Coastal Zone Management Section 309 Grant:

1998 Nearshore Rocky Reef Assessment

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Oregon Department of Fish and Wildlife: David Fox, Jim Golden, Michele Long
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Terra Surveys, Ltd.: Harry Olynyk, Dean Johnson
F/V Reliance: Eric Hamilton

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1. Introduction

Oregon is facing increasing pressure to utilize living marine resources of nearshore subtidal rocky reef areas. Much of the increase has resulted from a shift toward nearshore reef fisheries due, initially, to the dramatic decrease in traditional salmon harvest, and now to a reduction of traditional groundfish fishing opportunities. Emerging or proposed marine resource uses include the live-fish fishery, expansion of open access hook and line fisheries, kelp (*Nereocystis luetkeana*) harvest, propagation or enhancement of sea urchins, abalone, and other species, and increased and diversified recreational uses.

Because nearshore reefs are in state waters, Oregon is responsible for managing these habitats to sustain their long-term use and productivity. Resource managers lack scientific information about the organisms and habitats on Oregon's nearshore (<50 m deep) rocky reefs, and need to develop this information for making sound resource management decisions.

We initiated a nearshore rocky reef research project in 1995 to begin gathering information necessary for managing nearshore reef uses. This report summarizes work completed during 1998, and includes a summary of 1995 habitat mapping work. In 1998, we repeated our kelp biomass study on the Southern Oregon coast. This report includes estimates of bull kelp (*Nereocystis luetkeana*) biomass at Orford, Blanco, Redfish Rocks, Humbug Mountain, and Rogue Reefs for 1998 and compares the results to previous years. In 1998, we also expanded habitat studies to map seafloor characteristics at two reefs south of Newport. The reef mapping effort was part of a larger project in ODFW’s Marine Resources Program to compare fish communities at a heavily fished reef (Seal Rock) to a lightly fished reef (Cape Perpetua). The purpose our 1998 habitat mapping work was to provide information for comparing reef structure between the two areas. In addition, this report presents the results of our side scan sonar reef mapping work completed in 1995 and compares the 1995 mapping methods to those employed in our 1998 work. The final section of the report analyzes nearshore reef research and management needs.

2. Kelp Biomass

2.1 Methods

We estimated kelp biomass following methods used in our previous work (Fox, et al. 1996; Miller, et al. 1997). The biomass estimate is based on three main components: weights of individual plants, kelp plant density derived from kelp canopy percent cover estimates, and total area coverage of the kelp canopy on the ocean surface.

The project team sampled kelp plant weights at Orford, Redfish Rocks, and Humbug reefs on September 8 and 9, 1998. We contracted with two local fishermen to collect plants at Rogue Reef on September 10, 1998, and Blanco Reef on October 6, 1998. We weighed the plants upon delivery to the dock. Plant sampling involved collecting 10 plants from each of 7 areas spread out among each reef's kelp beds. The blades and bulb of each plant, trimmed to 10 cm below the bulb, were first placed in a basket to drain, and then weighed individually using an electronic balance (Weigh-Tronix, Inc., Model QC 3265, Fairmont, MN). We compared plant weights among reefs to determine if data from multiple reefs could be pooled in order to increase sample size for the biomass estimate.

We estimated kelp density following the KIM-1 method developed by Foreman (1975) and Foreman and Cabot (1979). This method involves first estimating canopy percent cover from the aerial photos using a point-intercept sampling method, and then converting percent cover to density using a regression formula. We changed the previous years' sampling rate for the percent cover estimates to 1 grid per hectare (see Miller, et al. 1997).

The aerial photos provided the basis for mapping kelp beds and estimating canopy surface areas. Our aerial photography contractor, Bergman Photography (Portland, Oregon), photographed kelp beds at Orford, Blanco, Redfish, Humbug Mountain, and Rogue Reefs on September 28, 1998, between 12:26 p.m. and 3:38 p.m., at an approximate tidal height of +1.4 to 1.8 meters.

We geo-referenced the photos using rocks and other features as horizontal control points. Sufficient horizontal control was obtained for 12 of the photographs, facilitating transformation to the Universal Transverse Mercator projection (UTM). Transformation accuracy ranged between 0.034 m and 46.8 m. The remaining 9 photographs had insufficient horizontal control for accurate transformation. Transformation of data with poor horizontal control distorts the shape and size of the beds which in turn affects the surface area calculations. Surface areas for beds with accurate horizontal control were obtained from the transformed UTM maps, while surface areas for beds with poor horizontal control were obtained from the maps prior to transforming them to UTM projection. Once the surface areas were obtained, the individual maps derived from photos were merged to create the final kelp bed maps.

2.2 Results and Discussion

2.2.1 Kelp Plant Weight

Analysis of Variance (ANOVA) of the log-transformed plant weights showed no statistical difference between plant weights for Humbug and Redfish Rocks Reefs ($p = 0.9388$) and plant weights from Orford and Rogue Reefs ($p > 0.9999$). As a result, we pooled the plant weights for each pair to increase the sample size for the final biomass estimate (Table 2.2.1).

In the two previous years of biomass estimations, Rogue Reef had not been sampled for plant weights. We had used Orford Reef plant weights with the assumption that Rogue Reef is characteristically similar to Orford Reef. The finding that Orford and Rogue Reef plant weights were not statistically different in 1998 supports previous years' assumptions.

Table 2.2.1 Mean pooled kelp plant weights and statistics for 1998. Pooled pairs of weights are denoted by † and *.

Reef	Mean weight (kg)	Sample Size	Variance	Standard Error
Blanco	3.123	75	2.752	0.192
Orford †	2.884	143	8.317	0.181
Redfish *	1.971	144	3.885	0.123
Humbug *	1.971	144	3.885	0.123
Rogue †	2.884	143	8.317	0.181

2.2.2 Percent Cover

Percent kelp canopy cover ranged from 17.4% to 37.9% (Table 2.2.2). Rogue and Redfish Reefs had the highest percent cover in the study area. The high percent plant cover on these reefs is also evident by directly viewing the photographs. Most of the kelp beds appear dark orange throughout, indicating a thick plant layer on the color infrared photos. Beds with lower percent plant cover appear as speckled orange on a blue (ocean) background.

Table 2.2.2. Kelp canopy percent cover and surface area.

Reef	Mean Percent Cover	Sample Size	Standard Error of Percent Cover	Canopy Surface Area (ha)
Blanco	19.02	102	1.44	102
Orford	17.45	146	0.98	145
Redfish	34.62	4	11.54	0.88
Humbug	13.6	22	2.54	22
Rogue	37.92	52	2.60	52

2.2.3 Mapping and Surface Area Estimation

A total of 21 photographs supplied complete coverage of the kelp beds in the study area (Figures 2.2.1, 2.2.2, and 2.2.3.). Kelp canopy surface areas ranged from 0.88 ha at Redfish Reef to 145 ha at Orford Reef (Table 2.2.2). Total kelp canopy surface area in the study area was 321 ha.

Surface area and percent cover estimates are directly related to the interpretation of kelp bed boundaries from the aerial photographs. Kelp beds that occurred in tight clusters, as on Rogue and Redfish Reefs, were more easily defined, thus polygons drawn to define the beds were less ambiguous. On other reefs, plants were more loosely associated and spread over larger areas, thus the polygons could not be drawn to define the boundaries of kelp beds as discretely. Inconsistencies in photo interpretation can bias the percent cover and surface area estimates. For future biomass analyses, we may employ computer-assisted image analysis to obtain percent cover and surface area estimates directly from the photographs, thus minimizing the inconsistency.

2.2.4 Kelp Biomass

The total kelp canopy biomass for the study area in 1998 amounted to 16,583 tons ± 2,103 tons (95% confidence intervals). This equates to 52 tons/ha (Table 2.2.3). The total harvestable biomass within the Oregon Division of State Lands experimental harvest lease area which consists of Blanco, Orford, Redfish and Rogue Reefs was 16,019 tons ± 2,094 tons (95% confidence interval).

2.2.5 Annual Variation

The total kelp biomass estimate for 1998 represents a 204% increase from 1997 (Table 2.2.4). This is attributed primarily to a 232% increase in plant density in 1998. Plant weight did not differ significantly between 1997 and 1998 (ANOVA, p=0.79),

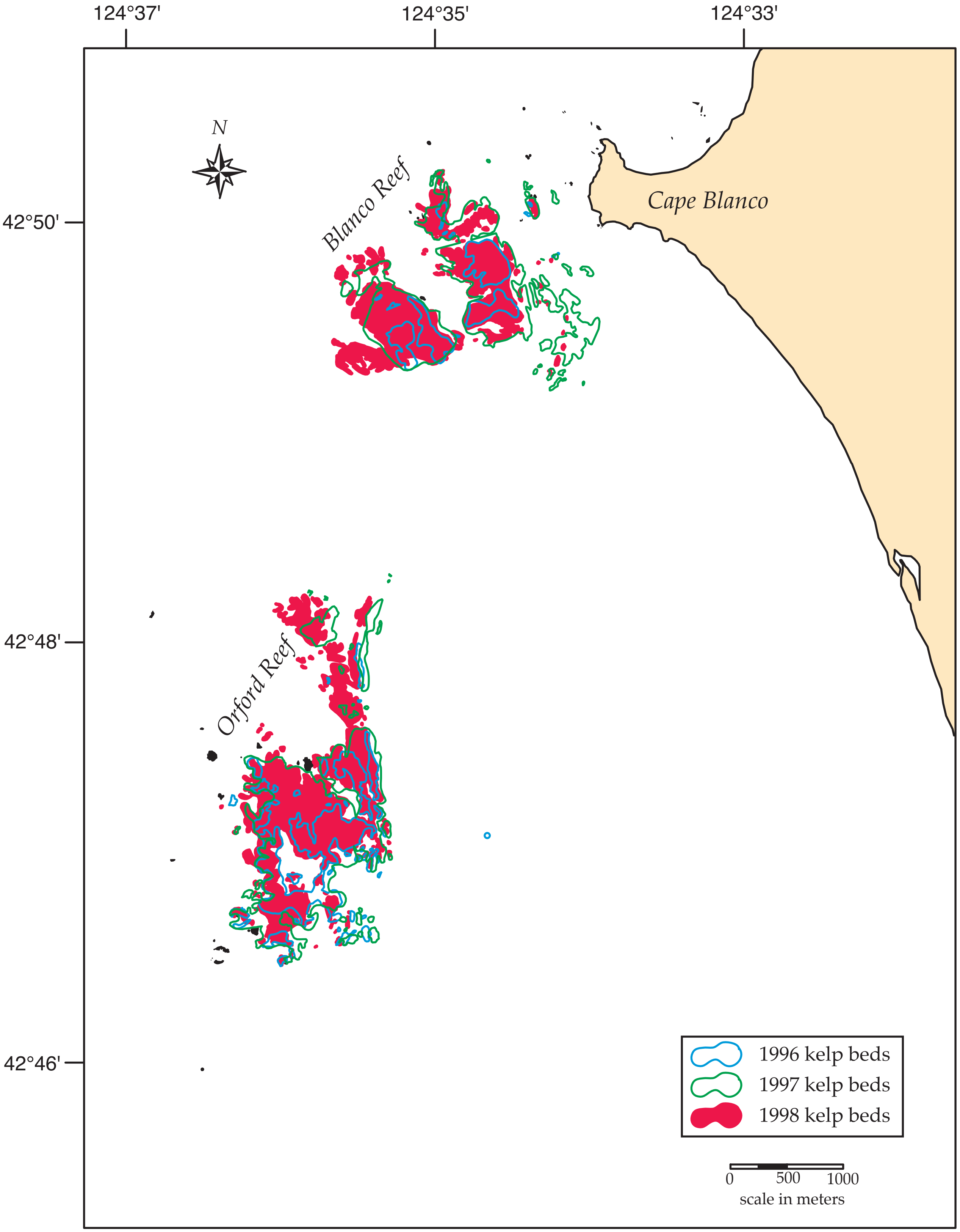


Figure 2.2.1. Kelp beds on Orford and Blanco Reefs in 1996, 1997, and 1998.

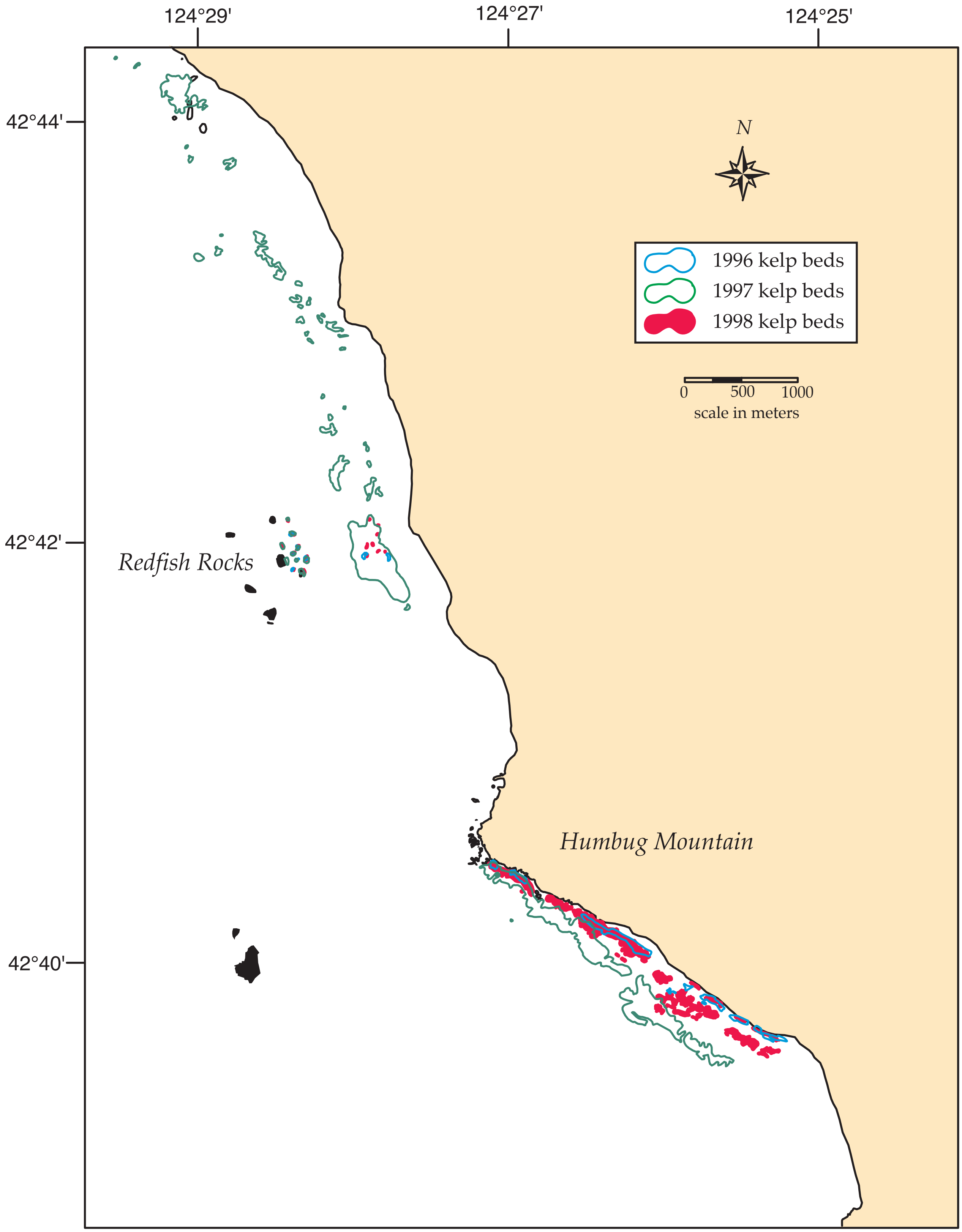


Figure 2.2.2. Kelp beds on Redfish Rocks and Humbug Mountain Reefs in 1996, 1997, and 1998.

