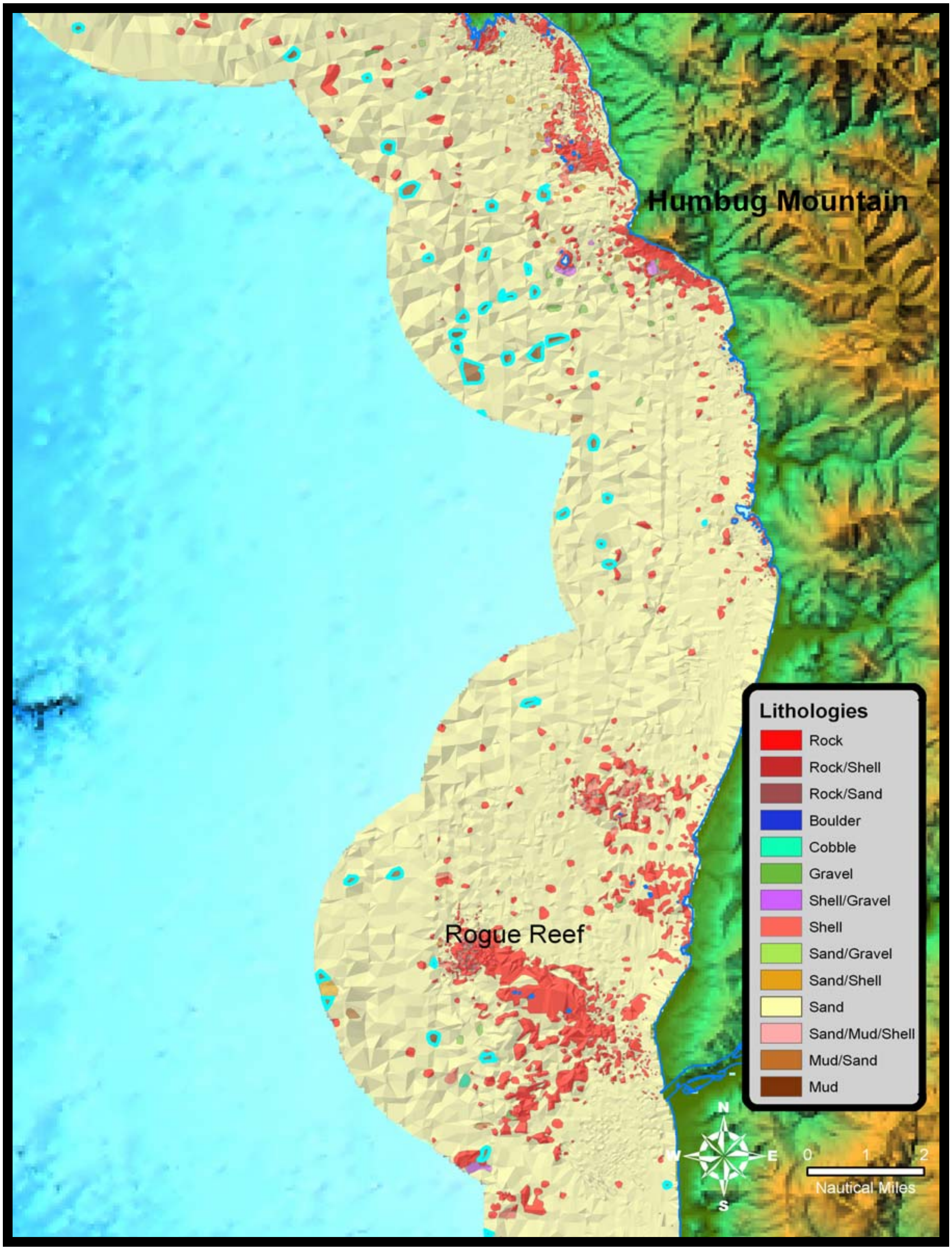

Figure 3.3 Seafloor lithology of southern Oregon, patches of mud (turquoise highlight) overlaid on triangulated irregular network (TIN) surface model. Most of these mud polygons are found close to the west boundary and deeper portions of the territorial sea

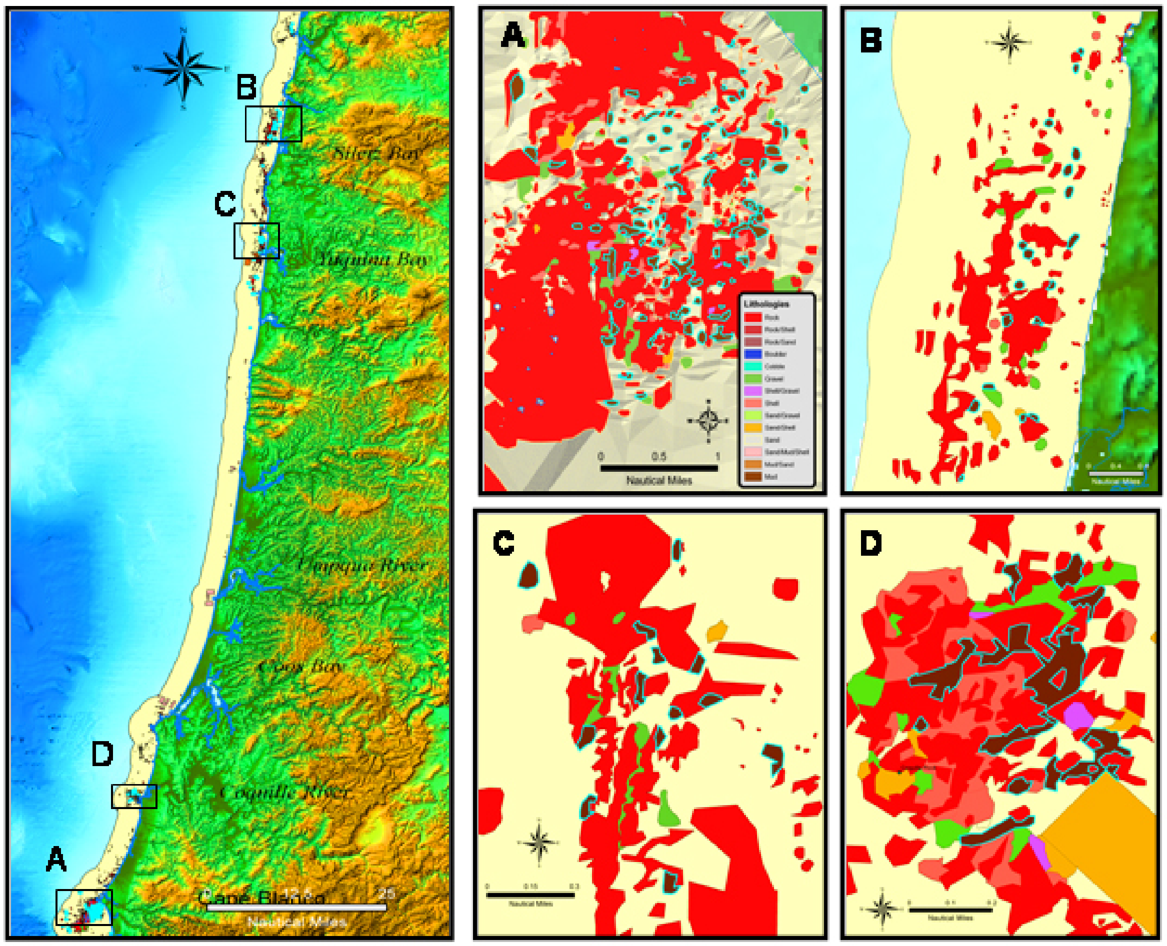

Figure 3.4 Left panel: territorial sea map from Siletz Bay down to Cape Blanco area highlighting mud lithology (brown with turquoise outline). Right panels: A) mud trapped at Cape Blanco reefs, B) mud within Siletz Reef, C) mud within the rocky reefs around Newport, and D) mud within the rocky reef in Bandon.

3.2. Data Density Mapping Results

Four major maps of data density (see figure 3.4 and figure 3.5) were produced in this study to indirectly assess the quality of the lithologic interpretation. Three maps describe the distributions for bathymetry, for bottom samples, and for the merged islets and kelp data. The fourth map is an additive composite of the above three map densities. The coefficient of variation (measure of dispersion of data points around the mean) is used to describe the distribution of data points within the map using a search radius of 1,500m^2.

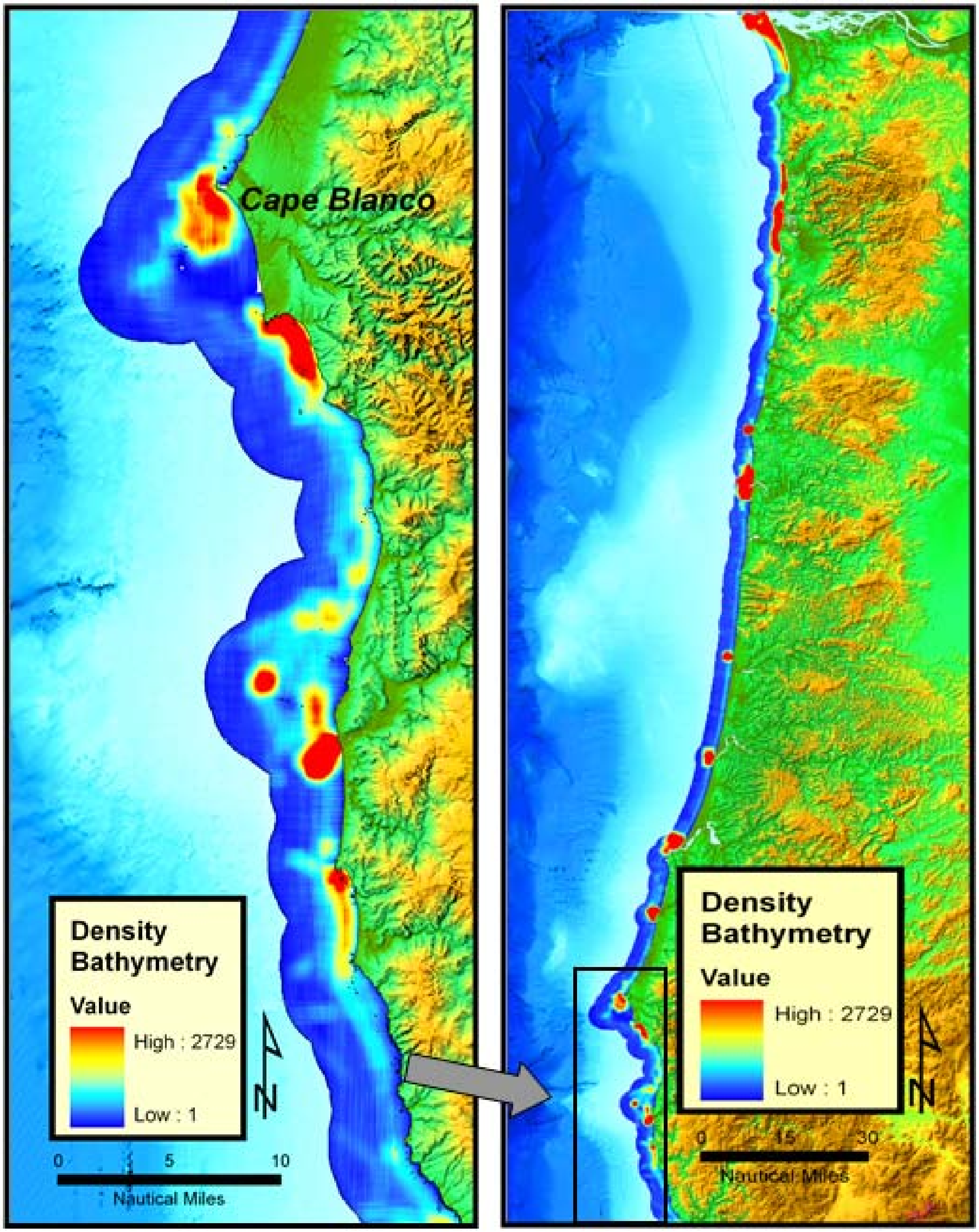

Figure 3.4 Density maps. A) Bathymetry density; B) bottom sample density, C) kelp-Islets. The values per grid cell are expressed in terms of number of data points per $100m^2$. The white portion of the territorial sea means no data.