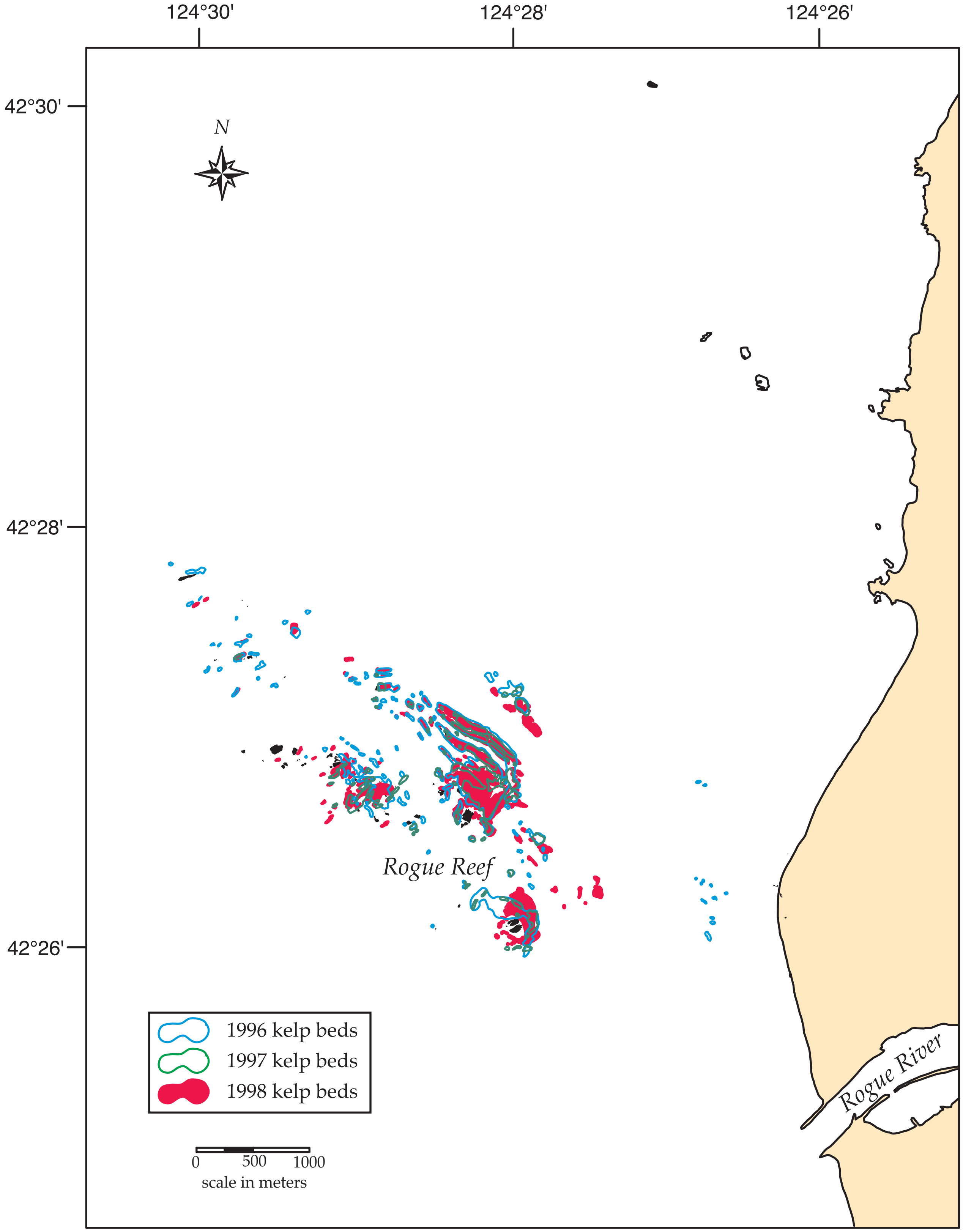


Figure 2.2.3. Kelp beds on Rogue Reef in 1996, 1997, and 1998.

Table 2.2.3. Kelp bed biomass.

Reef	Biomass (tons)	Standard Error	95% Confidence Interval	90% Confidence Interval	tons / ha
Blanco	5239	553	1084	912	52
Orford	6454	793	1553	1308	45
Redfish	46	12	24	20	53
Humbug	564	95	187	158	26
Rogue	4279	456	893	752	83
Totals	16583	1909	2103	1770	52

and total surface area decreased by only 13%. In comparison, the difference in kelp biomass between 1996 and 1998 was largely attributed to an increase in kelp canopy surface area (Table 2.2.4). Although kelp density and plant weights varied between 1996 and 1998, their effects on the final biomass estimate cancelled each other. As a result, kelp weight per unit area was virtually the same in 1996 and 1998, and the increase in biomass in 1998 was directly related to an increase in kelp canopy surface area. In contrast to the 1996 - 1998 comparison, surface area did not account for the difference in the biomass estimates of 1996 – 1997. Despite the 200% increase in surface area from 1996 to 1997 (Table 2.2.4), biomass was lower in 1997. This was attributed to both lower plant weights and density in 1997.

Annual variation within a single reef did not necessarily parallel the annual variation of all reefs combined. For example, Blanco and Orford Reefs both had inverse relationships between density and weight for 1996 and 1998 (Figure 2.2.4a and b). Biomass appeared to parallel changes in surface area for the three years sampled at Rogue Reef (Figure 2.2.5d). This was not the case for Humbug Reef where surface area fluctuated between years and biomass remained constant (Figure 2.2.5c). For Blanco and Orford Reefs, there was no discernable trend for biomass and surface area (Figure 2.2.5a and b).

The areal extent of kelp beds was noticeably different between years for some reefs. On Blanco Reef, 1998 kelp beds occupied much of the same location as the 1997 beds, with the exception of a large southeast bed that was present only in 1997, and a northwestern extension of a bed in 1998 not present in 1997 (Figure 2.2.1). Redfish Reef consistently had very small patches of kelp in the vicinity of the emergent rocks during all three years, and only in 1997 were there large inshore beds (Figure 2.2.2). Heavy winter storms may have been responsible for the absence of inshore kelp beds at Blanco and Redfish Reefs. However, this does not hold true for Humbug Reef, where 1998 kelp beds were located inshore of the 1997 beds (Figure 2.2.2).

With the three years of data we have thus far, no consistent or recognizable trend in kelp bed dynamics has appeared. All three components of the biomass estimate, plant weight, density, and surface area, have fluctuated inconsistently among the years, making it necessary to continue quantifying all three components to obtain a realistic biomass estimate. A longer time series of kelp biomass data is needed to examine multi-year patterns of kelp growth.

Table 2.2.4. Comparison of biomass estimate components by reef for 1996, 1997 and 1998.

Reef * Year	Mean Plant Weight (kg) unpooled	Plant Weight n	Mean Percent Cover	Percent Cover n	Mean Density Plants/ha	Surface Area (hectares)	Biomass Estimate (tons)
Blanco * 98	**3.12**	**75**	**19.02**	**102**	**14977**	**101.6**	**5239**
Blanco * 97	2.51	102	6.92	139	7270	112.5	2259
Blanco * 96	5.04	44	8.99	42	8324	33.2	1717
Orford * 98	**3.16**	**72**	**17.45**	**146**	**14052**	**144.5**	**6454**
Orford * 97	3.82	102	4.39	194	5984	159.4 •	3900
Orford * 96	5.61	72	9.23	77	8446	65.6	3442
Redfish * 98	**2.10**	**72**	**34.62**	**4**	**24189**	**0.9**	**46**
Redfish * 97	2.03	99	12.34	44	10032	36.6	743
Redfish * 96	2.19	60	25.17	6	16569	0.3	13
Humbug * 98	**1.84**	**72**	**13.60**	**22**	**11776**	**22.0**	**564**
Humbug * 97	1.60	80	9.34	36	8504	32.9	566
Humbug * 96	not sampled	N/A	6.05	18	6828	13.5	574
Rogue * 98	**2.60**	**71**	**37.92**	**52**	**26140**	**51.5**	**4279**
Rogue * 97	not sampled	N/A	3.36	37	5455	29.1	669
Rogue * 96	not sampled	N/A	14.13	99	10945	66.5	4522
	Average	Total	Average	Total	Average	Total	Total
1998	**2.96**	**362**	**21.00**	**326**	**16146**	**321**	**16583**
1997	2.97	383	6.33	450	6968	371•	8137
1996	5.41	176	10.79	242	9243	179.2	10267

• Note: This was reported incorrectly in the 1997 report.

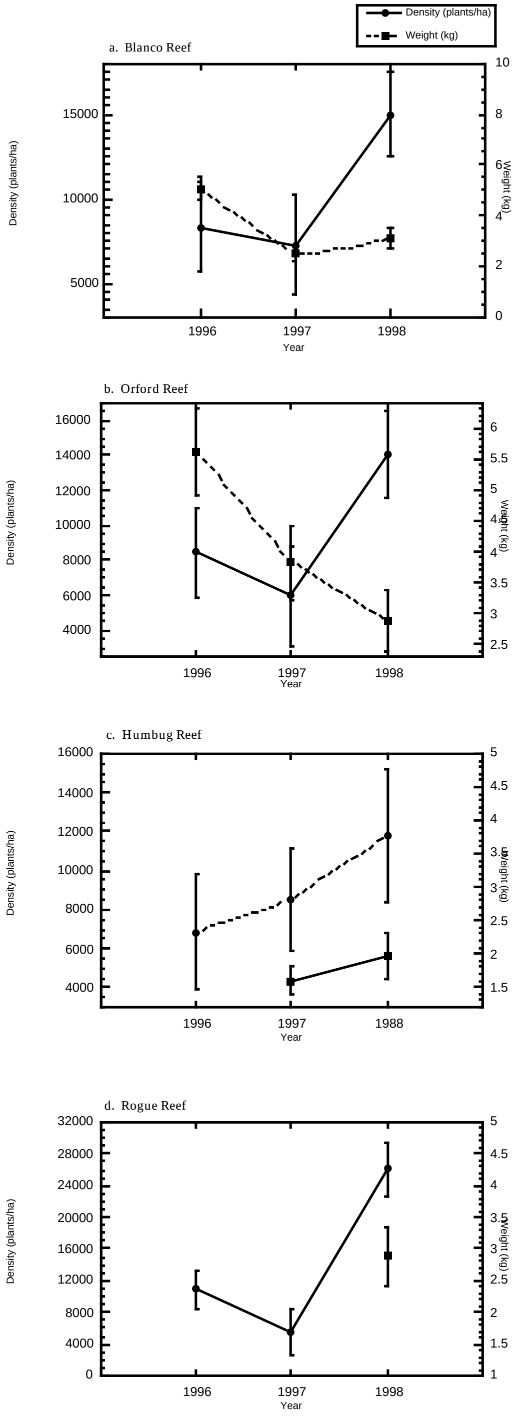
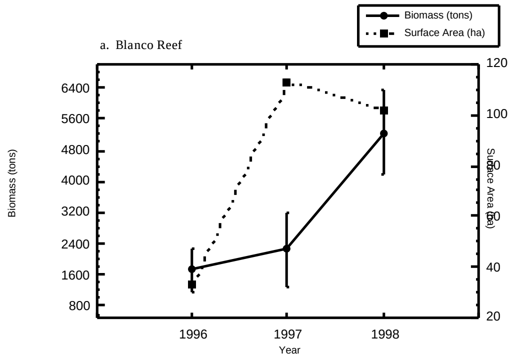
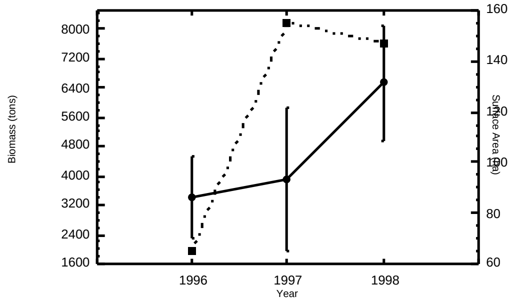
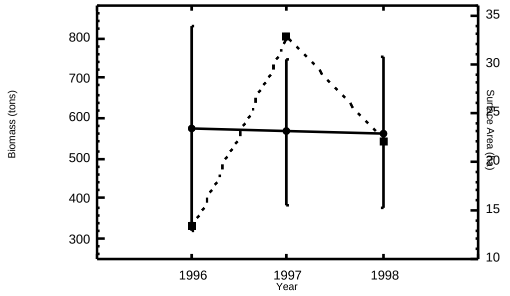


Figure 2.2.4. a-d. Plant density and weight for Blanco, Orford, Humbug and Rogue Reefs. Error bars denote 95% confidence intervals.


a. Blanco Reef


b. Orford Reef


c. Humbug Reef

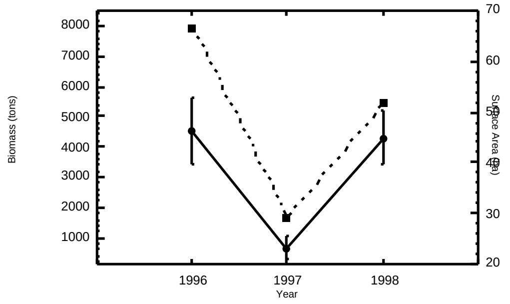

d. Rogue Reef

Figure 2.2.5 a-d. Biomass and surface area for Blanco, Orford Humbug and Rogue Reefs. Error bars denote 95% confidence intervals.

3. Bottom Habitat Surveys

We evaluated two survey methods to map seafloor and characterize bottom habitats. The first survey, conducted in 1998, employed an acoustic ground discrimination system (AGDS) called RoxAnn® to map nearshore reefs at Seal Rock, Cape Perpetua, and Humbug Mountain (Section 3.1). The second survey, conducted in 1995, used side scan sonar to map Orford, McKenzies, Redfish Rocks, and Humbug Mountain Reefs (Section 3.2). Section 3.3 compares the results of two survey techniques in a common survey area at Humbug Mountain, and evaluates the effectiveness of each survey tool for describing nearshore rocky reef habitat.

The primary objective of both surveys was to classify and map bottom types as characterized by meso-scale (1 to 100 m scale) physical reef morphology. Reef morphology at the 1 to 100 m scale can be expressed in terms of rock size (e.g., gravel vs. cobble vs. boulder), vertical relief and slope (e.g., pinnacles vs. low bedrock outcrops), and rock surface complexity. These types of features at the 1 to 100 m scale influence reef fish abundance, distribution, and community composition. A second objective of the surveys was to test different instruments and methods on Oregon's reefs to determine appropriate survey techniques to meet our needs.

3.1 1998 Acoustic Ground Discrimination Survey

3.1.1 Methods

Survey Instrument

Our primary survey instrument was the RoxAnn Groundmaster® (Stenmar, Inc.) acoustic ground discrimination system (AGDS) designed to produce real-time seabed classification data. The instrument consists of an echosounder, a transducer, and a processor/amplifier/receiver unit. The analog acoustic pulse produced by the echosounder is sent and received through a vertically mounted transducer. The processor then converts acoustic returns (echoes) into digital geo-referenced data streams viewable in software on a computer.

The acoustic return data consists of two types of integrated echoes, E1 and E2, corresponding to bottom "roughness" and "hardness", respectively. The processor unit calculates E1 and E2 by integrating the first two echo return signals. The first echo values returning to the transducer are the direct reflections off the bottom. RoxAnn calculates depth from this signal, similar to any echosounder. The tail end values of the first echo, however, are oblique reflections that are a result of a rough bottom. The rougher a bottom is, the more likely sound will reflect obliquely back to the transducer. E1 is the integration of the tail end (oblique reverberation portion) of the first echo. The second echo values are a result of bottom reverberations that then reflect off the sea surface and reverberate a second time off the bottom before returning to the transducer. The received signal strength of the second echo is related to the hardness of the bottom, i.e. how much sound is or is not absorbed by the bottom. A soft bottom would absorb most of the signal and thus second echo signal strength would be low. E2 is the integration of the entire second echo.

The typical implementation of RoxAnn® involves pre-survey “training” of the unit by collecting E1 and E2 data while driving the boat over known bottom types. These data are then used to set Cartesian limits (E1 as the x-axis, E2 as the y-axis) to each known bottom type (minimum and maximum E1 and E2 values of sand, for example). The system software uses the limits to allow real-time classification of bottom types while surveying, provided bottom types encountered are similar to training areas. Pre-survey training requires both considerable knowledge of the bottom types expected during real-time data collection and that the bottom types are distinguishable using bounds set by the Cartesian limits. This method, in our case, was not logistically feasible since we knew very little about the bottom types of the survey areas. Also, our need to distinguish several hard bottom types with variable and probably overlapping acoustic signatures (assuming variable ground cover of algae and invertebrates) could not be accomplished using simple Cartesian bounds of E1 and E2.

Sotheran, et. al (1997) provided another approach to using AGDS, essentially treating E1, E2, and depth as a three-band multispectral image. This allows for objective analysis of bottom types based on acoustic qualities, represented by a multispectral acoustic image. Image processing follows steps typical of multispectral satellite imagery processing (Wilkie and Finn 1996) used to identify land cover types. These techniques include: (1) image enhancement, (2) clustering of data with similar pixel values (unsupervised classification), (3) substrate determination via “ground truthing” and (4) using ground truth location samples to “train” the computer to identify substrate classes based on pixel statistics gathered from those samples (supervised classification). The benefits of using these multispectral processing methods with AGDS data are that they are objective and can be used with little or no prior knowledge of the bottom types in the survey area.

Study Areas

· Seal Rock and Cape Perpetua

Survey areas were planned to encompass sampling sites from the study comparing heavily fished with lightly fished reefs described earlier. The Seal Rock survey area extends from 5 to 16 km south of Yaquina Bay and is easily accessible to small boats and charters departing from the bay. The Seal Rock area is known to consist of rocky outcrops that are frequently visited by both fishers and divers. Consequently, Seal Rock is considered a heavily fished reef. The Cape Perpetua survey area is adjacent to an isolated and exposed coastline 40 km south from Yaquina Bay. Only larger vessels, such as charter and commercial boats, will occasionally make the journey and so it is considered a lightly fished reef.

· Humbug Mountain Reef

Humbug Mountain Reef is a south coast location that our research group has visited for several years. It is located approximately 6.5 km south of the port of Port

Orford. The area just south of Humbug Mountain Reef was surveyed with sidescan sonar in 1995 as part of a cooperative mapping project with the Canadian Geological Survey (see Section 3.2), and was chosen as an area to compare the AGDS and sidescan results.

Data collection

We set up the AGDS unit to work aboard our 8 meter research boat, the R/V Shearwater. The transducer was mounted vertically amidships about 1.5 m below the surface of the water. The echosounder/ processing unit was mounted inside the boat and interfaced with a PC and differential GPS. The echosounder (Furuno LS-6000 200kHz, Furuno Electric Co, Ltd.) delivered an acoustic beam angle of 12°, giving an acoustic footprint of approximately 4 m width at 10 m depth. The output was displayed through software (RoxMap, Stenmar, Inc.) on a laptop PC. Following the manufacturer's standard procedures, we calibrated the processor unit in the South Beach marina over a muddy bottom at 4- 5 m depth.

We ran survey tracklines parallel to each other across the study sites at a boat speed between 7 and 10 kts. Between-trackline spacing was 200 m at Seal Rock and Cape Perpetua and 100 m at Humbug Mountain. The between-line spacing for each site was roughly proportional in size to the total area surveyed.

Data quality was constantly monitored by examining the RoxAnn output data stream on a laptop computer. Depth and echo values that appeared to increase or decrease suddenly were cross-checked against the more detailed output on the echosounder's LCD screen. Data not consistent with the echosounder were labeled as "bad" (fish schools, for example, might give false bottom readings). The beginning and end of each trackline were noted to reflect periods of constant cruising speed. The laptop's clock was synchronized to the recorded notes to give a time-data reference for post-processing.

3.1.2 Data analysis

Image processing

RoxAnn time- and geo-referenced (Universal Transverse Mercator (UTM) coordinates, 1993 North American Datum) data were post-processed to edit erroneous data values, correct for tide level, and interpolate across the surveyed areas. Echo data values noted as 'bad' (see previous section) during each survey were deleted from the data files. Depth data were adjusted to match chart datum (Mean Lower Low Water) using NOAA Tide Gauge data at South Beach and Port Orford, Oregon (NOAA, www.opsd.nos.noaa.gov/opsd.html). Data were then brought into Surfer® (Golden Software, Inc.) where a linear kriging algorithm (Clark, 1987) was applied to interpolate between the survey tracklines. For each of our survey areas, a uniformly spaced grid was created through interpolation with Surfer. Grid spacing (the interpolated pixel size) varied for each site, depending upon the survey trackline spacing. Pixel size was 50 m at Seal Rock and Cape Perpetua, and 20 m at Humbug Mountain.

The data layers (E1, E2, and depth) for each survey area were exported from Surfer as individual *xyz* point files. The data files were then imported into one three-band (E1, E2, and depth) multispectral image file per survey area using the image processing program, DIMPLE (Process Software, Inc.). The importing process transformed the data layers into 8-bit pixel values between 0 and 255. This representation of the acoustic data appears as a grayscale image with the *x* and *y* axes corresponding to UTM coordinates and each *z* value representing acoustic intensity. Only the E1 and E2 bands were used for classification of bottom types, as depth is unlikely to influence geomorphology at the scale of our survey.

Image enhancement provided a method to broaden the separation of pixel values in the echo bands (E1 and E2). A linear histogram stretch was first applied to the data, based on the minimum and maximum values. This transformation assigns 0 to the minimum acoustic value and 255 to the maximum acoustic value, increasing the contrast of the image. Next, a principal components transformation was applied to produce the first two principal components. This transformation acts to spread the pixel values across the data space, removing the correlation between E1 and E2 and thus helping to increase the information visible within the image (Wilkie and Finn 1996).

Unsupervised classification

Unsupervised classification of the E1 and E2 bands was performed on the first two principal components using a K-means classification algorithm with 20 initial classes (overestimating the expected number of bottom types). This algorithm assigns initial classes evenly across the data range and is followed by iterations that estimate each class' mean (Verbyla 1995; Wilkie and Finn 1996). During each iteration, pixel values are assigned or reassigned into classes based upon a minimum distance criterion (i.e. if a pixel value is within some minimum distance to the mean of a particular class, it gets assigned to that class, otherwise it gets assigned to the next closest class or starts a new class). While these iterations were taking place, the software created a map showing the various classes in the survey area. The iterations were repeated until the class means achieve stability. In our case, we stopped when the class means moved 0 to 1 pixel values since the last iteration. The resulting final unsupervised classification map shows acoustically distinct classes of ocean bottom but provides no information on the actual bottom composition of each class. Thus, the unsupervised map was used to choose video ground truthing sites (also called training areas) based on these class groupings. The number of initial classes in the algorithm was reduced to 10, due to the expectation of time constraints for ground truthing. Ground truthing site locations were selected based on a desire to sample each class evenly.

Ground truthing

We ground truthed the classes established in the unsupervised classification using a “drop video” system. The drop video camera consisted of a large PVC housing (30 cm diameter x 53 cm length) encasing a low light-sensitive wide angle color video camera, a 100 watt SeaBlaze® light, and two parallel lasers set 0.20 m apart to provide a distance and horizontal reference. The video signal ran up a coaxial cable onto the boat and into a video recorder and monitor. Before lowering the camera, the boat was brought to a halt just upcurrent or upwind of the desired site location. We then lowered the drop video camera over the side of the boat by hand until observing the bottom on the video monitor. The video recorder was then turned on and the counter time and geographic location noted. The camera was kept at a distance off the bottom to avoid disturbing the sediment, anchoring the housing, or damaging the camera while the boat drifted with the wind and water currents over the ground truth site. Video counter time, bottom type, and GPS location were recorded periodically during the drift. Our intent was to drift over the survey trackline at each ground truth site, but the direction and speed of the drift was not always predictable (some video was 5-30 m off station).

Video review back on land was performed using one thirty-second video clip centered around the location where the video drift crossed the AGDS survey trackline. If a drift never crossed the line, the nearest point to the trackline was used as the mid-point. Bottom type was characterized for each video clip using a scheme developed in our 1997 field season (Table 3.1.1)

Supervised Classification

Once video sites were interpreted, a supervised classification was performed on the multispectral image. Video locations of a given bottom type were sampled by selecting pixels from the E1 and E2 bands to develop a spectral “signature” (also called training set) for each bottom type. A classifier algorithm then assigned likely bottom types to every pixel in the image using the spectral statistics of the training sets.

There are numerous classifiers used in remote sensing analysis. We chose to use a Gaussian classifier, which assumes a normal distribution of the final spectral statistics. A pixel that fell in a set of overlapping class distributions was assigned to the class with the highest weighted probability (we used a 95% confidence limit for distribution boundaries).

With the Seal Rock survey data, we used an additional image processing package, MultiSpec (Purdue University), to try different classifier, the Fisher Linear Discriminant classifier. This classifier assumes the classes have similar variance and correlation structures. The assignment cutoff is linear and is positioned between the class signatures' centroids, similar to the Gaussian classifier. This particular classification process also produces a "probability map", which estimates the likelihood of pixels belonging to their assigned class.

Table 3.1.1. Bottom Type Classification. Descriptors of bottom type were created by categorizing primary (>50%) and secondary (<50%) components of the ground truth video footage. (e.g. "CB" would describe a cobble bottom with scattered small boulders)

Code	Bottom Type Description (size range, angle)	
S	Sand 0.0625 mm- 2 mm	
P	Pebble 2 mm- 6.4 cm	
C	Cobble 6.4 cm- 25.6 cm	
B	Small Boulder 0.25 m- 1 m	Small scale geomorphologic modifiers on the F and R classes
L	Large Boulder 1 m- 3 m	
F	Continuous Level Rock 0- 45°	(L) low relief, (H) high relief
R	Continuous Sloping Rock > 45°	(L) low relief, (H) high relief

3.1.3 Results and Discussion

Seal Rock

The acoustic survey of Seal Rock took four separate trips to complete, August 4, 10, 11, and 17, 1998. The survey required a total of 60 tracklines and covered an area of 3075 ha (Figure 3.1.1). Figure 3.1.2 shows the grayscale interpolated acoustic data layers, E1, E2, and depth. There are two distinct characteristics about the survey data: (1) a north-south "roughness" (E1) disparity and (2) north-south depth contour ridges and trenches that are morphologically similar to the coastal landforms visible on the beach.

The northern portion of the survey area is dominated by acoustically rough bottom (high E1- bright values) as compared to the southern portion, which appears to be mostly acoustically smooth (low E1- dark values). There also are several isolated areas of high roughness values that are distinct from neighboring pixel values. Values for E2 appear to be more evenly distributed.

Depth ranged from 6 to 40 m, with contours generally running parallel to the coastline. However, several shallow (15 m) features were detected in the northwest portion and continued to the south and west. There were also very long ridge- and trench-like features that run transversely from the northeast towards the southwest. These features are broadly consistent with the geomorphology that emerges on the nearby beach. The southern portion of the survey area appeared to be relatively flat, with the exception of a transverse trench running from the north.

A total of 80 drop video sites were sampled for ground truthing (Table 3.1.2), based on locations chosen from the unsupervised classification map (Figure 3.1.3). Both final supervised maps of the survey area (Figures 3.1.4a,b) depict a flat bedrock / small boulder bottom running from the northeast to the southwest, a reef-like northern and middle portion, and a sandy southern portion with a concentration of sand dollars (Gaussian classifier only) and small boulders and cobbles on the southernmost end. The flat bedrock that extends down from the northeast appears to be associated with uplifted contours (Figure 3.1.5) that are also present on the shoreline (Figure 3.1.6). The "flat bedrock" bottom type here is most likely uplifted sedimentary layers of mudstone, sandstone, and ash (Lund, 1972). The "high relief bedrock" associated with the shallow areas on the western side of the survey area are probably eroded basaltic formations. Seal Rock is known to be an area where basaltic remnants of sills and dikes are common (Lund, 1972).

The two classifiers, Gaussian and Fisher Linear Discriminant, use slightly different criteria in deciding pixel assignment to a given bottom type. The Gaussian classifier assumes a normal distribution of the final class statistics, which may work best when the distinction is clear (e.g. sand and rock). Because of this factor, some of the bottom type classes were merged to carry out the classification (Table 3.1.3). The Fisher classifier assumes that the classes have the same variance structure. This classifier, then, would work best with bottom types that show similar degrees of variation. It appears to have correctly assigned pixels to appropriate bottom types for most of the survey area, with the exception of high relief bedrock and the sand dollar site on the southern end (see Probability Map, Figure 3.1.4c). A few pixels were labeled "unclassified" since they didn't fall into any of the classifier's decision boundaries. The two maps based on the different classifiers show similar bottom types in a broad sense (primary types are similar: flat bedrock versus sand, for example). Because the Gaussian classifier does not produce a probability map as a

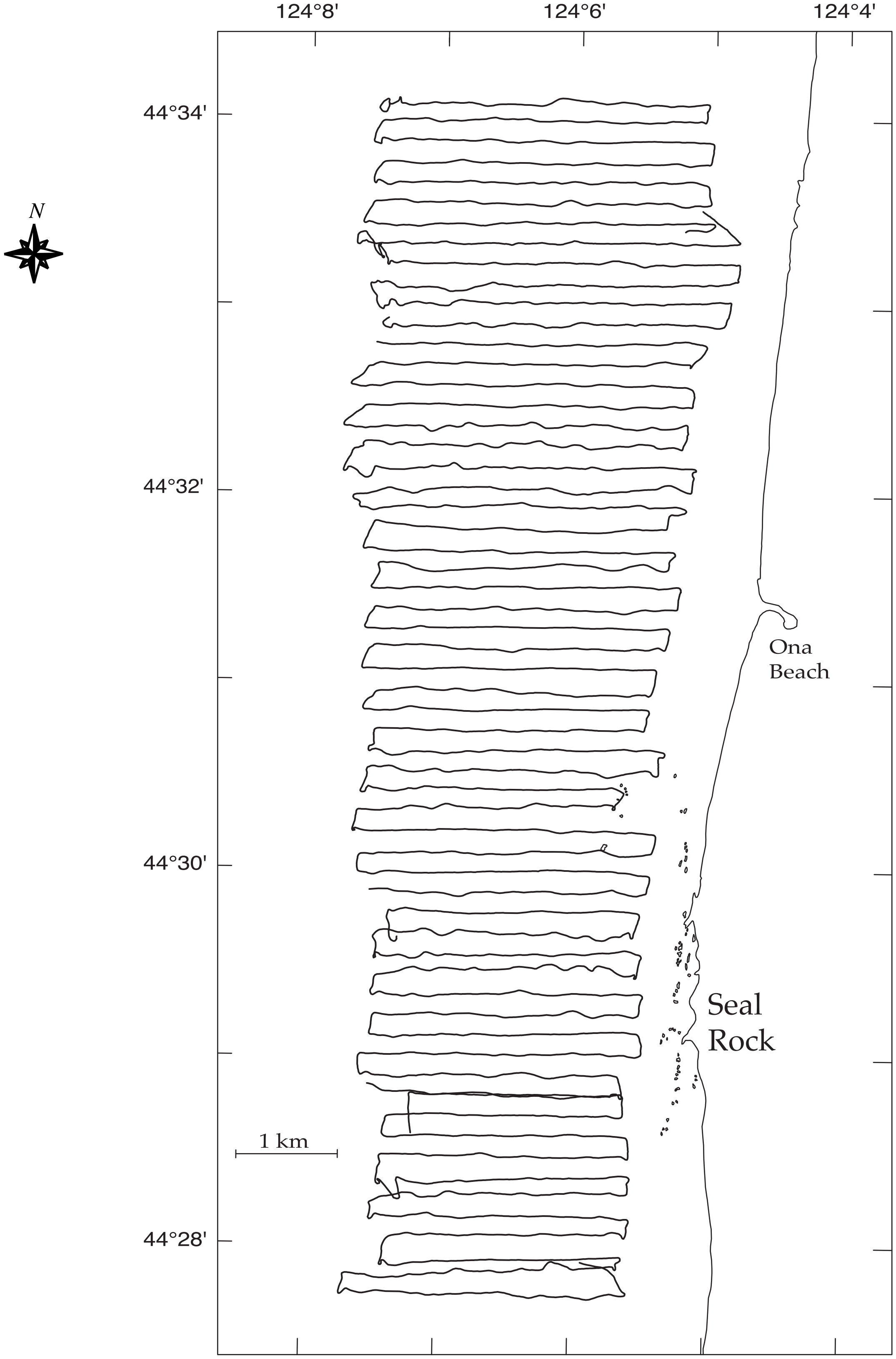
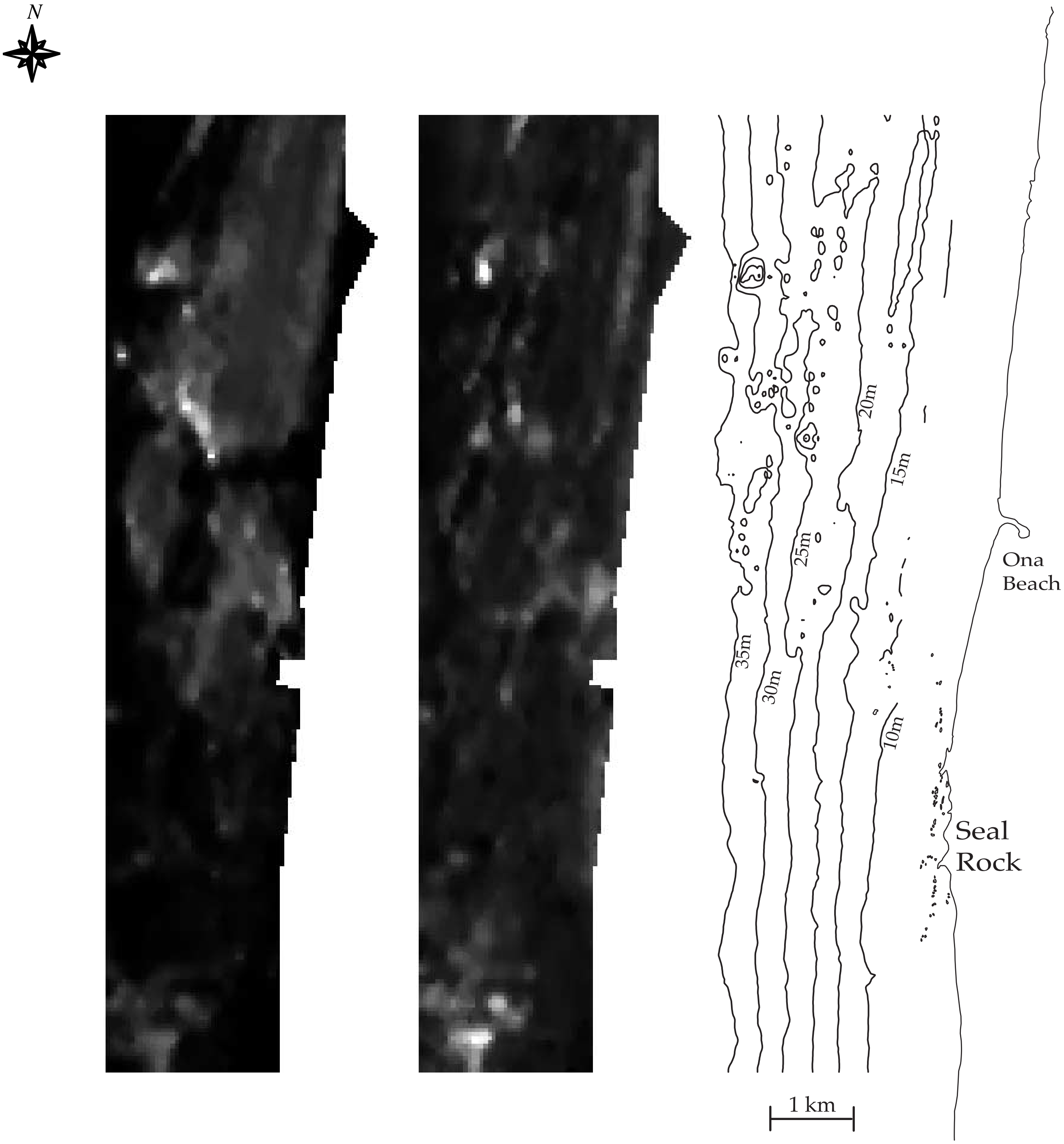


Figure 3.1.1. AGDS survey tracklines at the Seal Rock survey area.