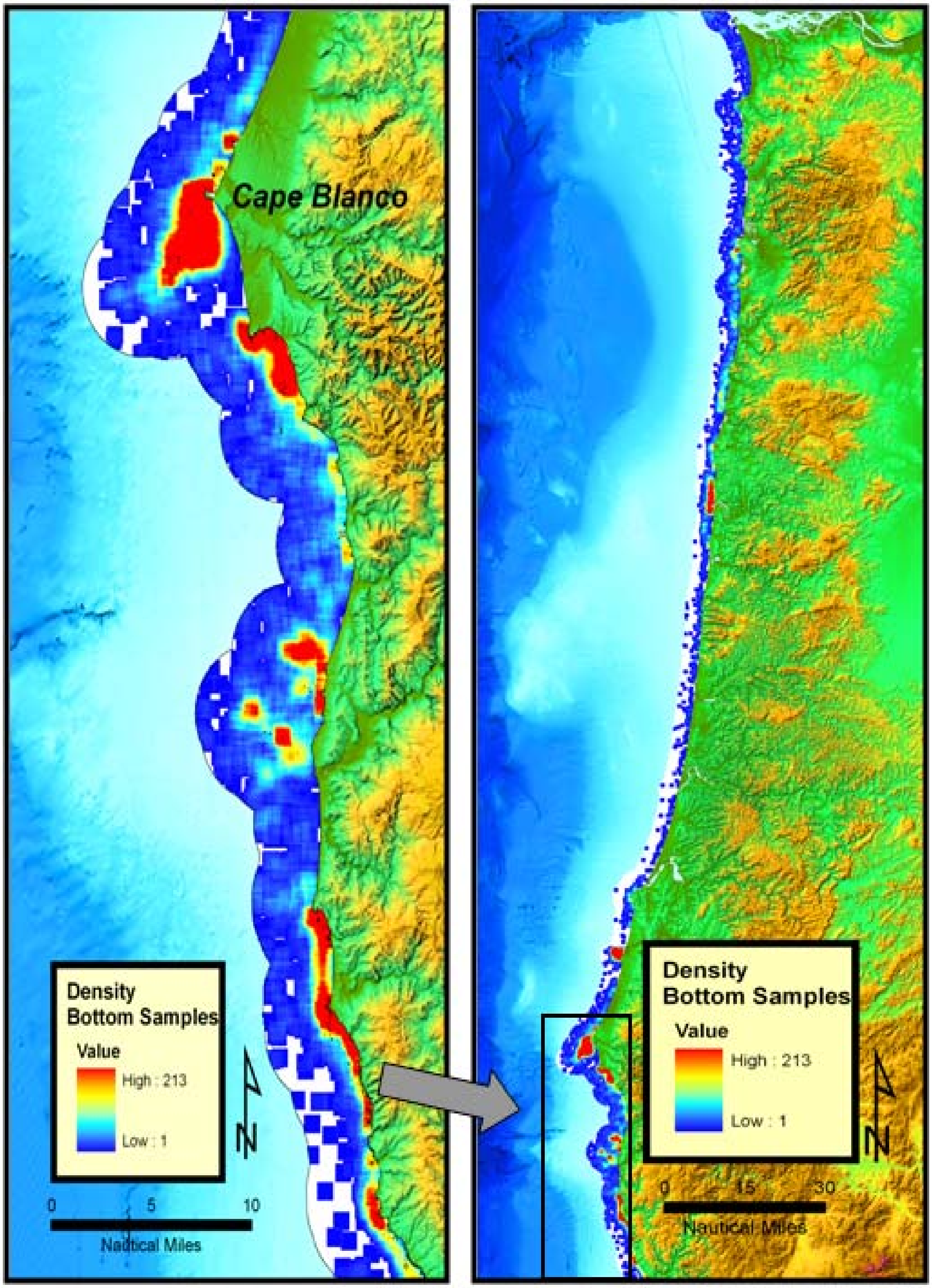

Figure 3.4 B. Bottom Samples Density

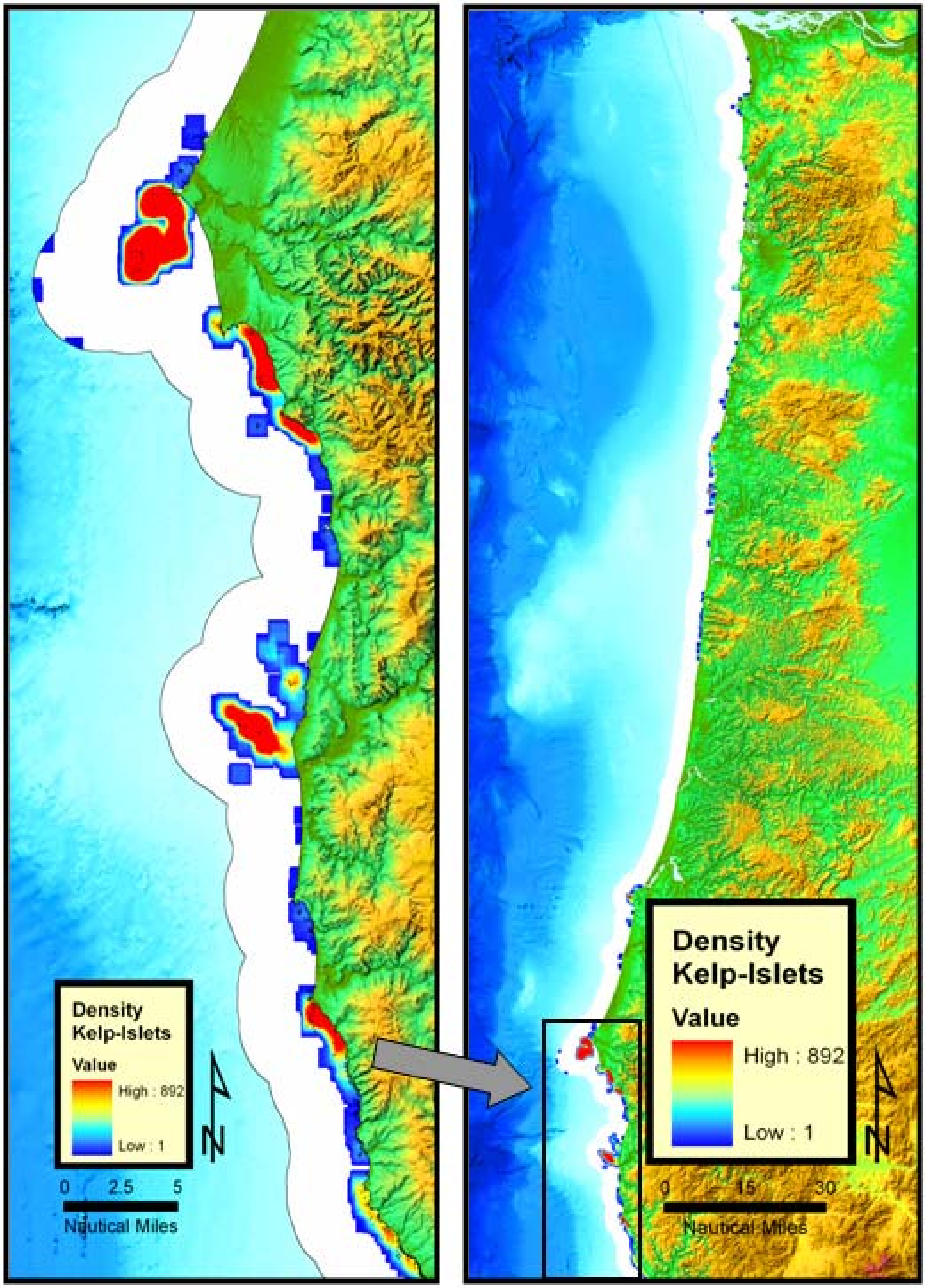

Figure 3.4 C. Kelp-islet density

3.2.1. Bathymetry

There are approximately 183,000 soundings within the bounds of the territorial sea, used here to create the density. An average of 105.5 (max 2729, min 1) sample points were recorded per $100m^2$. The depth measurements range from 0.2 to 177 meters with a relatively high percent coefficient of variation of 72 percent (sample mean = 23 with SD=16) giving it a positively skewed frequency distribution. This skewness of the depth indicates that soundings were concentrated in the shallow depths (12-51 m). Also, spatial distribution of the soundings has a large coefficient of variation (202%) implying that the data is non-uniform and sparsely distributed. This is due to the fact that soundings are relatively dense on the first 1.5 nautical miles while some portions have very sparse soundings such as most of central Oregon coast and the deeper areas of the territorial sea. Figure 3.4 A shows the bathymetry density.

3.2.2. Bottom samples

The coefficient of variation for bottom samples was 188 percent (sample mean=8.28 with SD=15.6) indicating that the spatial distribution of datasets is relatively more spatially condensed relative to other datasets. On the average, there are nine (9) bottom samples (max 213, min 1) per 100 m^2. This low average number of bottom samples is attributed to the uneven bottom sampling effort within the territorial sea (see Figure 3.4 B).

The bottom sample density is quite high in areas where rocky reefs were mapped and relatively low in areas interpreted as sand particularly in the lower portion of Central Oregon. This can be attributed to the fact that the USCGS purposely designed their bottom sampling collection to sample extensively in rocky areas in an attempt to determine the extent of the shoals. This highly dense bottom sampling is obvious in southern and northern Oregon, where most rocky reefs and rock outcrops were documented. Conversely, there is a relatively low density (1-3 bottom samples per $1500m^2$) of bottom samples in Central Oregon where sand constitutes over 95 percent of the area.

3.2.3. *Kelp and Islets*

Kelp and Islet density has a higher coefficient of variation of 188 percent (sample mean=60 with SD=113) implying that the data points are sparsely distributed. It is important to note that the mean and standard deviation are identical indicating that the data points are distributed in aggregates (see figure3.4 C). This is because the islets and kelp are found only in rocky reefs of shallow areas. The density map of kelp and islets shows that the patches of data points complement the rocky reef areas in the north and south of Oregon where NOS rock bottom samples aggregate as well. The kelp and islet data show a scarcity of kelp beds and a low abundance of rocky islets in the southern portion of the central Oregon Territorial Sea which agrees with the NOS sand samples from this region.

3.2.4. *Composite Density Map*

The additive composite map gridded to 100m^2 shows the overall trend in the density of input datasets (sample mean=0.024, SD=0.1429, coefficient of variation=595%). The coefficient of variation is relatively high reflecting the overall non-normal distribution of each dataset discussed above. The composite map summarizes the relative patchiness of each dataset in the north and south of the Oregon coast (see figure 3.5)

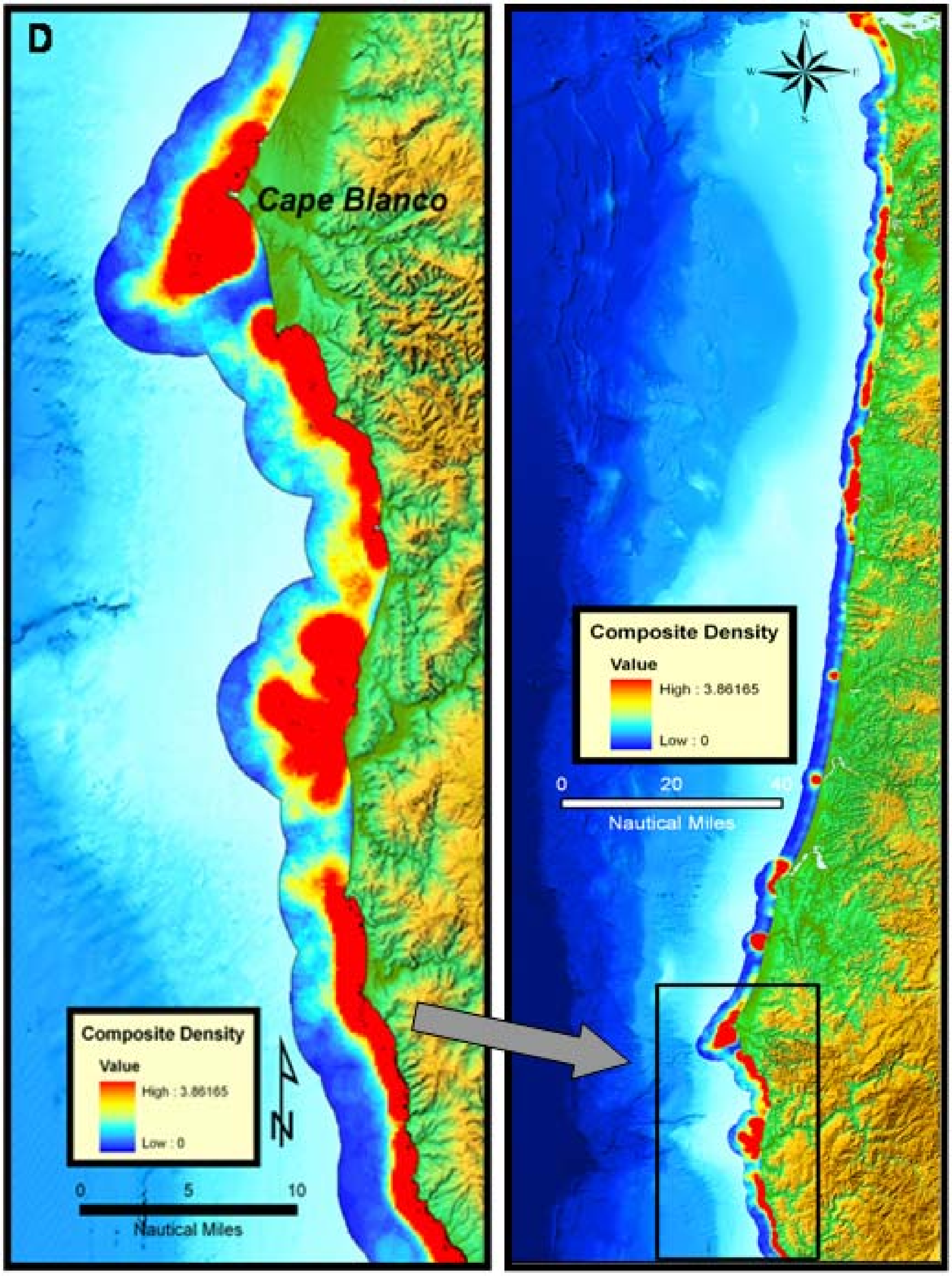

Figure 3.5 Additive composite density map. The values of grid cell are expressed per $100m^2$. Each of the data points were given with the following respective weights: 1, 3, and 2 for bathymetry, bottom samples and kelp-islets

3.3. Quantitative Assessment

A comparison between the coastwide lithologic interpretation of this study and the local ODFW habitat mapping is presented below using an error matrix. Table 3.1 – 3.4 present the quantitative comparison of the four rocky reef sites where ODFW conducted habitat interpretation. The *overall accura*cy refers to the general agreement of all the classes between the two datasets being compared while producer's and user's accuracy refers to the agreement of same class or category between the two interpretations. Specifically, *producer's accuracy* is referred to as the accuracy associated to each class or category while *user's accuracy* is referred to as the estimate amount of rock on the seafloor, thus, also referred in this paper as the *ground accuracy*.

3.3.1. Orford Reef

The 963 random samples generated an overall accuracy of 59 percent. Sand recorded the highest producer's accuracy of 93 percent followed by rock, 62 percent and Gravel/Cobble with the least accuracy at 7 percent. Although, only 62 percent of the rock points in the territorial sea classification match the rock points in the ODFW habitat interpretation, the rock category has a high user's accuracy at 93 percent. This implies that about 93 percent of the rocks mapped in the territorial sea are estimated to be rock on the seafloor. The omission report indicates that 39 percent of rocks are missed / omitted in the lithologic classification, therefore, the territorial sea map is accurate by not misclassifying rocks shown by a small commission error of 6 percent (see table 3.1).

3.3.2. Redfish Reef

The overall accuracy of 64 percent was calculated from 494 random samples at Redfish Reef. Rock accuracy is 56 percent indicating that 44 percent of the rock points in the ODFW interpretation map are omitted in the territorial sea map. However, the user's accuracy (77 percent) of Rock category is an indication that only 23 percent of rocks are misclassified. Again, sand has the highest accuracy of 74 percent while the Gravel/Cobble has the lowest accuracy at 27 percent (see table 3.2).

3.3.3. Humbug

The 399 random points for Humbug provided an overall accuracy of 55 percent. The rock accuracy is 54 percent indicating that 46 percent of rocks in the ODFW habitat map are overlooked in the lithologic interpretation of the territorial sea. The misclassified rocks are relatively small (20 percent), thus, the ground accuracy is high (80 percent). The accuracy of Gravel/Cobble category was a significantly low accuracy at 17 percent however, 40 percent (ground accuracy) of the mapped Gravel/Cobble in the territorial sea is real on the seafloor. The sand category has the highest class accuracy but with less than 50 percent ground accuracy (see table 3.3).

3.3.4. Siletz

In this assessment, 30 random points are considered inapplicable as they correspond to the mud class in the territorial sea lithologic interpretation, which is not represented in the ODFW habitat map. These points were excluded in the calculation of accuracy values (see table 3.4).

The classes considered in this assessment include Rock and Sand categories as there is no Gravel/Cobble interpretation in the ODFW habitat map. The 970 (excluding the mud samples) randomly generated points give an overall accuracy of 78 percent and a ground accuracy of 68 percent. While Siletz has the highest overall accuracy compared to other three sites, it records the lowest Rock accuracy of 47 percent implying that 54 percent of the rock points were missed in the lithologic interpretation of the territorial sea. Moreover, the producer's accuracy (91 percent) for Sand category is comparable to the other three sites but Siletz has the highest ground accuracy for Sand at 81 percent.

Table 3.1 Assessment results for 963 randomly generated samples at Orford Reef, Oregon

Territorial sea interpretation	ODFW habitat interpretation				
Class	**R**	**G/C**	**S**	**Row Total**	**Commission Error (%)**
Rock (R)	419	20	10	449	7
Gravel/Cobble (G/C)	32	9	5	46	80
Sand (S)	221	105	142	468	70
Column Total	672	134	157	963	
Ommission Error (%)	41	93	10		
Overall Accuracy = 59%					

Table 3.2 Assessment results for 494 randomly generated samples at Redfish Reef, Oregon

Territorial sea interpretation	ODFW habitat interpretation				
Class	**R**	**G/C**	**S**	**Row Total**	**Commission Error (%)**
Rock (R)	123	8	42	173	29
Gravel/Cobble (G/C)	18	7	23	48	85
Sand (S)	78	11	184	273	33
Column Total	219	26	249	494	
Ommission Error (%)	44	73	26		
Overall Accuracy = 64%					

Table 3.3 Assessment results for 399 randomly generated samples at Humbug Reef, Oregon

Territorial sea interpretation	ODFW habitat interpretation				
Class	**R**	**G/C**	**S**	**Row Total**	**Commission Error (%)**
Rock (R)	112	14	14	140	20
Gravel/Cobble (G/C)	21	14	0	35	60
Sand (S)	74	56	94	224	58
Column Total	207	84	108	399	
Ommission Error (%)	46	83	13		
Overall Accuracy = 55%					

Table 3.4 Assessment results for 970 randomly generated samples at Siletz Reef, Oregon

Territorial sea interpretation	ODFW habitat interpretation			
Class	**R**	**S**	**Row Total**	**Commission Error (%)**
Rock (R)	141	65	206	32
Sand (S)	144	620	764	19
NA	21	9	30	
Column Total	285	685	970	
Ommission Error (%)	54	11		
Overall Accuracy = 78%				

4. Discussion

Overview

Previous multibeam mapping conducted by ODFW (Fox et al., 1999; Merems and Romsos, 2004) comprises about five percent of the territorial sea and is limited to major rocky reef areas. In addition, the existing surficial geologic habitat (SGH) done by Romsos et al. (2007) missed most rocks in the shallow potion of the territorial sea due to insufficient data at the time that study was conducted. Therefore, this current mapping project is designed to provide a more comprehensive lithologic map of the territorial sea using additional datasets.

4.1. Lithologic Mapping of the Territorial Sea

4.1.1. Northern Oregon

The mapping conducted in this study showed that the northern part of Oregon's territorial sea particularly between the Columbia River and Cascade Head is composed mainly of sand and small patches of mud along the northwestern edge of the territorial sea (see Figure 4.1). This large sand unit in the northern portion of the coast is potentially due to its proximity to the Columbia River. Studies by Runge, 1966; Harlett, 1972; Kulm, 1975, and Karlin, 1980, have demonstrated that large quantities of sediment, (sand, and clay), from the Columbia River is transported southward with the California Current and northward with the Davidson Current in the summer and winter periods respectively. The winter northward transport coincides with high storm frequency and runoff in Oregon and Washington's Coast Ranges. While the area is dominantly unconsolidated, some rocks were mapped close to the prominent headlands such Tillamook Head, Cape Meares, Cape Lookout and Cape Kiwanda (see figure 4.2). Outcrop mapping was supplemented by a qualitative interpretation of geologic trends onshore and structural trends offshore.