(a) (b) (c)

Figure 3.1.2. Seal Rock acoustic survey raw results. Echo values E1 (a) and E2 (b), expressed in 8-bit greyscale pixel values. 0=black and 255=white. Depth contours (c) are at 5 meter intervals.

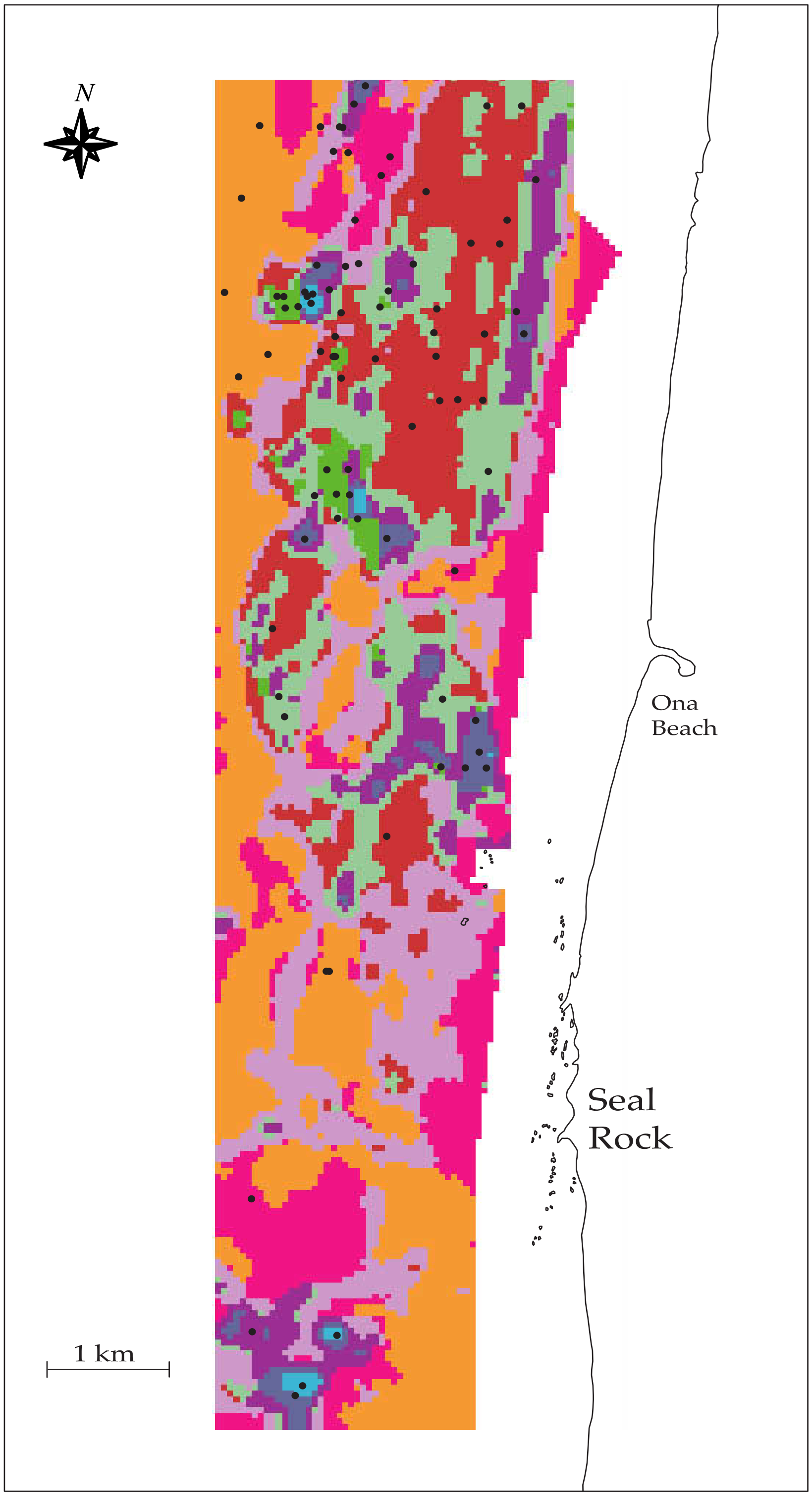


Figure 3.1.3. Seal Rock survey area unsupervised classification map. Drop video ground truth sites are shown as black circles.

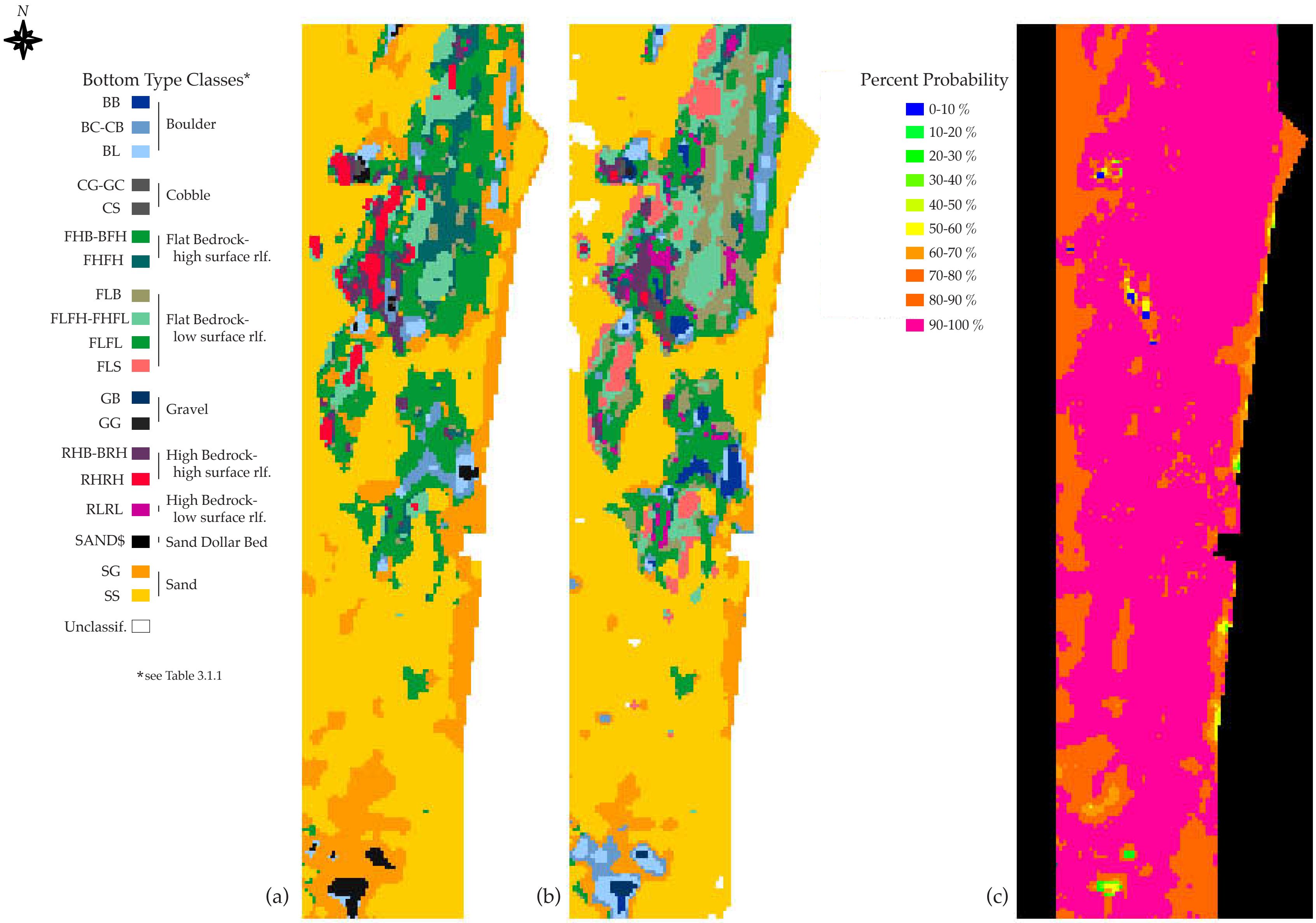


Figure 3.1.4. Supervised classification maps of the Seal Rock survey area. created using two different classifiers, (a) Gaussian and (b) Fisher linear discriminant, and (c) Fisher probability map (likelihood of pixels belonging to an assigned class). Some bottom type categories were merged in order to complete the classifications (see Table 3.1.3 for pixel comparisons).

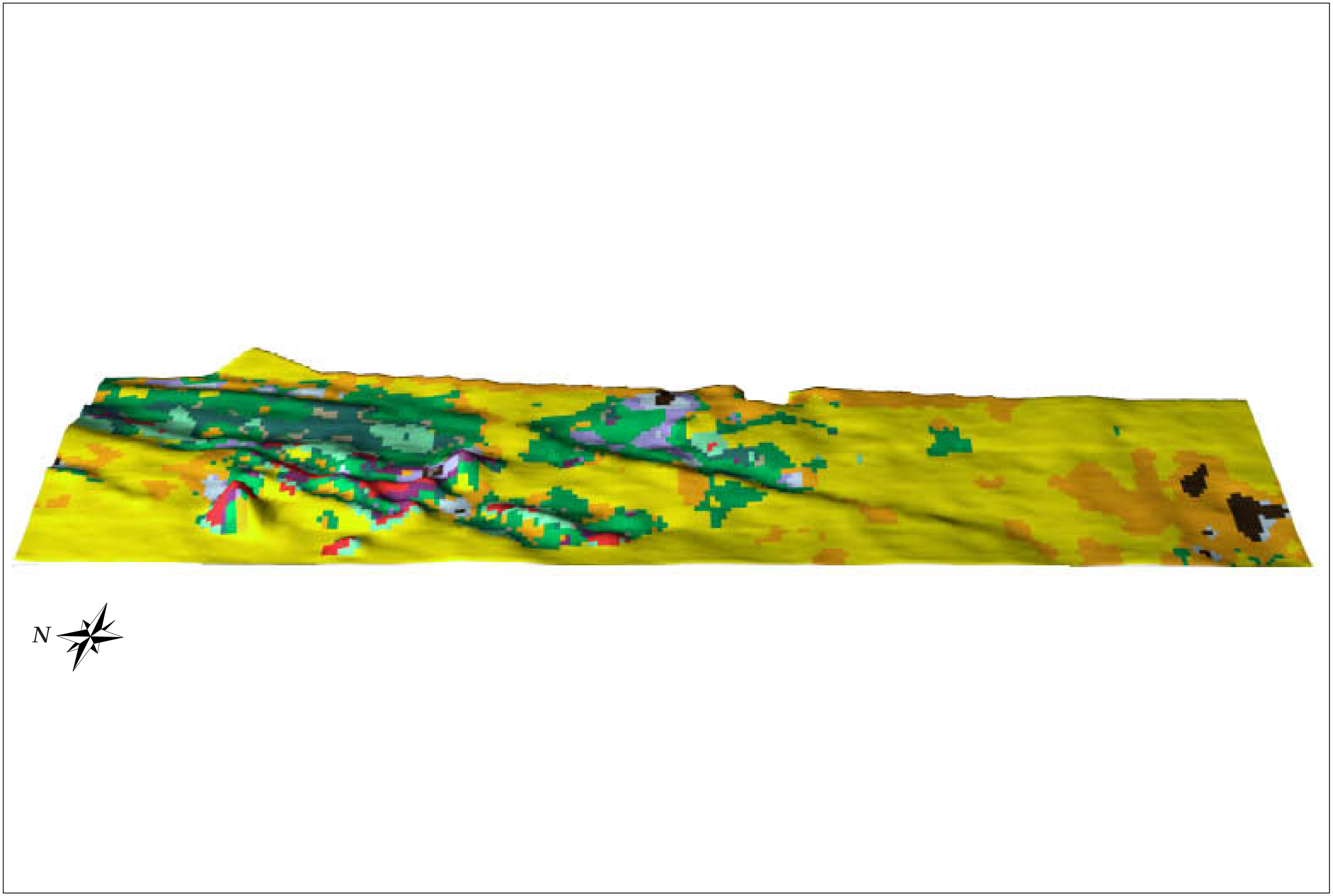


Figure 3.1.5. Eastward-looking 3-d perpsective of the Seal Rock survey area. Gaussian-classified bottom types are overlaid on bathymetry. Depth exaggeration is 10:1.

Table 3.1.2. Bottom types as observed in Seal Rock video ground truthing. Some types were merged for classification purposes. Type codes include both primary (>50%) and secondary (<50%) bottom types. See Table 3.1.1 for code description.

Primary bottom type	type code	# sites
Small boulder	BB	2
	BC-CB	9
	BL	1
Cobble	CG-GC	3
Flat bedrock -high surface relief	FHB-BFH	10
	FHFH	5
Flat bedrock -low surface relief	FLB	7
	FLFH-FHFL	3
	FLFL	9
	FLS	1
Gravel	GB	1
	GG	1
High relief bedrock -high surface relief	RHB-BRH	2
	RHRH	4
High relief bedrock -low surface relief	RLRL	1
Sand Dollar Bed	SAND$	4
Sand	SG	2
	SS	15
	total	80

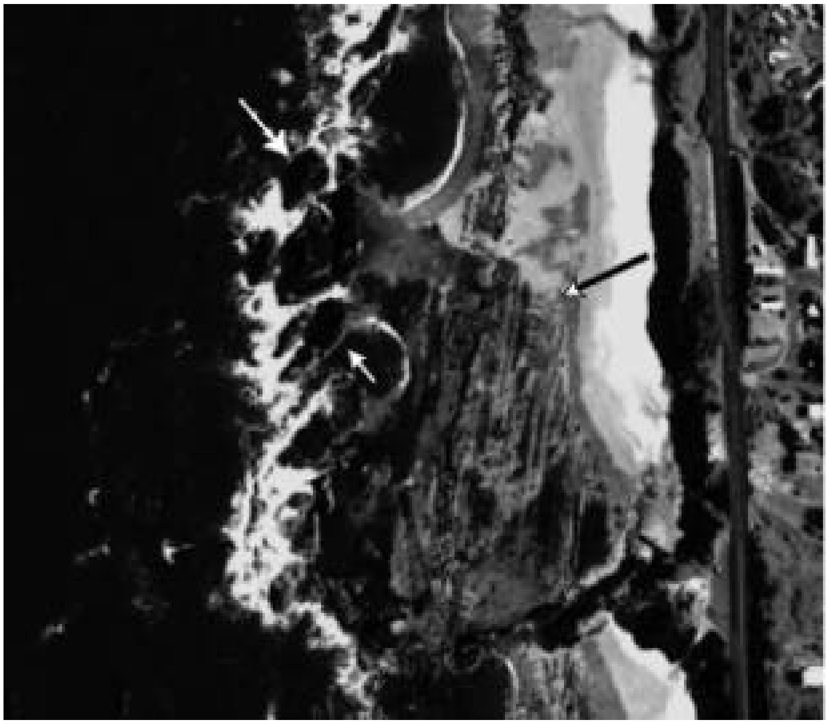


Figure 3.1.6. Aerial photo of the intertidal near Seal Rock, Oregon. A black arrow points to tilted and uplifted stratified bedrock. White arrows point to eroded basalt formations. The town of Seal Rock is on the right.

result, it is difficult to make comparisons between bottom types that were classified differently. At the very least, the two classifiers clearly succeeded in describing "rock" versus "sand". In terms of specific bottom morphology, these maps become predictive and should be used together when evaluating habitat.

Differences between the two classifiers' ability to detect variations of bottom morphology may involve several factors. In particular, the natural variation of bottom cover is likely greater than we can resolve using these remote sensing techniques. During video ground truth observations it was apparent that there were differences in the amount of invertebrate and algal fouling of bedrock. Some patches of bedrock were completely bare, likely a result of sand scour by wave action. These bare spots were typically on low-lying flat bedrock. Slight differences in flat bedrock morphology provided some protection from scouring, as organisms were seen in isolated clumps on small knobs and ridges. High relief bedrock was noticeably covered with encrusting invertebrates and various types of algae (foliose and encrusting). In the interpolation process, each pixel represents a 2500 m^2 area interpolated from trackline data nearby. Some of these pixel areas may in fact be a result of a mixed bottom type where differences such as scouring and fouling may

Table 3.1.3. Pixel comparison between the two classifiers used on the Seal Rock acoustic data. Some bottom types were merged in order to carry out the classifications. Type codes include both primary (>50%) and secondary (<50%) bottom types. See Table 3.1.1 for code description.

Primary bottom type	type code	Gaussian # pixels	Fisher #pixels
Small boulder	BB	4585	4850
	BC-CB	6010	11850
	BL	w/BB	5505
Cobble	CG-GC	400	1275
Flat bedrock -high surface relief	FHB-BFH	16320	19090
	FHFH	13185	4895
Flat bedrock -low surface relief	FLB	2225	22060
	FLFH-FHFL	11350	16815
	FLFL	31910	15610
	FLS	0	10285
Gravel	GB	w/CG-GC	875
	GG	w/CG-GC	100
High relief bedrock -high surface relief	RHB-BRH	5105	4800
	RHRH	5400	425
High relief bedrock -low surface relief	RLRL	50	3325
Sand Dollar Bed	SAND$	3325	0
Sand	SG	53665	20265
	SS	147520	155625
	unclassified	0	3568

confound the distinctiveness of the bottom type descriptor used in supervised classification.

Fishing locations around the Seal Rock area correspond to bottom types mapped by our survey. The majority of recreational and charter boats seen this season were either around the shallow areas off of Seal Rock State Park or over the reef areas visible in Figure 3.1.5. In addition, most of the ODFW charter fishing survey sites were in the northern portion of the survey area. The lack of overall fishing seen in the areas classified as “sand” was expected. Most of the fishing that occurs near Seal Rock is for black rockfish (*Sebastes melanops*), blue rockfish (*Sebastes mystinus*), and lingcod (*Ophiodon elongatus*), which are associated with reef and boulder structures and are typically less abundant over sandy areas (Fox, et al. 1996).

Some of the southern drop video sites showed sand dollars, *Dendraster excentricus,* in exceptionally high densities (approximately 30-50 per 0.25 m^2), situated in crowded piles on the sediment surface. Sand dollars are typically found partially or completely buried in sand (Chia 1969). The occurrence of sand dollars on the sediment surface suggests that there was high turbulence over the bottom and/or rapid sediment transport in the area. In addition, the Gaussian classifier map's inclusion of sand dollars illustrates the ability of these methods to delineate a "biotope", or organism distribution (Foster-Smith, et. al 1998).

Sotheran, et al. (1997) used these multispectral methods to classify biotopes. We used their methods with the assumption that there should be detectable differences in geomorphology similar to differences between organisms' biotopes. Our Seal Rock survey results suggest that while specific secondary characteristics of categorized bottom classes weren't readily distinguishable, the primary characteristics were. The results may be improved by collecting additional ground truth data from the survey site, helping the supervised classification to more accurately map the bottom types. Highly accurate bottom type data may be difficult to obtain due to environmental, logistical, and technical constraints. The final maps are predictive and should not be viewed as absolute.

Cape Perpetua

The acoustic survey of Cape Perpetua was completed on one day, August 20, 1998, during ideal weather conditions. We needed a completely calm day to quickly cruise 40 km to the survey site and to ensure data we collected were not influenced by any surface interference (wind, waves, etc.). The number of tracklines (21) was limited by fuel considerations; the survey area covered 1,389 ha (Figure 3.1.7).

The raw acoustic survey data appeared to be spatially similar between the two echo values (Figure 3.1.8). Maps of E1 and E2 show high pixel values running down the center surrounded by relatively low pixel values. The map of depth indicates that there were no detectable shallow structures, and the slope gently decreased with distance offshore. The survey area is distinctly deeper than the Seal Rock survey area, with minimum and maximum depths of 21 and 53 m, respectively.

In developing the bottom type maps for Cape Perpetua, we had a limited number of drop video samples due to unfavorable weather conditions. Because we were aware the trip would be weather limited, drop video locations were chosen to cover a wide area in a short amount of time. A total of 21 drop video ground truth samples were obtained on October 21, 1998, 19 of which showed either sand or gravel. The remaining two drop video samples included flat bedrock and a sand/gravel mix (Table 3.1.4). The supervised map assigned sand and gravel to nearly all of the Cape Perpetua survey area (Figure 3.1.9). A few pixels remained unclassified, due to the low number of ground truth samples and, thus, pixel statistics.

The video results and the completed supervised map were somewhat surprising. While the bathymetric data does suggest a gradual bottom contour, typical of a sedimentary bottom, the preliminary fish data suggests that there would be some sort of vertical structure (the two areas had similar fish species composition typical of nearshore rocky reefs). It may be that there are isolated boulders, high relief pinnacles, or even parts of shipwrecks that fell between the survey tracklines and were not detected acoustically or with the camera. Isolated structures may provide habitat for schools of fish. Echo data were interpolated between the tracklines, and small structures may have been lost in the smoothing effect of interpolation. Video ground truth locations, then, may have not been able to sample any rock structures since their location was chosen from the interpolated echo data. More video samples would have undoubtedly improved the supervised classification to help resolve these issues.

There also is a possibility that the gravel and sand provide relief of a scale similar to small and even large boulders. Large swells will tend to increase the size of sediment ripples and ridges on the bottom. Wave action also tends to concentrate detritus in the troughs of the sediment bedforms. Conceivably, the amplitude of the sediment ridges might be enough to act as habitat by providing both food and protection from visual predators.

While the effectiveness of the classification will not be known from these data, Cape Perpetua did appear to be different from Seal Rock in both bathymetric structure and bottom composition. The survey area is noticeably deeper, has no large vertical structures, and is primarily a sedimentary bottom. The presence of rock structure indicative of a rocky reef may only be known with a more rigorous sampling regime (more ground truth video samples) and perhaps a more detailed acoustic survey (closer tracklines, different instrumentation).

Table 3.1.4. Bottom types as observed in Cape Perpetua video ground truthing review. Type codes include both primary (>50%) and secondary (<50%) bottom types. See Table 3.1.1 for code description.

Primary bottom type	type code	# sites
Flat bedrock -high surface relief	FHFH	1
Gravel	GG	7
Sand	SG	1
	SS	12
	total	21

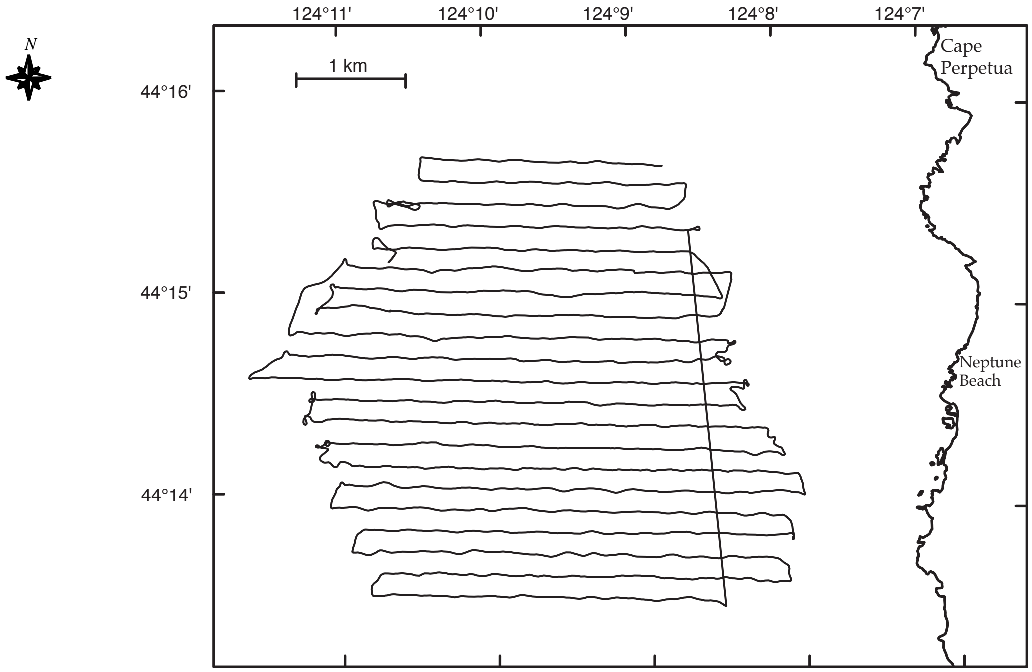


Figure 3.1.7. AGDS survey tracklines at the Cape Perpetua survey area.

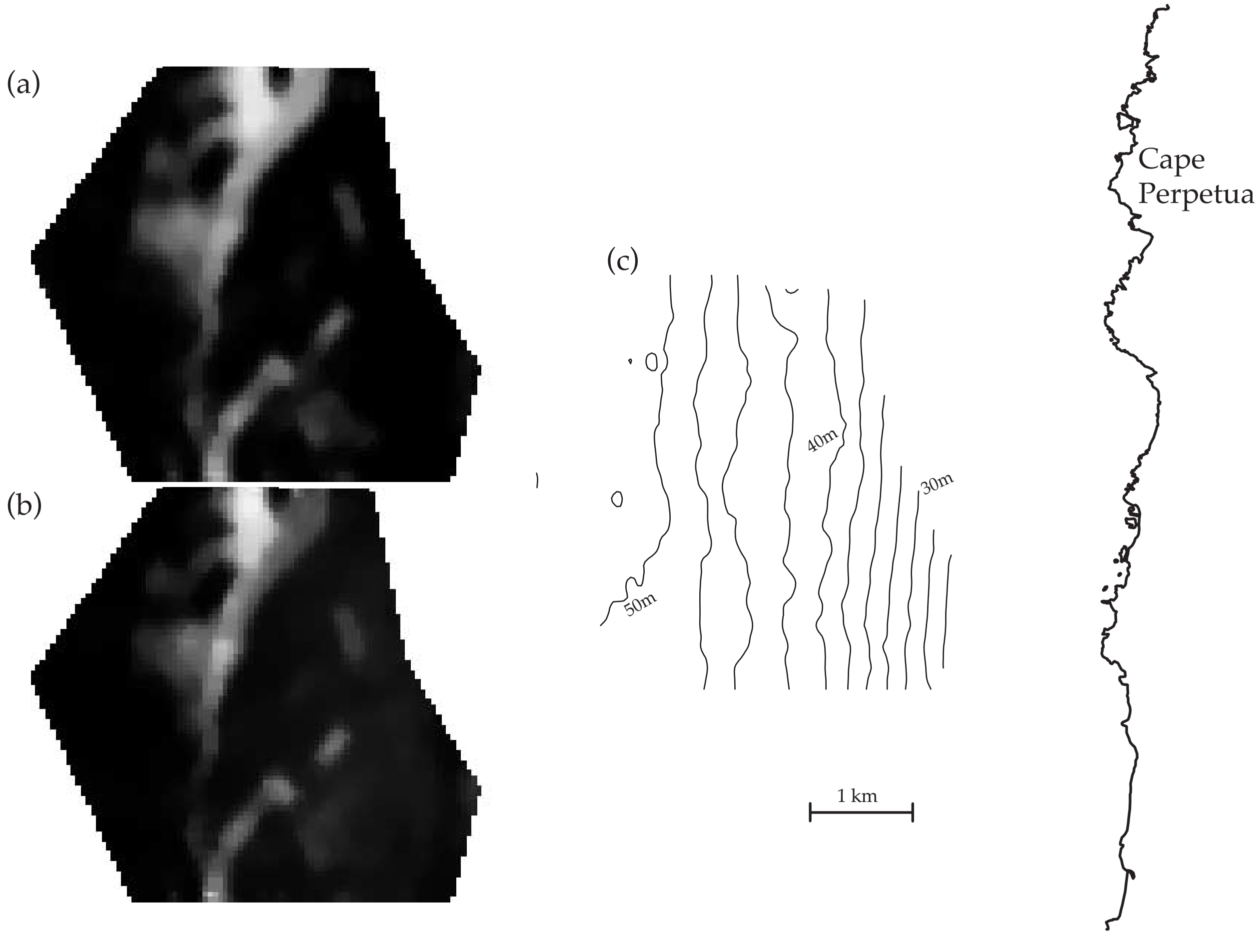


Figure 3.1.8. Cape Perpetua acoustic survey raw results. Echo values E1 (a) and E2 (b), expressed in 8-bit greyscale pixel values. 0=black and 255=white. Depth contours (c) are at 2.5 meter intervals.

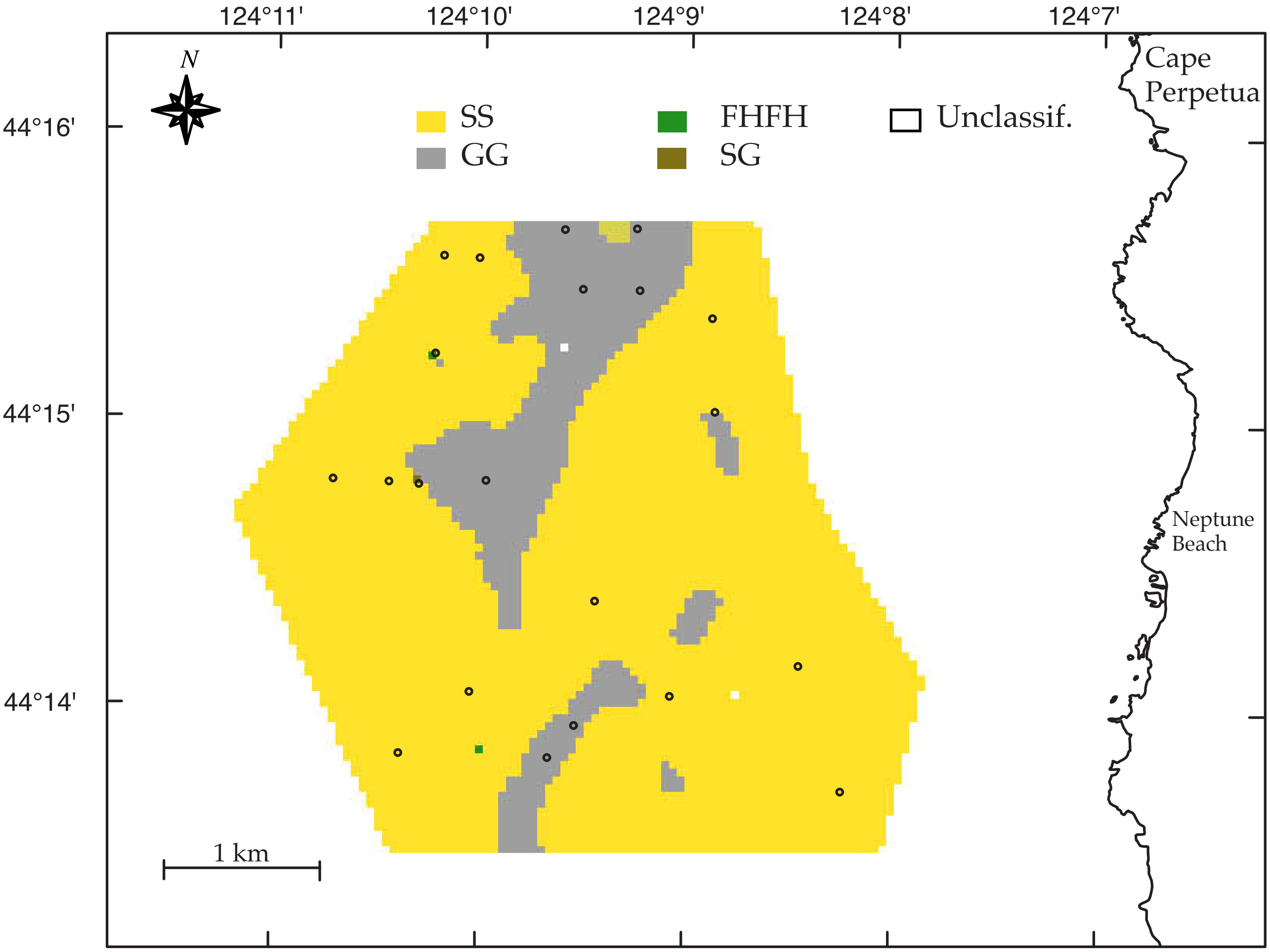


Figure 3.1.9. Supervised classification map of the Cape Perpetua survey area. Drop video ground truth sites are shown as black circles. See Table 3.1.1 for bottom type codes.

3.2 1995 Side Scan Sonar Survey

Working cooperatively with the Geological Survey of Canada and their subcontractor, Terra Surveys Limited, we completed a bathymetric and side-scan sonar survey of selected shallow rocky reef areas off the Southern Oregon coast. The objective of the survey was to characterize and map reef morphology at scale fine enough to be useful in future research relating fish distribution and abundance to bottom habitat.