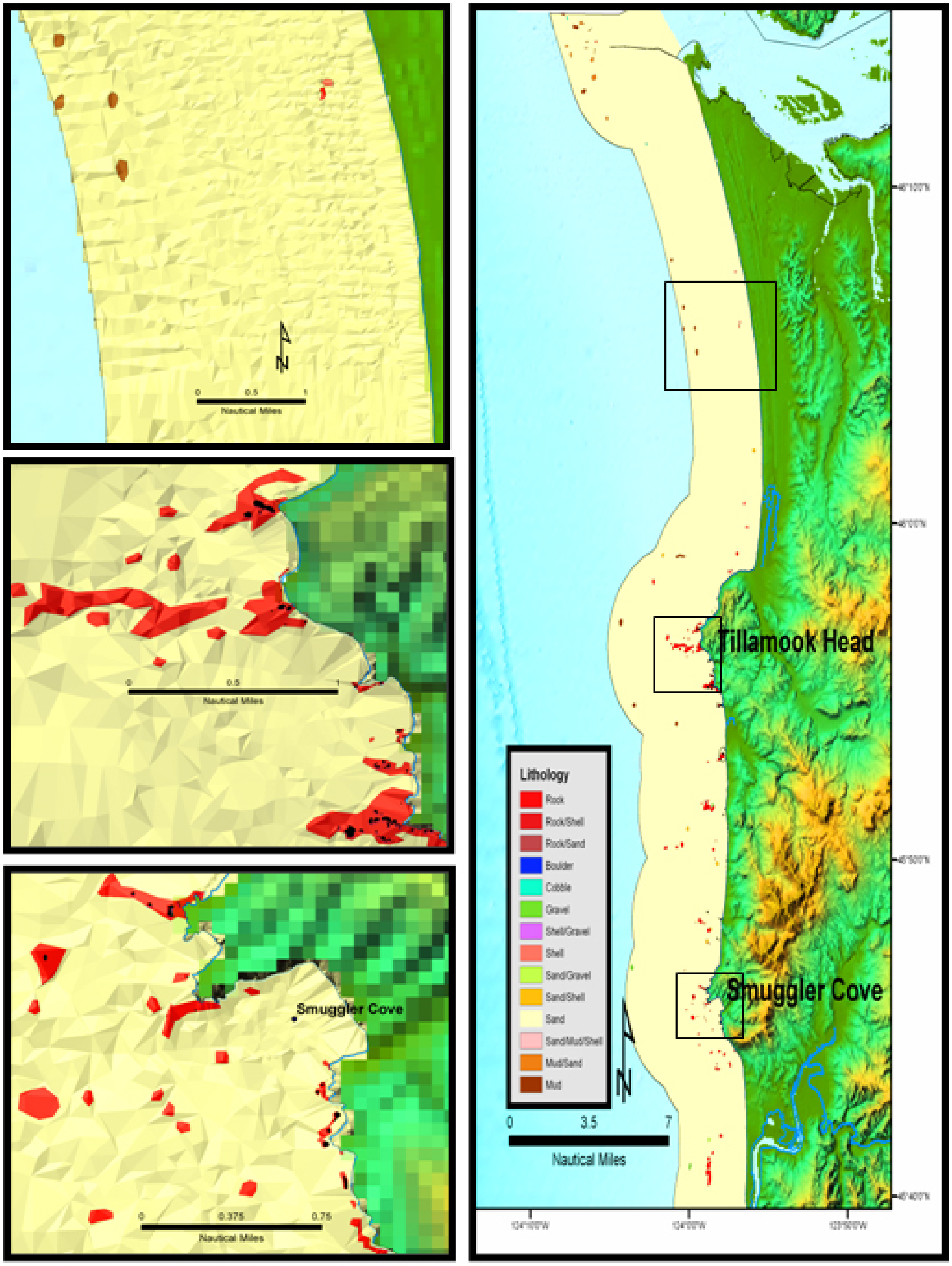

Figure 4.1 Seafloor Lithology from Astoria to Smuggler Cove, Oregon. Sand dominates this northern region of the territorial sea. Lef panel (top image): sand lithology with some mud patches close to the western edge of the territorial sea. Left panels (middle and bttom): some patches of rocks and islands are found by the headlands..

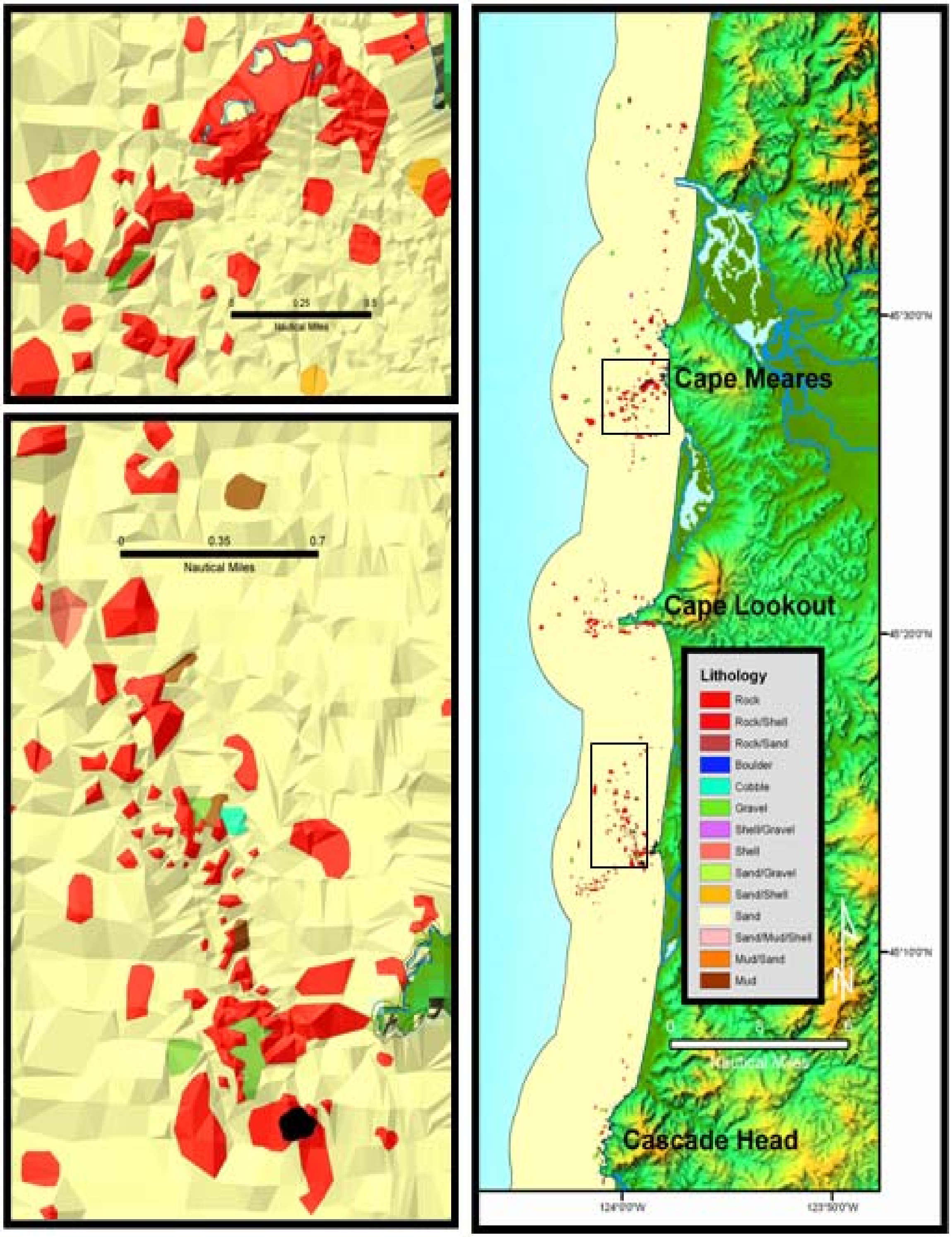

Figure 4.2 Seafloor lithology from Garibaldi to Cascade Head, Oregon. Most rock patches are found close to the prominent northernm headlands of the Oregon coast such as Cape Meares (top left panel), Cape look out and Cape Kiwanda (bottom left panel)

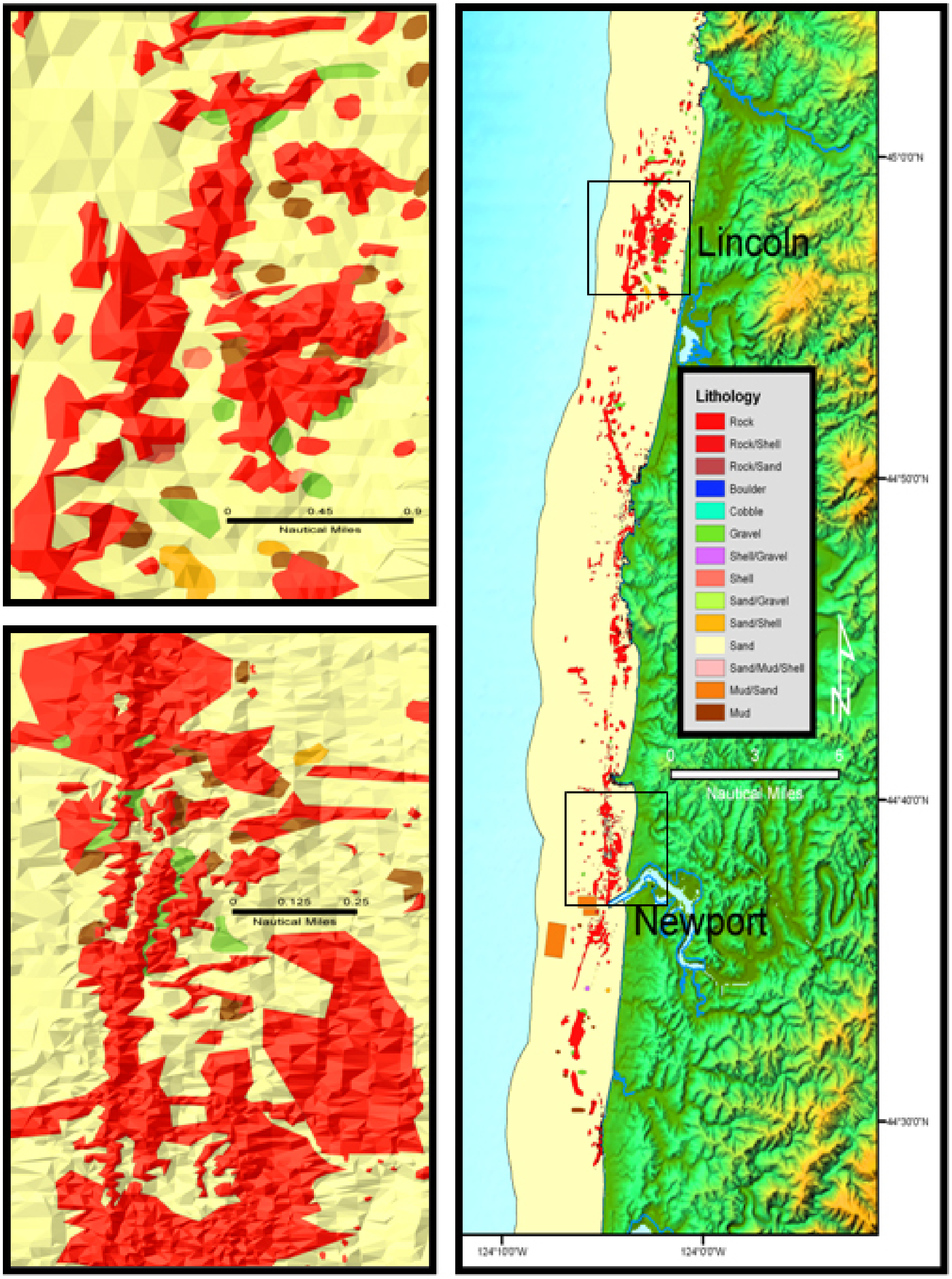

Figure 4.3 Seafloor Lithology from Lincoln to Newport, Oregon. Left Panel (top): portion of the rock at Siletz Reef. Left panel (bottom): portion of the rocky ridges mapped around Newport.

4.1.2. Central Oregon

A short stretch of the central Oregon Coast from Yaquina Head to Seal Rock (south of Ona Beach) is mapped as rocky. Sand is dominant in the southern part of this rocky stretch of the coast, which runs through Coos Bay where very few patches of mud or mixed lithologies can be located. Sparse soundings and bottom samples exist in the sandy area of the central Oregon coast and it is likely due to its low relief indicating that it is a sandy bed, which is of little importance to the USCGS. Figure 4.4 shows that Central Oregon is mostly sand.

4.1.3. Southern Oregon

The area existing between Coos Bay and the Sixes River Beach (north of Cape Blanco), is composed primarily of sand except in areas around the headlands of Cape Arago and Coquille Point (see figure 4.5). A previous mapping effort using multibeam (Fox et al., 2000) showed some rocky outcrops in Bandon which is consistent with the current findings. The rocky outcrops mapped offshore of Cape Arago were not captured in previous SGH mapping of the territorial sea. However, several studies suggest that rocky bottom is present in this area due the presence of kelp patches of *Macrocystis integrifolia* observed in the area (Connoly et al, 2001, Hansen, 1997) and some boulder fields (Fox, 1994).

South of Cape Arago is Oregon's most prominent headland, Cape Blanco. Two rocky reefs were mapped in this area, Blanco and Orford Reef (see figure 4.5). The former was depicted in Romsos et al. (2007) SGH map of the territorial sea while the latter was mapped by ODFW (Fox et al., 1999) using multibeam bathymetry. These reefs run diagonally northeast to southwest from the Cape Blanco headland. Previous surveys and mapping interpretation (Fox et al., 1994; Fox et al, 1999) showed that this area is covered by sloping bedrock and high relief boulders with a diameter. This study shows that the Cape Blanco reefs are interspersed with shells, mud, gravel and mixed class lithologies. Shells and mud were excluded from habitat interpretation of this same area by Fox et al. (1999) and Romsos et al. (2007).