3.2.1 Methods

Study Area

The study area consisted of shallow subtidal rocky reefs in the vicinity of Port Orford and Cape Blanco on the Southern Oregon coast. The study sites included Orford and McKenzies Reef; Redfish Rocks, and a reef area southwest of Humbug Mountain, referred to as Humbug Mountain Reef (Figure 3.2.1). Orford and McKenzies Reefs stretch southwest of Cape Blanco between about 10 m and 120 m water depth. The survey area included only water depths out to approximately 40 m. Numerous sea stacks at Orford Reef rise nearly vertically from depths as great as 40 m. Redfish Rocks lies 2-5 km southeast of Port Orford at depths of 5 and 30 m. Several sea stacks also punctuate this reef, with near vertical relief. Humbug Mountain Reef lies about 3 km southeast of Redfish Rocks. The area surveyed was between 10 and 30 m depth. Surveys were completed during late August, 1995.

Field Survey Techniques

The Geologic Survey of Canada and Terra Surveys Limited provided survey instruments and personnel to gather the side-scan sonar and bathymetric data. The survey employed the following equipment:

- Raytheon 719-C (200kHz) echosounder to acquire bathymetric sounding data,
- Simrad MS 992, dual frequency (120 and 330 kHz) side-scan sonar,
- digital tide gauge,
- Differential Global Positioning System (DGPS) base station (installed on a nearby headland) and a DGPS receiver on the survey vessel,
- Macintosh-based side-scan sonar logging system, using software developed by the Geological Survey of Canada,
- Exabyte tape system to record digital side-scan sonar data and a Sony DAT recorder to record the analog side-scan data, and
- PC-based system to record navigation data, using software developed by Terra Surveys.

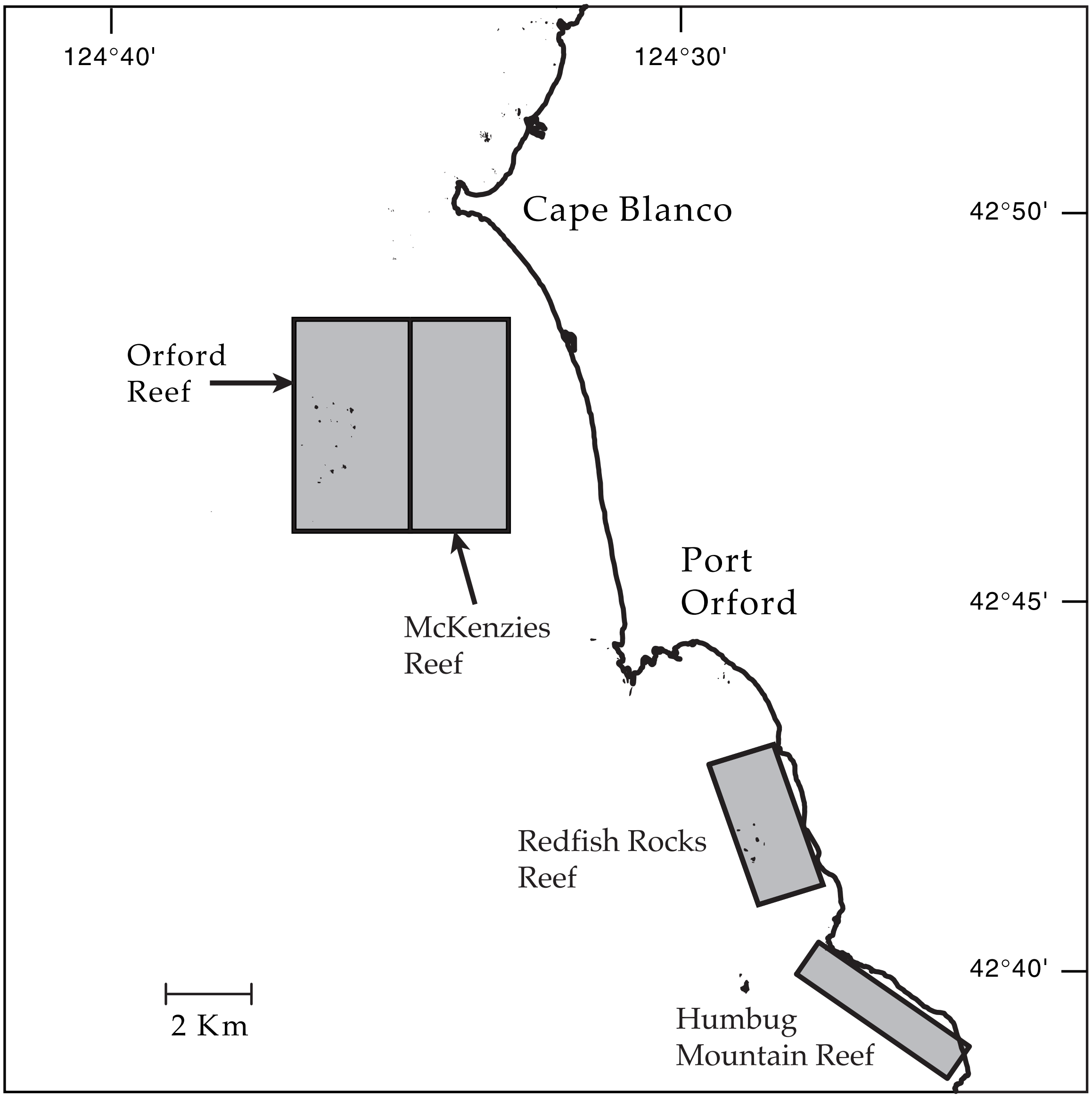


Figure 3.2.1. Side scan sonar survey areas at Orford, McKenzies, Redfish Rocks, and Humbug Mountain Reefs, 1995.

The F/V RELIANCE, a 12-m fishing vessel charted out of Port Orford, provided the platform for the survey. The echosounder was mounted on a vertical staff amidships on the starboard side of the vessel. The survey vessel towed the side-scan sonar towfish astern from a boom along the vessel's centerline. The tow wire was connected to a winch mounted amidships above the aft part of the houseworks. In an effort to reduce effects of vessel heave caused by swell, several lengths of bungy cord were installed between the deck and a pulley riding on the towfish tow wire. This was only partially successful in removing the effects of vessel motion on the towfish.

The survey vessel ran along pre-determined tracklines oriented approximately parallel to the shoreline in each survey area. Spacing between the tracklines at Orford and McKenzies reefs was 200 m, and the side-scan swath width was 400 m (200 m imaged on each side of the trackline). Spacing between the tracklines at Redfish Rocks and Humbug Mountain reefs was 100 m, and the side-scan swath width was 200 m. Maintaining a swath width of double the trackline spacing provided complete 200 percent side-scan sonar imaging of the seafloor. This allowed two sets of side-scan sonar mosaics to be created for each area, with ensonification directions from the "east" and from the "west". In addition to providing two independent sets of data for substrate interpretation, this coverage permitted a more complete imaging of the seafloor beneath the kelp beds.

We established a DGPS base station on a headland above the Port Orford dock. Although we were unable to locate suitable DGPS base station capable of serving all survey areas completely, our station covered most of the survey areas. Only minor post-survey editing of the navigation data files was necessary to acquire DGPS corrected files based on time of GPS readings.

The digital tide gauge was installed on the dock at Port Orford and referenced to local benchmarks. This provided data needed to correct the bathymetric survey to local Mean Lower Low Water.

Data Processing and Interpretation

The Geologic Survey of Canada processed the side-scan sonar data to prepare images of the seafloor. Initial processing included merging the sonar data with corrected navigation data, correcting for slant range error, and adjusting for gain imbalances. They then combined the side-scan sonar records to create mosaic images of the survey areas, using software developed by the Geological Survey of Canada-Atlantic. Although the survey acquired side-scan data at both frequencies (120 and 330 kHz), only the higher-resolution 330 kHz data were used for creating the mosaics.

Dr. Brian Bornhold, Geological Survey of Canada, developed interpretive maps of bottom types directly from the side-scan sonar mosaics. Data interpretation was aided by ground truth information provided by ODFW diver and submersible video, and from sediment and rock samples collected by ODFW divers. Most video data predated the surveys and was positioned with non-differential GPS. ODFW collected some dive video immediately after the survey to ground truth particular areas; however, poor weather prevented all but cursory data collection. Additional underwater video data obtained in 1996 provided a second ground-truthing check on the bottom-type maps (Fox, et al. 1996, fish transect sites).

The bottom-type maps classify seafloor features based on geology and geomorphology, using the following mapping units:

- sand,
- gravel-cobble,
- small boulders (<2 m in diameter),
- large boulders (>2 m in diameter),
- isolated areas of large boulders / blocks or small bedrock outcrops (>5 m in vertical relief),
- bedrock;
- fractures, joints, and crevices, and
- orientation of any bedforms in sand and gravel areas.

We developed this classification based on consideration of our need to characterize the various habitat types that may influence organisms distribution, the complexity of the areas surveyed, the scale of mapping, and the resolution of the side-scan sonar system.

The Geologic Survey of Canada created all mosaics and interpretive maps at a scale of 1:5,000, using a UTM Zone 10 coordinate system and 1983 North American Horizontal Datum. The interpretive maps were produced using AutoCad 13 ® and then translated to .dxf files for incorporation into our Geographic Information System. We used MapGrafix ®, Adobe Illustrator ®, and Dimple ® (an image analysis software) to generate map images and estimate surface area coverages of the different bottom types.

3.2.2. Results and Discussion

Figure 3.2.2 shows the tracklines surveyed. A large gap in the survey at Redfish Rocks and a smaller one at McKenzies Reef resulted from our avoidance of kelp beds to prevent fouling the side-scan sonar towfish.

Much of the seafloor on Orford and McKenzies Reefs is exposed, rugged, high-relief, fractured bedrock with dense concentrations of very large blocks and boulders, apparently from in-situ weathering of bedrock during low sea level stands (Bornhold, et al. 1996). Much of the bedrock consists of long curved ridges separated

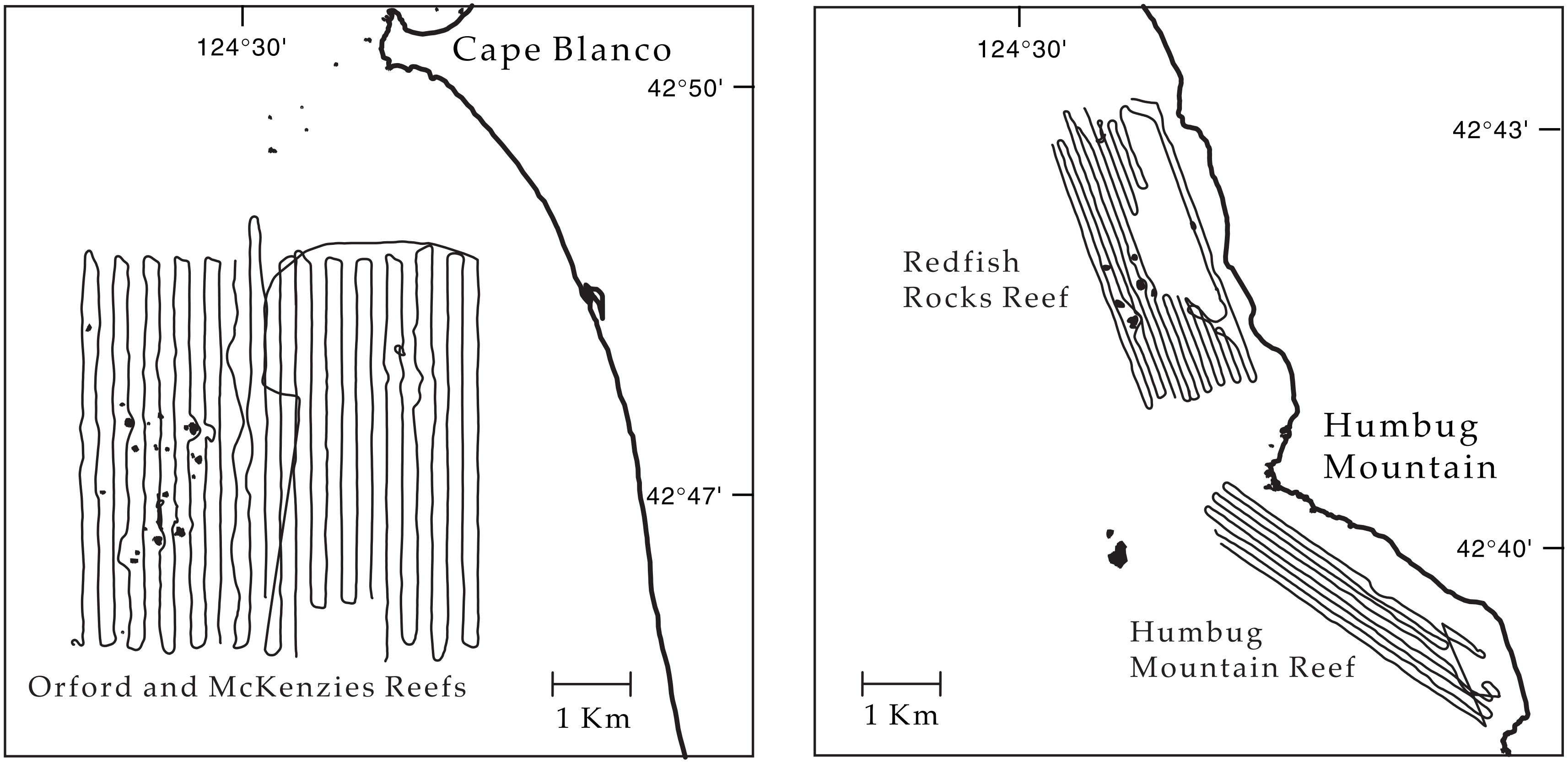


Figure 3.2.2. Side scan sonar survey tracklines at Orford, McKenzies, Redfish Rocks, and Humbug Mountain Reefs, 1995.

by troughs filled with boulders, gravel, and sand. The ridges are cross-cut by faults and joints. The outer perimeter of the reef areas is characterized by gravels, often formed into bedforms with wavelengths of many meters. The outer edges of the gravel patches are overlain by a thin layer of apparently mobile sand, again often exhibiting bedforms (Bornhold, et al. 1996). Redfish Rocks Reef is similar with bedrock and boulder terrain surrounded by gravels and sands. The bedrock at Redfish Rocks has less well-defined structure (ridges and troughs) than on Orford and McKenzies Reefs. Based on diver observations, much of the inner reef precluded from side-scan sonar surveys due to kelp consists of boulders. Humbug Mountain reef is composed of three broad bands of bedrock, trending approximately perpendicular to the shoreline. The bands are separated and surrounded by extensive gravels with long-wavelength bedforms, in turn overlain by mobile sands. The bedrock is extensively faulted and fractured. The inshore edge of the area is a complex mix of small outcrops, high-relief concentrations of large blocks and boulders, and some sand and gravel (Bornhold, et al. 1996).

Figures 3.2.3 through 3.2.5 show the bottom-type maps interpreted from the side-scan sonar mosaics and Figure 3.2.6 summarizes the proportional surface area coverage for each bottom type. Although the reefs are similar in that they contain a complex mix of both high-relief and low-relief habitat, there are some striking differences. Large sections of highly fractured bedrock, along with a distinctive ridge and trough system, dominate McKenzies Reef. There seems to be a transition to a bottom dominated by large boulders and eroded blocks as you move westward onto the main part of Orford Reef. Orford Reef has numerous small high relief features (Figure 3.2.3); over 10,000 individual features were mapped based on the survey data. Although these adjacent reef areas appear different from a geomorphologic standpoint, their features may be very similar as fish habitat. Concentrations of fish associate with both the large crevices at McKenzies Reef and the pinnacles, and large boulder/blocks of Orford Reef. Fox, et al. (1996) found no significant differences in fish densities when comparing high relief features at Orford Reef with those at McKenzies Reef.

Bottom habitats observed during our 1996 dives in the study area agreed favorably with the bottom-type maps. Of 42 dive sites, The bottom types at 25 matched the maps well, 15 partially matched the maps, and 2 did a poor job of matching the maps. The partial matches exhibited some consistent patterns that explain apparent differences between the maps and direct observation. Some of the sites interpreted from side-scan sonar as large boulder areas (boulders larger than 2 meters) actually contained mostly boulders in the 1 to 2 meter class. This indicates that the bottom-type maps may overestimated boulder size in some cases. The 2 meter size cutoff between large and small boulder sizes on the maps should, therefore, be considered approximate; it likely lies somewhere between 1 and 2 m. Some of the dive sites classified as primarily sand, but with some boulders, were mapped as boulder areas on the bottom-type maps. These sites often consisted of boulders scattered on a sandy substrate, accounting for the divers noting the preponderance of sand. The side-scan sonar images were interpreted with respect to

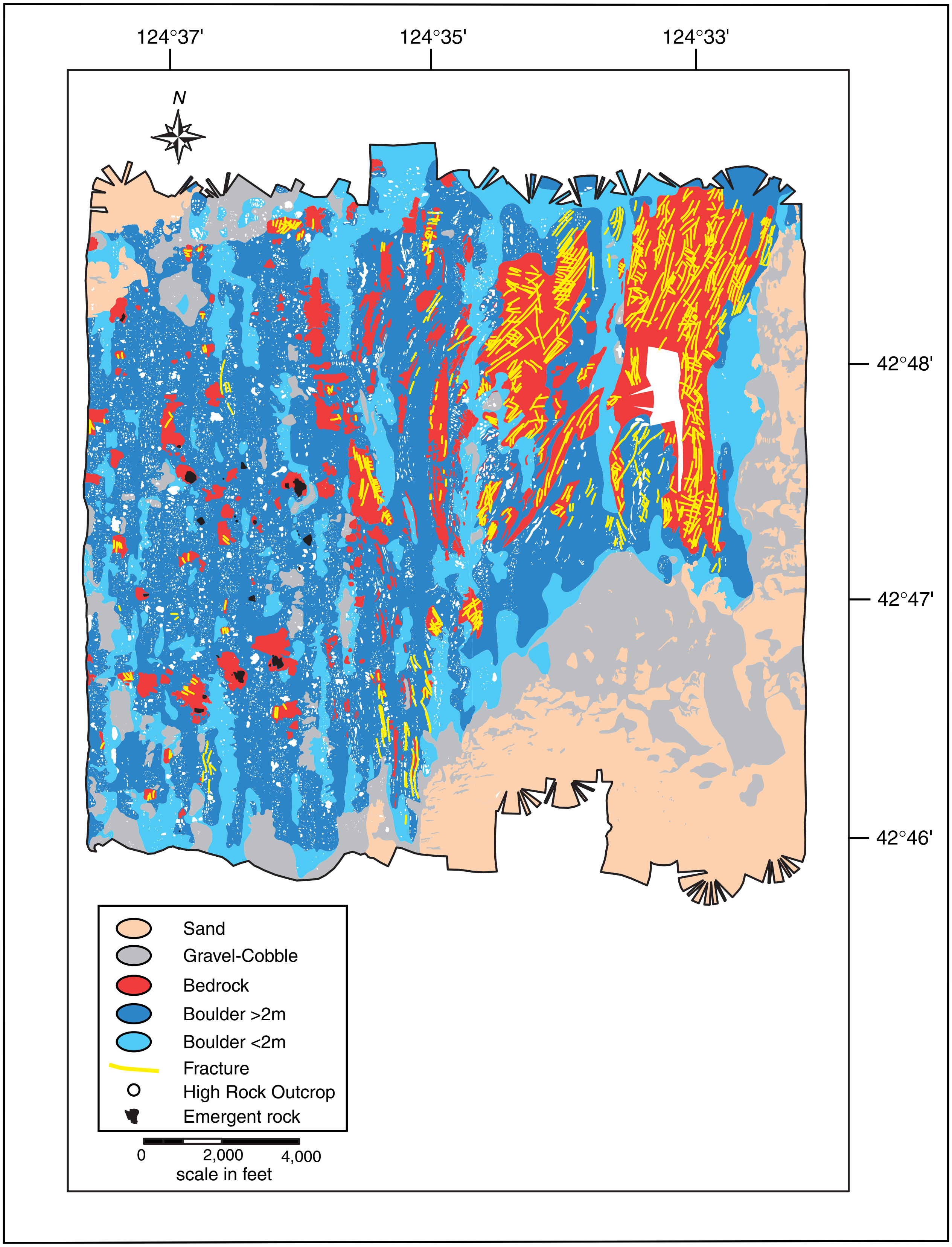


Figure 3.2.3. Bottom habitat types of Orford and McKenzies Reefs as interpreted from side scan sonar data.

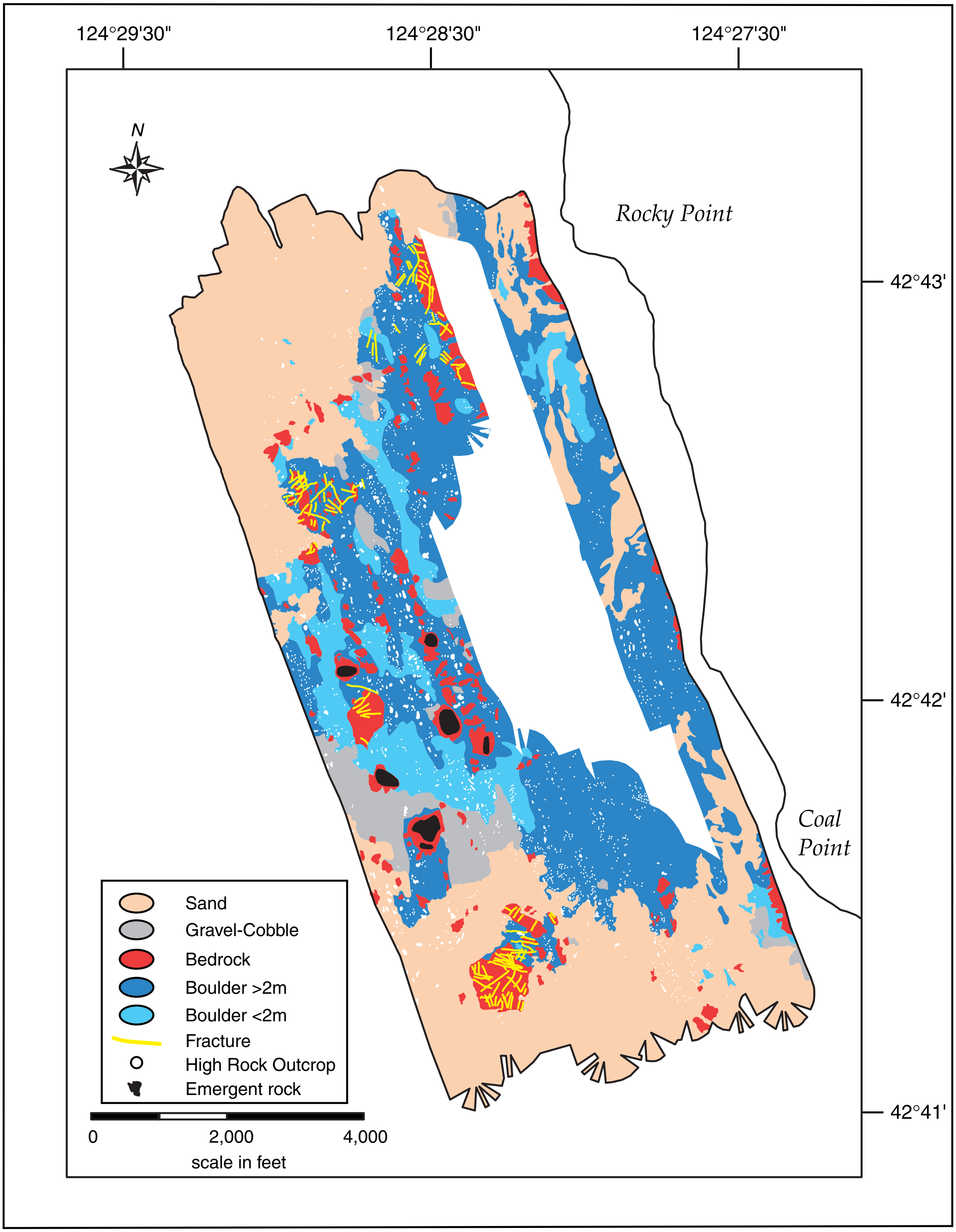


Figure 3.2.4. Bottom habitat types of Redfish Rocks nearshore area as interpreted from side scan sonar data.

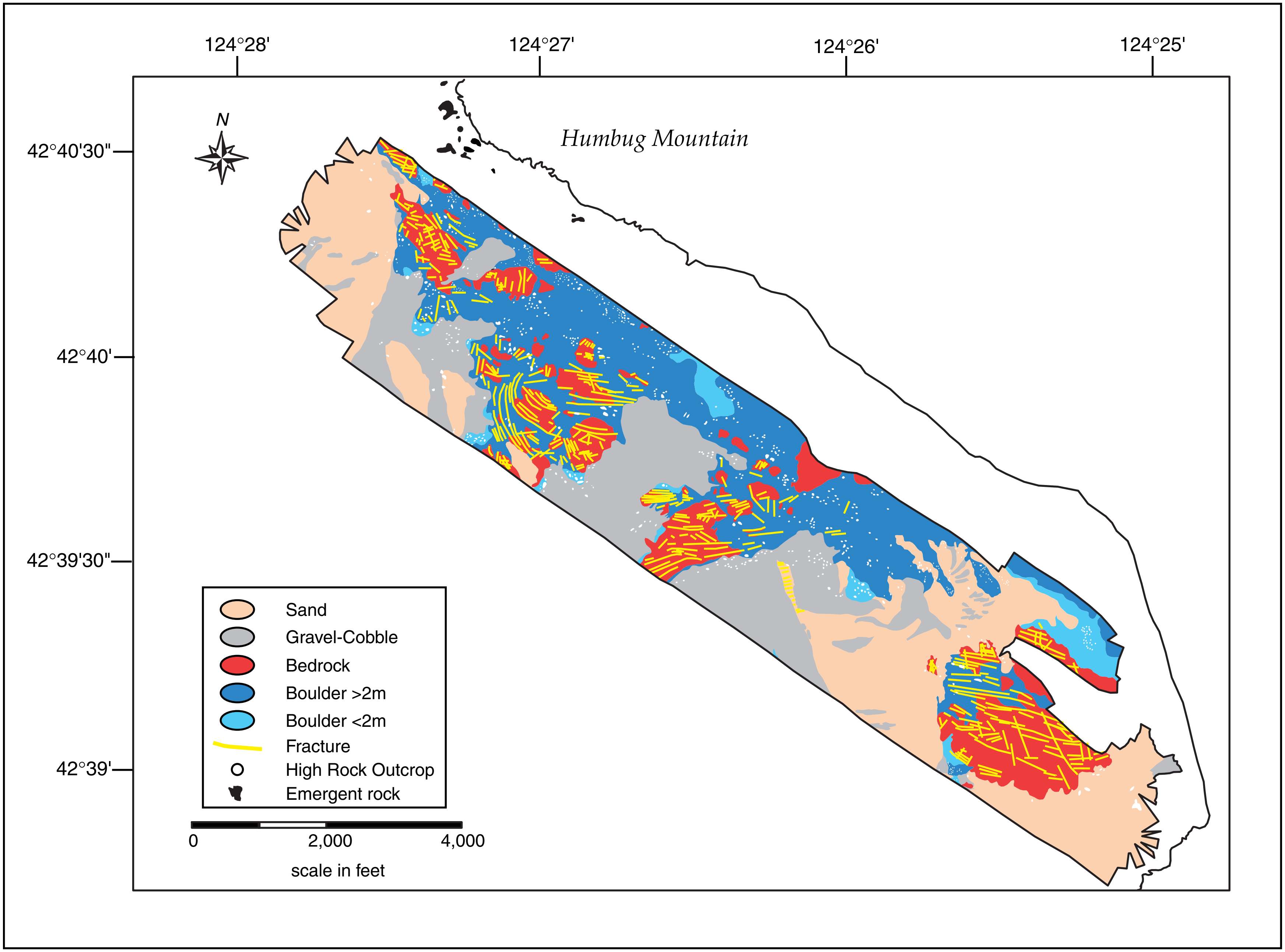


Figure 3.2.5. Bottom habitat types for Humbug Mountain nearshore area as interpreted from side scan sonar.

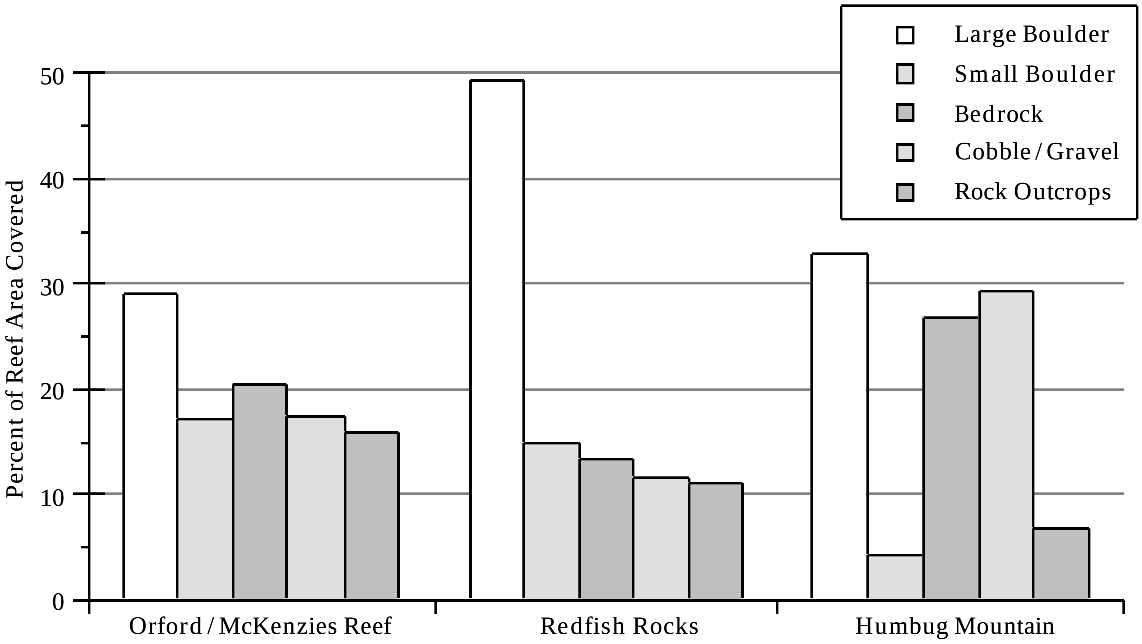


Figure 3.2.6. Percent surface area coverage of rock bottom types (excluding sand) within the study area.

the signal reflected from the boulders, and the bottom was classified as boulder regardless of the underlying substrate. In most cases the underlying substrate could not be interpreted from the side-scan sonar images.

The side scan sonar maps provide a useful tool for examining rocky reef and kelp bed ecosystems off the Southern Oregon coast. For example, based on our previous submersible studies and other research (e.g., Hixon, et al. 1991; Stein, et al. 1992; O'Connell and Carlile 1993; Auster, et al. 1991; Richards 1986; Matthews 1990a; Matthews 1990b; Krieger 1992a; Krieger 1992b; Murie, et al. 1994), we know that bottom composition and morphology play an important role in determining fish species occurrence and relative abundance. Our 1996 study of fish-habitat relationships on the rocky reefs surveyed by side-scan sonar confirmed this (Fox, et al. 1996). With further work examining organism density by habitat, these maps can provide a basis for estimating within-reef fish or invertebrate populations sizes. The maps also provide a means to ensure research is designed to adequately represent the mix of reef bottom habitats.

3.3 Comparison of AGDS and Side Scan Sonar Survey Methods

The 1998 AGDS and 1995 side scan sonar surveys both covered the northern part of Humbug Mountain reef, providing a means for direct comparison of the survey techniques. An unbiased comparison would require independent, accurate knowledge of the bottom characteristics. Since there is no independent data source, we needed to select one of the surveys as the control. This comparison assumes that the side scan sonar gives an accurate portrayal of the bottom and examines how well the AGDS survey matches the side scan sonar survey. As the discussion below indicates, this assumption limits the conclusions we can draw from the comparison.

3.3.1 Methods

The AGDS survey covered a 193 ha area at Humbug Mountain reef, of which 144 ha overlapped with the side-scan sonar survey (Figure 3.3.1). Survey methods followed the procedures described in section 3.1.1, above. AGDS survey tracklines paralleled the shoreline and were spaced at approximately 100 m intervals (Figure 3.3.1), similar to the side scan sonar survey. We used the drop video system described in section 3.1.2, above, to observe seafloor bottom characteristics at 11 stations within the AGDS survey area.

Classification and mapping of the AGDS data followed procedures outlined in section 3.1.2, above, except that the side scan sonar maps provided a basis for supervised classification, rather than seafloor observation data. Bottom type classification also followed the side scan sonar survey described in section 3.2.1, above. We selected supervised classification training sites by overlaying the AGDS survey tracklines with side scan sonar bottom types on a GIS and choosing approximately equal-spaced sites along the tracklines. The sites provided training locations to represent the underlying side scan sonar bottom types. This procedure resulted in selection of 185 training sites for use in the supervised classification of AGDS data. The drop video data provided a cross-check on the data classification.

Techniques for comparing the side scan sonar maps with the supervised AGDS classification maps included overlaying the two data types using a GIS to visually check for map similarities and creating a comparison map from the two data types. The comparison map cross-checks side scan with AGDS data on a pixel-by-pixel basis, indicating bottom type matches and mismatches.