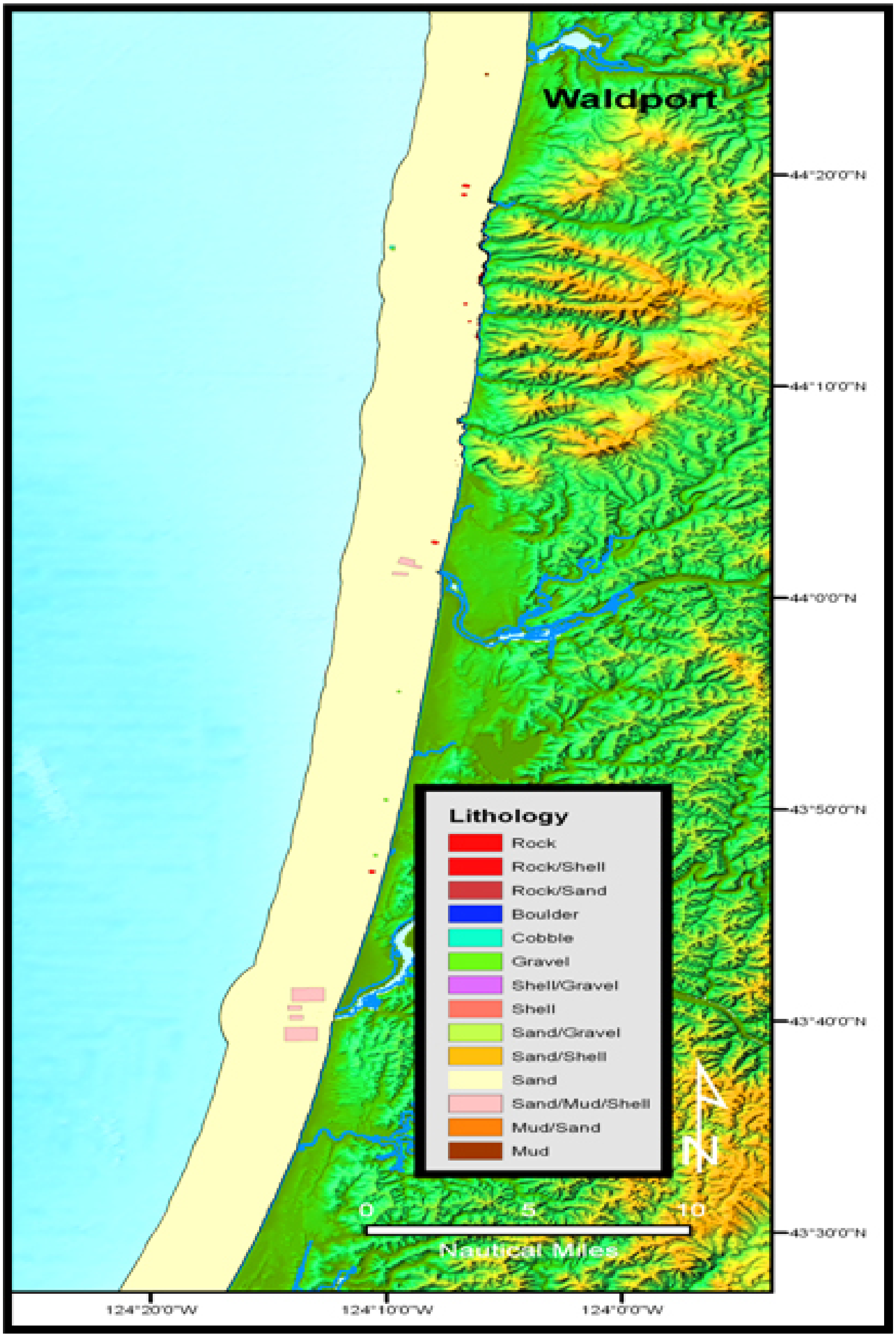

Figure 4.4 Seafloor lithology between Waldport and Umpqua, Oregon. Sand lithology dominates this portion of the central Oregon with a few patches of gravel and rock.

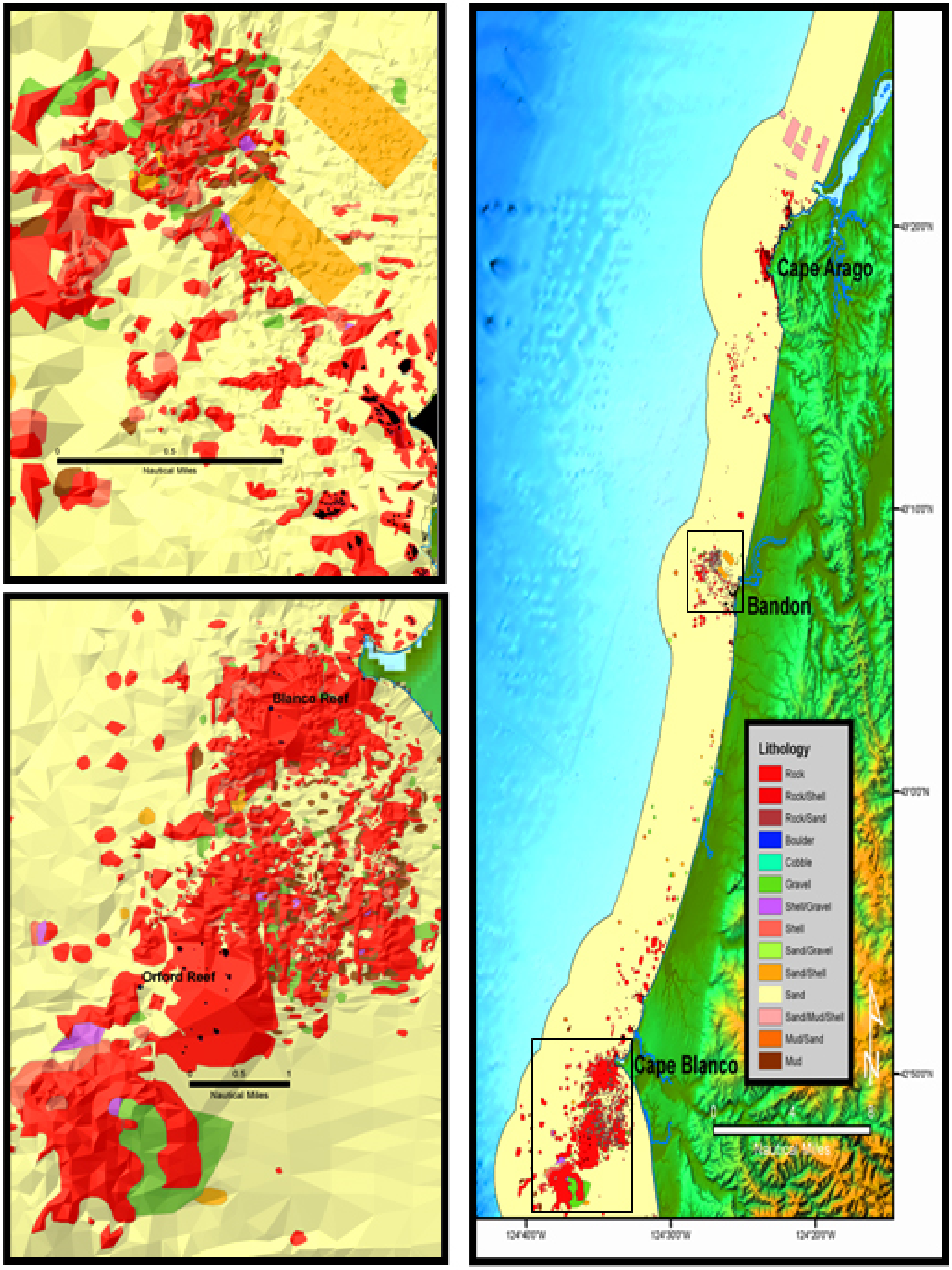

Figure 4.5 Seafloor lithology between Cape Arago and Cape Blanco, Oregon. Rocky patches are mapped around Cape Arago, Bandon (top left panel) and Cape Blanco (bottom left panel).

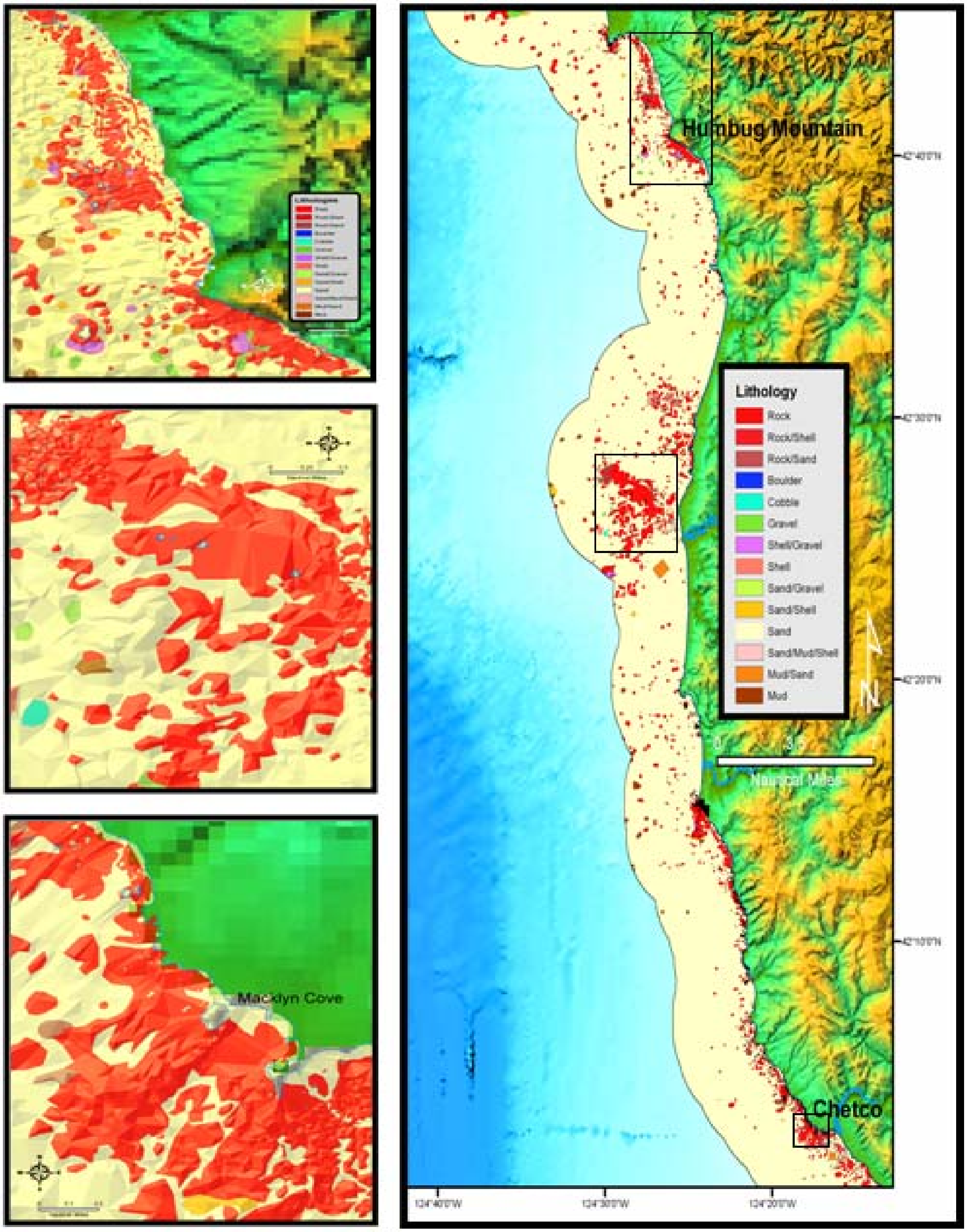

Figure 4.6 Seafloor Lithology between Nellies Cove and Chetco Cove, Oregon. Rocky portion of southern Oregon highlighting some area such as the rocky reefs around Humbug mountain and Redfish Reef (top left panel), Rogue Reef (middle left panel) and the rocky reefs around Chetco Cove (bottom left panel).

Also, the rest of the southern Oregon territorial sea map is extensively rocky as well and previous studies discussed the probable origins of the extensive rocky outcrops in the south (see figure 4.6). For example, Spigai (1971) suggested that the coastal region is composed of folded and faulted pre-tertiary rocks extending onto the shelf which is similar to the findings from studies by Kulm (1978) and MacKay (1969) where they showed that from Coos Bay to Cape Sebastian, the inner shelf consists of variable structural trends such as faults and folds of sedimentary units. However, Kulm explained that most of these rocky structures were covered by thin Pleistocene transgressive sands. Therefore, it is possible that the southern Oregon shelf is mostly rocky underneath the sandy surface mapped in this study. This suggestion is supported by submersible dives (Goldfinger, 1994) and seismic reflection data interpreted by Romsos et al. (2007).

In general, comparing the new territorial sea map with the existing territorial sea habitat interpretations by Merems and Romsos, 2004 Fox et al., 1999; Romsos et al., 2007, our lithologic interpretations generally underestimated the extent of the reefs and were sometimes problematic in connecting patches of rocks due to relatively low data density. Nevertheless, our territorial seabed interpretation was able to map additional rocky outcrops and captured the general shapes of the rocky reefs as depicted in high resolution multibeam mapping conducted by Oregon Department of Fish and Wildlife (see figures 4.7)

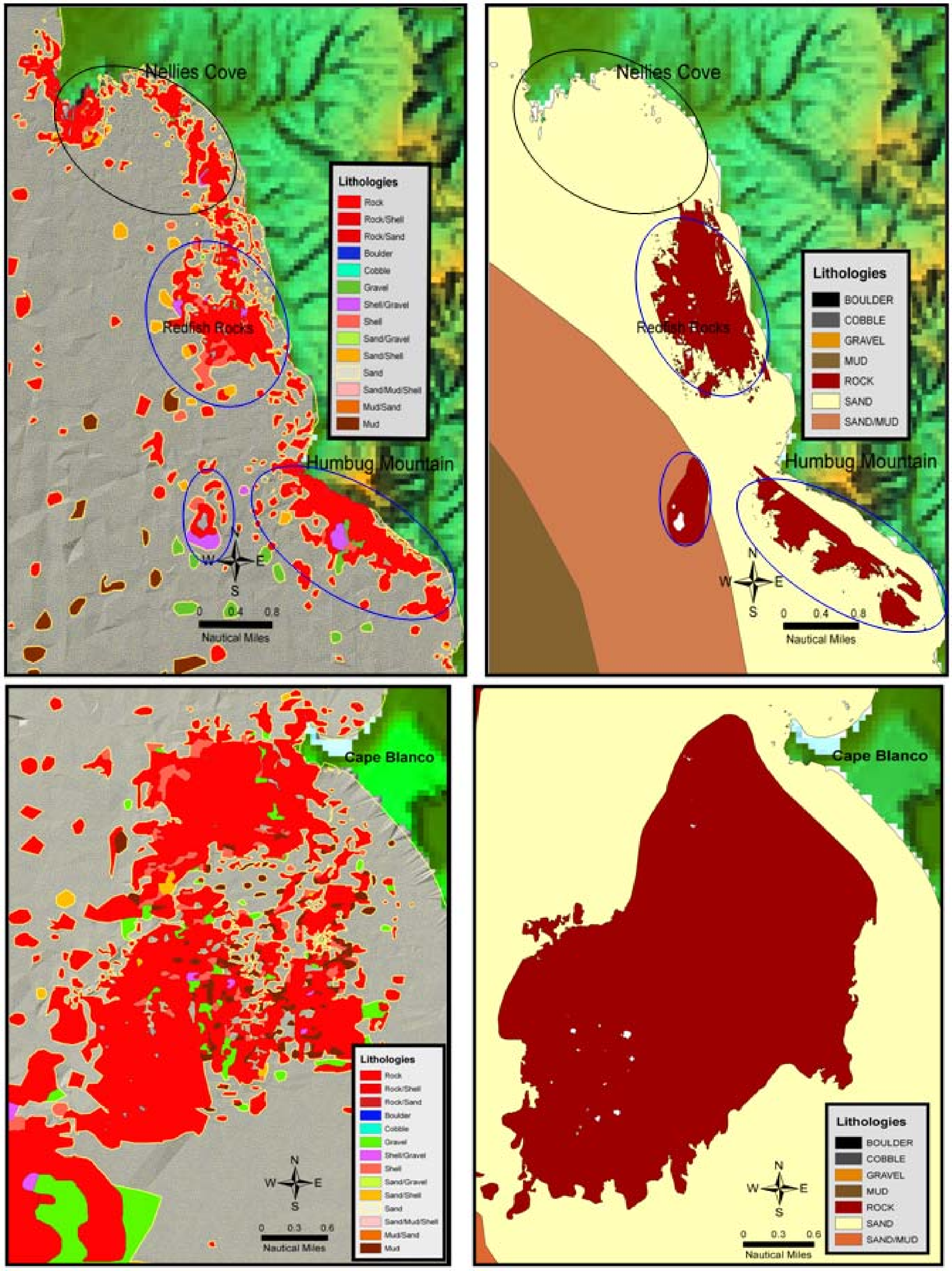

Figure 4.7 Left panels - portion of the new territorial seafloor map; Right panels - similar portion taken from existing surficial geologic habitat map (SGH) by Romsos et al., 2007. Top panels - rocky outcrops from Nellies Cove to Humbug Mountain; Bottom panels – Blanco and Orford Reefs around Cape Blanco, Oregon

4.2. Quantitative Map Assessment

The ODFW habitat interpretation on the four rocky reef sites was used as the reference data in this study. This data was used because it is the only existing detailed map interpretation of some rocky portions of the territorial sea derived from high resolution multibeam bathymetry which includes Siletz, Orford, Redfish and Humbug Reef. Bandon and Cape Pepetua are found to have rocky outcroppings based on the ODFW multibeam surveys (Fox et al., 2000). Notwithstanding, these were excluded in our map assessment sites as there is no existing interpretation made for Bandon multibeam bathymetry and that there is no rock interpretation for Cape Perpetua in our territorial sea map.

The objectives for this assessment include: 1) to know if territorial sea interpretation misclassified lithologies particularly rocks; 2) to see if rocks are omitted/missed in the territorial sea map and 3) to examine the overall agreement of the territorial sea interpretation with the ODFW interpretation.

Results show that territorial sea interpretation has misclassified rocks from the Oregon Department of Fish and Wildlife (ODFW) interpretation by an average of 22 percent and has an average rock omission of 46 percent. While these values signify that rocks are under interpreted, they also imply that the territorial sea interpretation is generally satisfactory and acceptable at an overall accuracy of 64 percent. In addition, the ground accuracy (user's accuracy) of 78 percent for rocks is relatively high. For this reason, the techniques and methods used in this territorial sea mapping with respect to rocky reef sites is found to be effective.

On the other hand, sand was found to be over interpreted with an overall average accuracy of 87 percent. It has a relatively high ground accuracy and very low omission error at 13 percent. This result was expected considering the fact that an area without sample was interpreted as sand.

The Gravel/Cobble category in general has the least ground and overall accuracy and it lowers the overall accuracy assessment value. It appeared that most Gravel/Cobble exists between boulders or high relief rocks, thus making its real extent difficult to resolve by either the multibeam or using the NOS bottom samples. For example, it was found out that the NOS groundtruth bottom samples of Gravel/Cobble are inconsistent with some of the Gravel/Cobble in the multibeam bathymetry interpretation. It appeared that in order to map small patches of gravel, it must be resolved in a microhabitat scale (1m to 1cm). Considering this scale issue of resolving the Gravel/Cobble, it is suggested that this category be merged to sand category in the thematic map assessment and it is expected to increase the existing assessment value.

4.3. Issues and limitations of Datasets

4.3.1. Bottom Samples

It is important to note that the data digitized from smooth sheets was collected over a span of approximately 150 years. This suggests that this study ruled out the potential temporal and spatial variability of sediment types that may be caused by factors such as seasonal change, currents, bioturbation, sediment accumulation and erodability, and episodic sedimentation phenomenon. For instance, in California some short-lived episodic sedimentation events have been shown to cause some ephemeral flood-deposits in the nearshore (Wheatcroft and Borgeld, 2000). Stevens et al. (2007) demonstrated that sediment erodability of the seabed along the western Adriatic margin in Italy varies seasonally and spatially. In addition, an earlier study (Kulm, 1975) in Oregon suggested that sediment transport is active in winter when storm waves can powerfully carry the sediments in a direction that is determined by the oceanic current regime at that specific time period.

Recently, a number of studies described the Oregon beaches as being morphodynamic (Komar, 1994; Ruggiero et al., 1997, Komar and Allan, 2000) due to storm waves and cliff erosion. However, this mapping project was able to consider some of these changes along the beaches. For instance, during the capturing process, some of the individual or groups of rocks that were noted on the smooth sheets but were no longer visible in recent aerial photos were not digitized as shown in Figure 4.8.

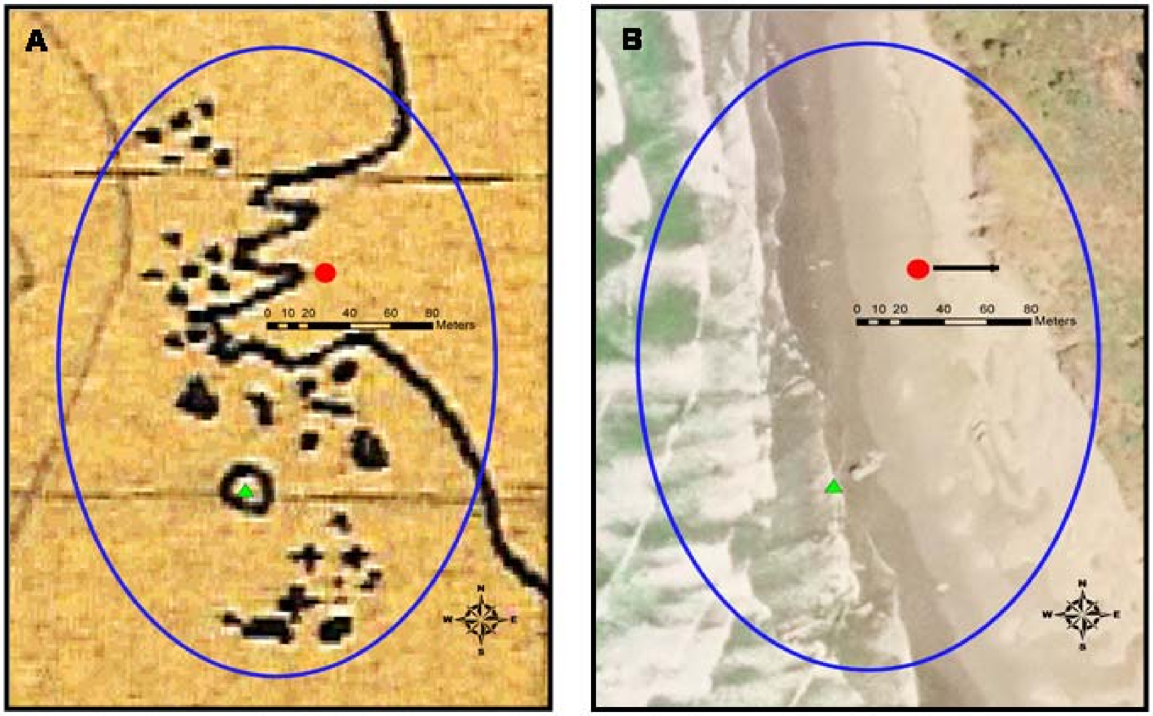

Figure 4.8 (A) 1945 survey smooth sheet indicating some rocks and rugged edges of mountains south of Hunter's Cove, and (B) 2005 aerial photos for the same area showing that the mountain edges have become less rugged and have moved ~30m eastward and most of the rocks are gone.

4.3.2. Bathymetry and TIN model

Two issues have been observed for bathymetry data. One of these issues cannot be resolved by any qualitative interpretation techniques. Since bathymetry data is not uniform and becomes relatively sparse in deeper areas, the bathymetry is not capable of distinguishing rocky outcropping in a scale of less than ten's of meters. Therefore, the mapping unit and mapping scale must be interpreted in a larger scale of ten's of meters to ten's of kilometers.

Secondly, some artifacts that are found in older surveys; however, with a qualitative and careful visual examination of the TIN surface, many of these artifacts were avoided during the interpretation process. Figure 4.9 is a comparison of bathymetric points (from older and later surveys) overlaid on the TIN model showing that the newer surveys depicts a low relief bottom surface whereas the older surveys depicts some degree of roughness. Another issue with older surveys is the noise created by survey boat turns (see figure 4.9, bottom panels).

4.3.3. Kelp data

Fox et al. (1994) observed that kelp in the Cape Blanco area delineates the bedrock or boulder habitats. In this study, kelp served as a proxy for rocky outcrops but could not distinguish on the basis of type (bedrock, boulder, or ridge) or morphology (flat or with some degree of relief). Also, since the kelp data was acquired using aerial photographs, there may be some geometric and positional errors associated with it in the absence of control points for rectification in the ocean. In addition, Britton-Simmons et al. (2008) discovered that currents and tides can introduce significant variability to the estimates of kelp population size. They showed that current speed of up to 100 cm s^{-1} can make the kelp disappear from the surface. There is a potential current related error rate associated with the oblique angle approach that is usually used to generate the aerial photographs of kelp (Guillaumont et al., 1997).

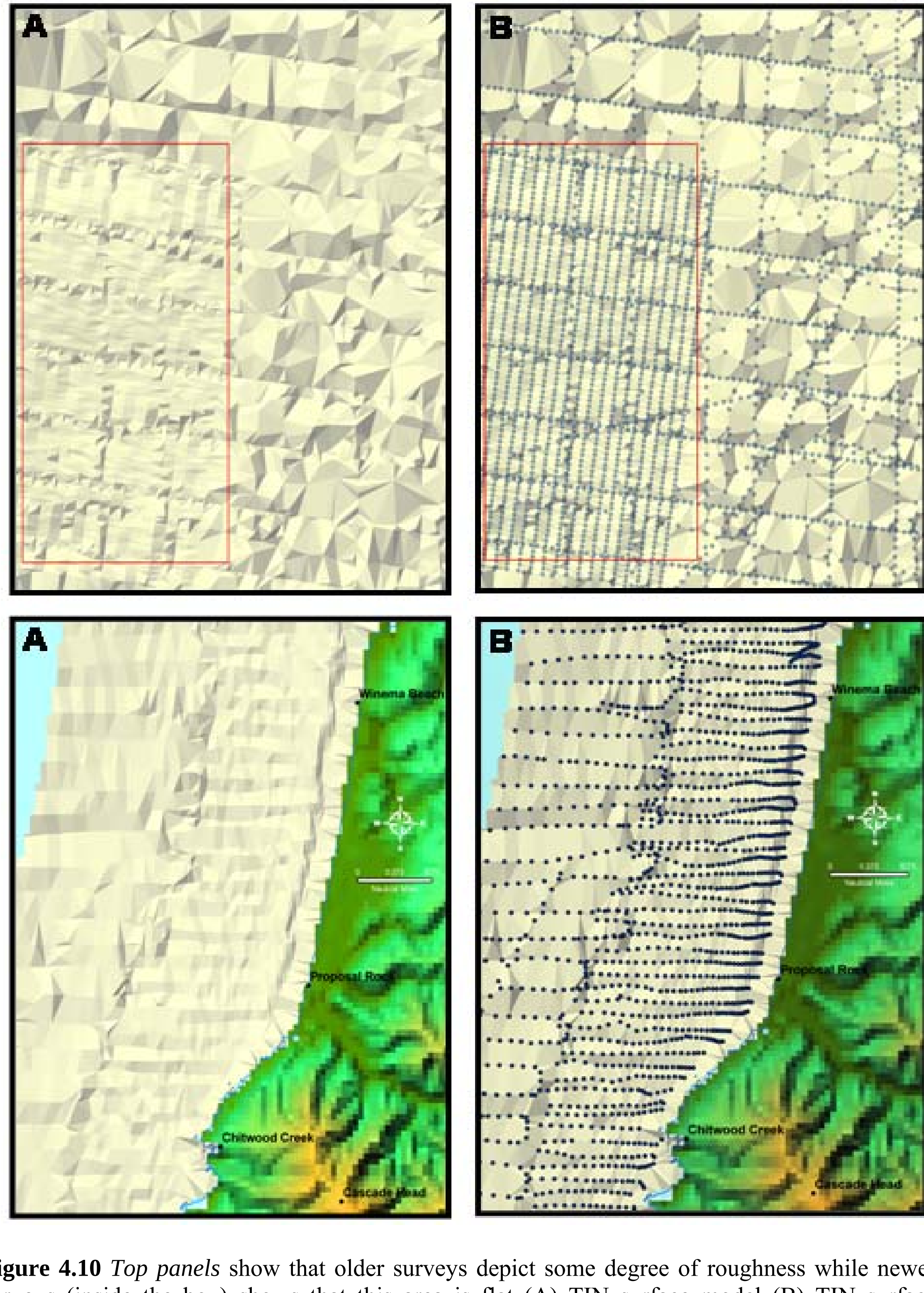

Figure 4.10 *Top panels* show that older surveys depict some degree of roughness while newer surveys (inside the box) shows that this area is flat (A) TIN surface model (B) TIN surface overlaid by bathymetry points. *Bottom panels* show some noise associated to survey boat turns (A) TIN surface model (B) TIN surface overlaid by bathymetry points.

4.4. Interpretation Scale

The scale at which sediment types was resolved is on the order of tens of meters to tens of kilometers. For example, most rocky reefs such as Siletz, Orford, Blanco, Rogue and the ridges stretching from Yaquina Head to the South of Newport were interpreted on the order of tens of kilometers. In areas where the density of data is relatively high, interpretation can be done on the order of ten's of meters like Cape Blanco where many other sediment types were captured in between the rock outcrops. All three datasets (kelp, bathymetry and bottom samples) were incapable of interpreting the lithologic classes to a finer scale such as the microhabitat (1m to 1cm) defined by Greene et al. (1999). Recent studies (Fox et al., 1994, Lanier et al., 2006) suggest that this fine-scale mapping is possible with the use of high resolution multibeam bathymetry and backscatter data, but at this point, 95 percent of the Oregon's territorial sea is yet to be surveyed with multibeam.

4.5. Agreement of Datasets

Overall, the three major datasets (kelp, bottom samples and TIN model) are consistent with each other. For example, most kelp polygons are found in areas where TIN shows roughness and bottom samples occurred in aggregates. Conversely, sandy areas are found to have no kelp, and with flat TIN surface. Some rock pinnacles were exhibited by TIN surface coupled with NOS rock bottom samples. Gravelly, muddy and shelly areas are observed in places where kelp polygons are found to be patchy (see figure 4.11). While the datasets shows agreement, it also has some issues. For instance, the kelp polygons at Cape Blanco are overlaid with bottom samples such as shell, sand and gravel. Some of the potential reasons can be associated to some temporal change of bottom sediment surficial character, or that the kelp may have some positional error associated to it or it could be due to the disparity in the spatial representation of the datasets (points for bottom sample polygon for kelp).

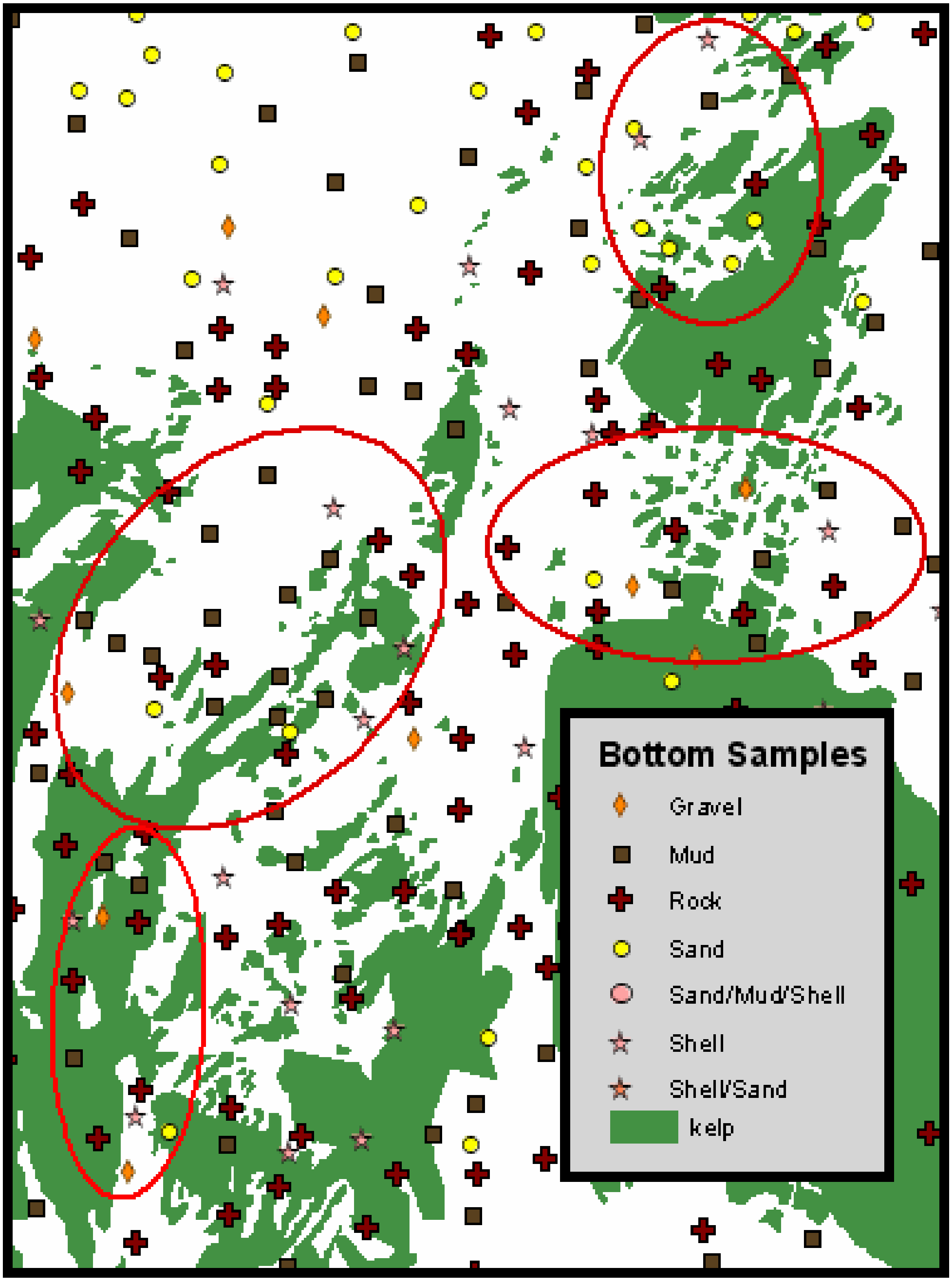

Figure 4.11 NOS bottom samples (shells, sand, gravel, mud) limiting the extent of kelp, a macroalgae known to grow on hard / rocky substrate

4.6. Implications

The Oregon territorial seabed map was generated primarily for the on-going marine reserves process in order to provide a comprehensive lithologic characterization applicable to identifying marine reserve sites. The technique of using lithologic maps in siting marine reserves has been applied in state of California such as the Channel Islands National Marine Sanctuary (CINMS) and the Marine Life Protection (MLPA). Airame et al. (2003) reported that textural characterization of seafloor lithologies as soft and hard was used as basis for identifying benthic habitats and conservation targets at CINMS.

Lithologic types (mud, gravel, cobble, rock etc.) have been used in distinguishing marine habitats (Kostlyev et al. 2001, Anderson et al., 2002) and delineating fish-habitat association. Hewitt et al. (2004) have demonstrated the importance of mapping soft sediments in conducting quantitative assessment of subtidal epibenthic communities. Pickrill et al. (2005) reported the existence of associations between scallops population and substrate type. These studies suggest that seafloor information is relevant to impact assessments as well as ecological patterns and processes. However these, require the use of multibeam data and acoustic groundtruthing if detailed substrate mapping is to be achieved (Siwabessy et al., 1999; Auster et al., 2001 and Diaz et al., 2004). While this new map of the territorial sea can support the demand for seafloor information for managing ocean resources such as the on-going marine reserve process, a multibeam mapping is more appropriate if a greater degree of detail and accuracy is required. This makes it necessary for the State of Oregon to adopt the technique of multibeam mapping of the territorial seabed in order to produce a far more detailed map with a higher degree of accuracy and wider use.

This new territorial sea map product serves as geological base map required for marine resource management particularly in making decisions related to habitat conservation. Studies by Lindholm et al., 2001, Williams et al., 2001 and Jordan et al., 2005 have demonstrated the significance of habitat information as a requirement for marine reserve design.

4.7. Further Studies

The data collected from smooth sheets in this study could serve as reference data for the historical distribution of sediments on the Oregon's seafloor. This data will provide a platform for future studies that will further improve our much needed understanding of temporal and spatial variability of sediment distribution.

In this study, a smaller mapping scale (tens of meters to tens of kilometers) was used in the absence of uniform bathymetric data. In view of this, smaller rocky outcrops likely remain unmapped, resulting in a map of the seafloor with a lower degree of detail, as well as underestimating the size of outcrops. Therefore, it is recommended that future studies from interpreting high resolution data (such as multibeam bathymetry and backscatter) as reported by Fox et al., 1999, Bax, et al., 2001; Auster et al., 2001; Merems and Romsos, 2004; Hewitt et al., 2004, and Jordan et al., 2005.

5. Conclusions

The mapping approach used in this study is a qualitative interpretation of the patterns of seafloor lithology and uses geologic interpretation of disparate geological and biological datasets in the absence of uniform multibeam data. This approach facilitates the interpretation of geological trends and favors user input. This input excludes the digital noise associated with each dataset, and weighs the importance of each dataset as the density of the sparse data varies spatially. This interpretation process relies on the geographic information system (GIS) which serves as an effective tool in displaying and integrating varied datasets.

Unlike the previous maps of the territorial seabed, the current map is able to depict most of the rocky areas that are adjacent to the coastline. Also, the additional classes of lithologies in this mapping project extend the interpretation to a more detailed sediment characterization of the seafloor than previous studies.

There are a number of limitations associated with the smooth sheet data notwithstanding the new information it provides about the distribution of sediments on the territorial sea. These limitations include the irregular distribution of datasets results in uneven interpretation. Relatively detailed and high quality interpretation is feasible only in areas with highly dense samples. Data density maps serve as visual and quantitative representation of the disparity of the datasets. Hence, data density should be considered along with the maps in order to evaluate the quality of lithologic interpretation. This data does not consider spatial and temporal variability of sediment distributions. However, the spatial distribution of rocky outcrops as represented by kelp beds and by the rough surface of the TIN model is found to be consistent with the National Ocean Service (NOS) bottom samples. This is mostly the soft sediment classes, not the rock outcrops that are most susceptible to temporal change. While the average overall consistency between the ODFW and territorial sea map is relatively high, the quantitative assessment shows that the rock outcrops are underestimated while sandy areas are overestimated.

Mapping the Gravel/Cobble category in the interpretation scale used in this study appears to be difficult suggesting that a small local mapping scale is required for the interpretation.

The current study represents an improvement in the characterization of the Oregon territorial sea lithology. The development of this current map provides vital seafloor information required for scientific investigation, planning, and marine reserve design, as well as updating the existing SGH map of the Oregon's territorial sea.

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Appendices

Appendix A. Cartographic Code for sediments classified by grain size.

Bottom Characteristics		
Sediments Classified by size		
Type	*Term*	*Grain Diameter (mm)*
Clay		
	Mud	0.02-0.1
Silt		
	Fine	0.1-0.3
Sand	Medium	0.3-0.5
	Coarse	0.5-1.0
	Fine	1-2
Gravel	Medium	2-4
	Coarse	4-6
	Fine	6-10
Pebbles	Medium	10-20
	Coarse	20-35
Stones		50-250
Boulders		≥250

Appendix B. Cartographic Codes for Bottom Characteristics.

Bottom Characteristics					
Single purpose cartographic code--Point Features					
Nouns	**Examples**	**Adjectives**	**Examples**	**Colors**	**Examples**
Ooze	*Oz*	Gritty	gty	Black	bk
Clay	*Cl*	Rocky	rky	White	wh
Silt	*Silt*	Fine	fne	Gray	gy
Mud	*M*	Meduim	med	Brown	br
Sand	*S*	Coarse	crs	Red	rd
Gravel	*G*	Soft	sft	Yellow	yl
Shingle	*Sn*	Hard	hrd	Blue	bu
Coral head	*Co Hd*	Sticky	stk	Orange	or
Pebbles	*P*	Broken	brk	Green	gn
Stones	*St*	Speckled	spk	Violet	vi
Boulders	*Blds*	Light	lt		
Shells	*Sh*	Dark	dk		
Coral	*Co*	Small	sml		
Oysters	*Oys*	Large	lrg		
Sponge	*Spg*				
Seaweed	*Wd*				
Grass	*Grs*				

Appendix C. Conversion of NOS cartographic code for sediments following Wentworth grainsize scale (Boggs, 2001)

NOS cartographic code	Wentworth classification
Blds	Boulder
St Blds	Cobble/Boulder
Stone	Cobble
Gravel, Pebble, Shingle, fne gravel	Gravel
Gy S G,	Mix Sand / Gravel
Oz, Cl, Silt,	Mud
rky, rky Sh, Rk (Island), Shale	Rock
rky S,	Rock / Sand
S, gy S, fne gy S, crs gy bk S, crs bk S, hrd S, fine gravel	Sand
gy S M Sh	Sand/Mud/Shell
M S	Sand / Mud
G bk Sh	Gravel/ Shell
rky Sh	Rock / Shell
Sh	Shell
crs bk S Sh,	Sand / Shell

Appendix D. (1) The 108 random points intersected to the territorial sea and ODFW habitat interpretation, (2) Error matrix for the above 108 intersected points, and (3) Formula and calculation for Accuracy and errors

D.1 The 108 random points intersected to the territorial sea and ODFW habitat interpretation. Note: *ODFW interp* and *ATSML interp* are the simplified category of the ODFW habitat interpretation (*ODFW interp*) and the territorial sea interpretation (*tersea_interp*) respectively.

ODFW Interp	ODFW lith	tersea interp	ATSML lith
Boulders_>2m	Rock	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_<2m	Rock	Rock	Rock
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Shell	Gravel/Cobble
Sand	Sand	Sand	Sand
Boulders_<2m	Rock	Rock	Rock
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Rock	Rock
Boulders_>2m	Rock	Rock	Rock
Boulders_>2m	Rock	Rock	Rock
Sand	Sand	Sand	Sand
Sand	Sand	Rock	Rock
Boulders_>2m	Rock	Sand	Sand
Boulders_>2m	Rock	Sand	Sand
Sand	Sand	Shell	Gravel/Cobble
Sand	Sand	Sand	Sand
Boulders_<2m	Rock	Rock	Rock
Sand	Sand	Sand	Sand
Boulders_>2m	Rock	Rock	Rock
Boulders_>2m	Rock	Sand	Sand
Bedrock_1	Rock	Rock	Rock
Boulders_>2m	Rock	Rock	Rock
Sand	Sand	Sand	Sand
Boulders_>2m	Rock	Rock	Rock
Gravel_-_Cobble	Gravel/Cobble	Rock	Rock
Bedrock_1	Rock	Rock	Rock
Sand	Sand	Rock	Rock
Bedrock_1	Rock	Rock	Rock
Bedrock_1	Rock	Rock	Rock
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_<2m	Rock	Sand	Sand

Boulders_<2m	Rock	Rock	Rock
Boulders_<2m	Rock	Rock	Rock
Boulders_>2m	Rock	Rock	Rock
Boulders_>2m	Rock	Shell	Gravel/Cobble
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_>2m	Rock	Rock	Rock
Boulders_>2m	Rock	Rock	Rock
Gravel_-_Cobble	Gravel/Cobble	Sand	Sand
Boulders_>2m	Rock	Rock	Rock
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Shell	Gravel/Cobble
Gravel_-_Cobble	Gravel/Cobble	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_>2m	Rock	Sand	Sand
Boulders_>2m	Rock	Rock	Rock
Bedrock_1	Rock	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_>2m	Rock	Shell	Gravel/Cobble
Boulders_<2m	Rock	Rock	Rock
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_>2m	Rock	Rock	Rock
Boulders_>2m	Rock	Sand	Sand
Sand	Sand	Rock	Rock
Sand	Sand	Rock	Rock
Sand	Sand	Sand	Sand
Gravel_-_Cobble	Gravel/Cobble	Shell	Gravel/Cobble
Sand	Sand	Sand	Sand
Sand	Sand	Rock	Rock
Boulders_<2m	Rock	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_>2m	Rock	Sand	Sand
Sand	Sand	Sand/Shell	Gravel/Cobble
Sand	Sand	Sand	Sand
Bedrock_1	Rock	Shell	Gravel/Cobble
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_<2m	Rock	Rock	Rock
Boulders_>2m	Rock	Sand	Sand
Sand	Sand	Sand	Sand

Sand	Sand	Sand	Sand
Gravel_-_Cobble	Gravel/Cobble	Rock	Rock
Boulders_>2m	Rock	Sand	Sand
Bedrock_1	Rock	Rock	Rock
Sand	Sand	Sand	Sand
Boulders_>2m	Rock	Sand	Sand
Bedrock_1	Rock	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_<2m	Rock	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_>2m	Rock	Rock	Rock
Sand	Sand	Sand/Shell	Gravel/Cobble
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Boulders_>2m	Rock	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand	Sand
Sand	Sand	Sand/Shell	Gravel/Cobble
Boulders_>2m	Rock	Sand	Sand
Sand	Sand	Rock	Rock
Boulders_>2m	Rock	Rock	Rock

D.2 Error matrix for the above 108 intersected points. Note: The error matrix is color coded based on the color codes on table D.1.

Redfish with 108 random points

	Rock	Cobble/Gravel	Sand	Row total	Commission error (%)
Rock	25	2	7	34	26
Cobble/Gravel	3	1	6	10	90
Sand	17	2	45	64	30
Column Subtotal	45	5	58	108	
Omission error (%)	44	80	22	108	

Total Accuracy **66 %**

D.3 Formula for calculating accuracy and errors

Total Accuracy: (25+1+45)/108 * 100 = **66**

Producer's Accuracy
Rock: (25/45)*100 = 56
Cobble/Gravel: (1/5)*100 = 20
Sand: (45/58)*100 = 78

Omission Error
Rock: (45-25)/45 * 100 = 44
Cobble/Gravel: (5-1)/5 * 100 = 80
Sand: (58-45)/58 *100 = 22

User's Accuracy
Rock: (25/34)*100 = 74
Cobble/Gravel: (1/10)*100 = 10
Sand: (45/64)*100 =

Commission Error
Rock: ((9/34)*100 = 26
Cobble/Gravel: (9/10)*100 = 90
Sand: (19/64)*100 = 3