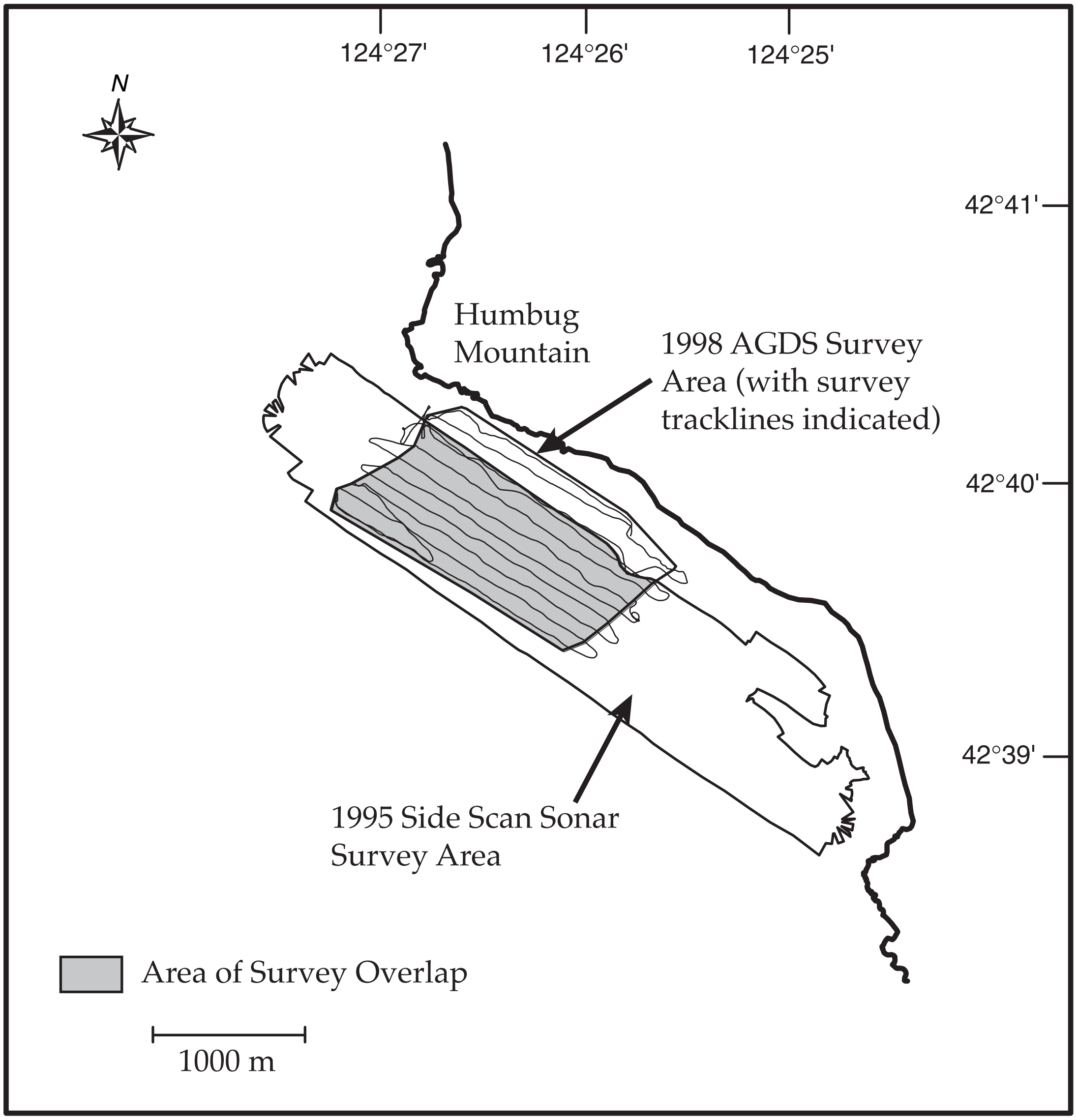


Figure 3.3.1. AGDS and side scan sonar survey areas at Humbug Mountain Reef showing the area of survey overlap.

3.3.2 Results and Discussion

Figure 3.3.2 shows the side scan sonar, AGDS survey, and comparison map for the area of survey overlap. The AGDS data classification successfully defined the principal areas of large boulder, small boulder, and sand as depicted on the side scan sonar maps (Figure 3.3.2). There were significant mismatches in the cobble/gravel, and bedrock bottom types (Figure 3.3.2). The AGDS survey classified much of the cobble/gravel habitat as small boulder. The survey also classified some bedrock areas as large boulder, while classifying other large boulder areas as bedrock (Figure 3.3.2). The AGDS classification matched 76% of the sand area successfully and 61% of the large boulder (Table 3.3.1). There was a 50% overall match between the two survey results (Table 3.3.1).

Possible reasons for mismatches between survey results include:

1) the bottom type classification is based on differences in rock morphology that are readily detected visually; acoustic differences often do not parallel visual differences, thus, some visual differences may not be easily detected acoustically,
2) parts of the side scan sonar interpretation may not accurately reflect the true bottom type,
3) changes in bottom type (e.g., movement of sand) may have occurred during the time between the 1995 side scan sonar and 1998 AGDS surveys.
4) interfaces between bottom types are mapped as distinct lines but may be gradual transitions

The confusion between bedrock and large boulder areas may be due to acoustic similarities in the rock structures. Large boulders are often closely packed and stacked on one another, and can resemble bedrock with geomorphologic features of similar scale as groups of boulders. Also, boulders often overlay a base of bedrock, further accounting for acoustic similarity. Figure 3.3.3 shows a pronounced degree of overlap between large boulders and bedrock bottom classes derived from the AGDS survey. Although large boulders are readily distinguishable visually from bedrock with boulder-like relief, they may be very similar acoustically.

Confounding cobble/gravel and small boulder bottom types can result from a number of factors. The AGDS data at Humbug Mountain showed a large acoustic overlap between the two bottom types (Figure 3.3.3). Also, the side scan sonar interpretation could not absolutely distinguish cobble from small boulders. Larger cobble could easily be confused with smaller small boulders because the sizes of individual rocks are nearly the same. Finally, gravel areas can change over time due to bedload transport of gravel during the strong winter storms typical of the study site.

Seven of the eleven drop video sites occurred within the area of survey overlap. Of those, four matched with both the side scan and AGDS data. Three of

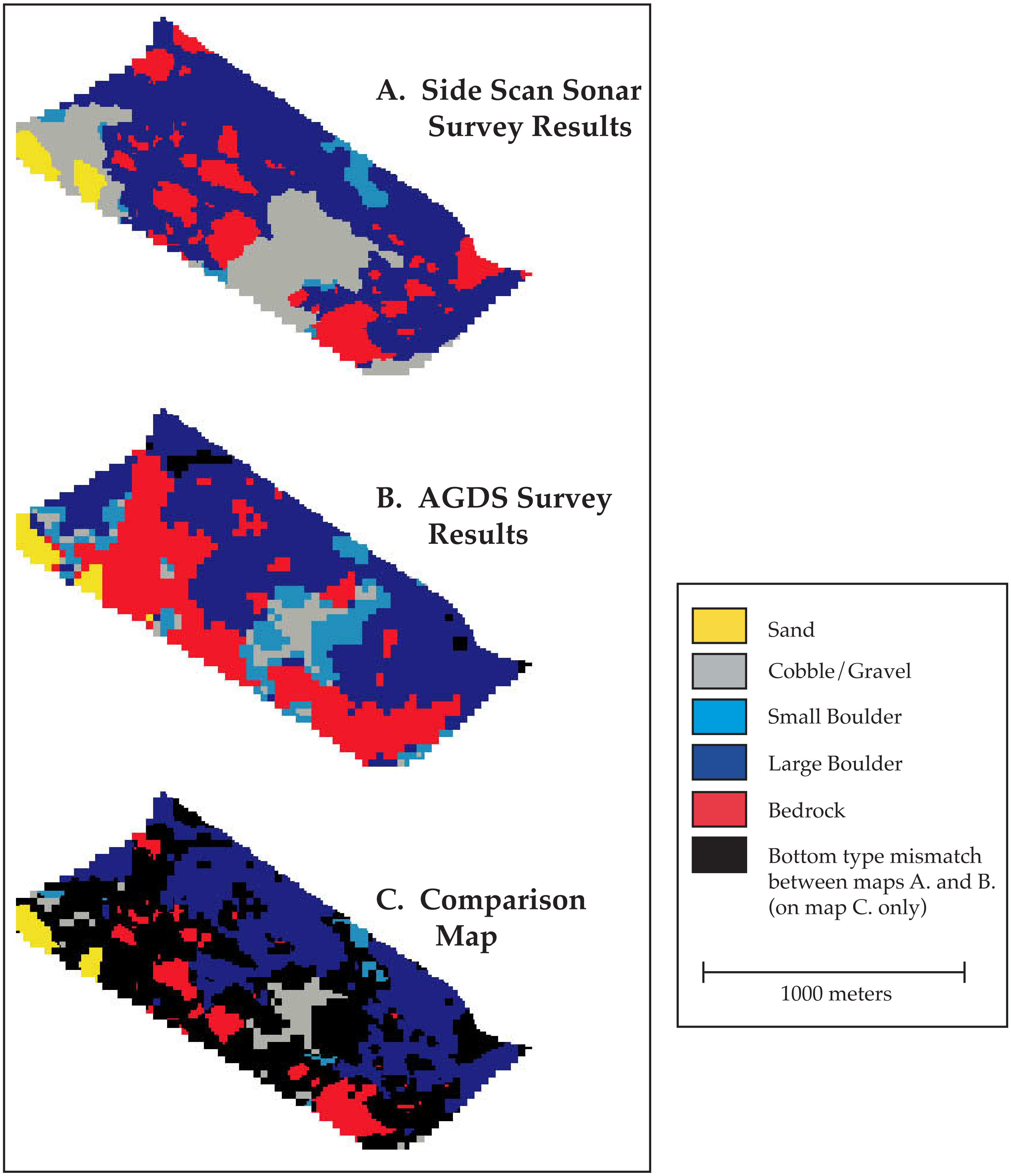


Figure 3.3.2. Comparison of side scan sonar and AGDS surveys (see Figure 3.3.1 for location of survey comparison area). A. shows the results of side scan sonar data interpretation, B. shows AGDS survey results, and map C. depicts areas where the bottom types in maps A. and B. match (colors other than black) and where they do not match (black).

Table 3.3.1. Percentage occurrence of each bottom type in the maps from Figure 3.3.2.

Bottom Type	Side scan sonar survey	AGDS survey	Comparison map	Percentage match (side scan vs. AGDS)
Sand	2.7%	2.5%	2.1%	76.2%
Cobble / Gravel	21.2%	5.2%	4.1%	19.5%
Small Boulder	3.1%	11.4%	1.3%	41.1%
Large Boulder	56.1%	48.5%	34.4%	61.2%
Bedrock	16.8%	30.9%	7.9%	47.2%
Data Mismatch			50.2%	

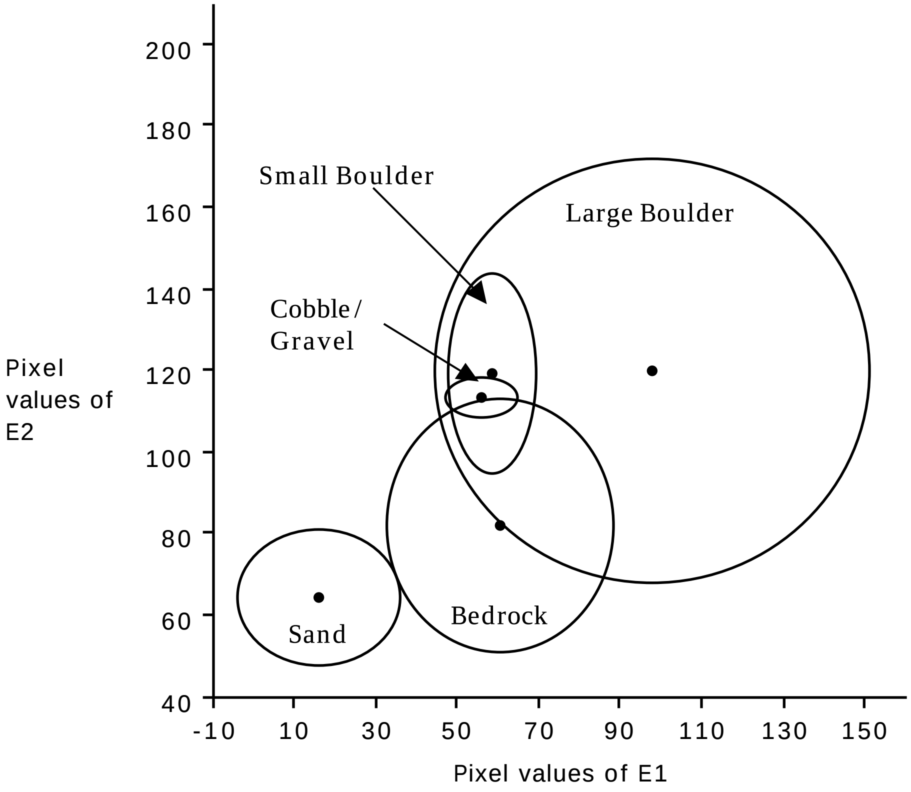


Figure 3.3.3. Cross Plot of the E1 vs. E2 principal components. Points indicate means and ovals indicate bounds of two standard deviations for each bottom-type class.

the sites occurred in areas where the side scan data indicated cobble / gravel and the AGDS classification indicated boulders. The video showed sand at these sites, suggesting that sand had migrated into these areas since the side scan sonar survey and assigning these areas to the cobble / gravel training set may have partially confounded the AGDS classification.

3.3.3 Conclusions

Comparing side scan sonar and AGDS data provides insight on the advantages and disadvantages of each survey method. The AGDS instrument is excellent for rapid surveys of bottom characteristics. It can be used at relatively high vessel speeds, instrument monitoring during the survey is minimal, and data processing time is relatively quick. However, the time required to complete a survey is proportional to the total length of the survey tracklines. Much of our study used 200 m spacing between tracklines, with the recognition that there is a degree of uncertainty about data interpolated between tracklines. For example we feel that we missed small, but important features at Cape Perpetua due to the wide trackline spacing. This can easily be solved by increasing the number of tracklines, with a resultant increase in survey time. The AGDS data lend themselves to quantitative and objective classification techniques as used in this study. Data objectivity is an important characteristic of any information used in supporting management of public resources.

A primary goal of this study was to classify rocky reef bottom types in terms of meso-scale (1-100 m) physical structure. The acoustic characteristics within individual meso-scale bottom classes can vary widely both within and between survey areas. Much of this variation can be attributed to within-class differences in fine scale rock morphology, rock geologic composition, and invertebrate and algal cover. Acoustic detection of these within-class features can be powerful tool in determining fine-scale habitat characteristics. However, the within-class acoustic variation confounded our ability to consistently differentiate bottom classes based on meso-scale physical structure. As a result, we were unable to transfer data classification parameters based on AGDS from one survey site to another, and concluded that ground truthing should be more extensive than undertaken in our study to gain full confidence in the classification results.

Side scan sonar can provide 100% coverage of the bottom, thus avoiding the uncertainties of data interpolation. Features that we missed on our Cape Perpetua survey would, most likely, have been detected by side scan sonar. Side scan sonar output is graphic in nature, and many bottom features can be intuitively recognized. However, the output is sometimes deceptive and requires careful analysis and ground truthing. The output lends itself to mapping because feature outlines or boundaries between bottom types can be directly transferred to a map base. Meso-scale reef physical structures are recognizable on side scan sonar output and are not usually significantly confounded by invertebrate cover, fine scale structure, or differences in geologic makeup. Side scan sonar has some disadvantages in that surveys and data processing are technically more difficult and time consuming than AGDS surveys. Also, the equipment is more expensive. Finally, the interpretation of side scan output is subjective in nature and does not lend itself to quantitative classification.

4. Analysis of Management and Research Needs

4.1 Background

As fisheries on nearshore rocky reefs continue to develop and competition among user groups intensifies, management programs will need to adapt to meet new challenges. At present, most regulations that apply to nearshore bottom fish are species-specific and are generally uniform along long stretches of coast. Traditional single species approaches to management need modification to account for habitat differences, fish assemblage structure, and human use on a site and reef specific basis.

The current fishery management system is poorly equipped to deal with slow-maturing, long-lived fish with sporadic recruitment, and often has problems managing mixed-species assemblages. The new requirements of the revised Magnuson-Stevens Sustainable Fisheries Act require a more conservative approach to fishery management. New guidelines require protection of stocks lacking fishery information and the identification and protection of essential fish habitat (EFH). As demersal fish stocks are fished down, management measures require a more pre-cautionary approach. Under the current management system, trip limits on species of concern are reduced. In mixed stocks, reduced trip limits often result in discarded fish when healthier stocks are pursued. In addition, managers and users now recognize the need to identify and protect essential fish habitat for marine species, but lack of information and tools to do so have prevented significant action to date.

Rockfish fisheries present a particularly difficult management problem. First, there are about 72 species of rockfish coastwide (Kendall 1991), each with different distributions, habitat requirements, life histories, and vulnerability to harvest. While there is some life history information for many species, little is known about their ecology and only a few have sufficient information to assess their stock status. Second, rockfish are particularly vulnerable to overharvest due to a number of life history characteristics (Yaklovich 1998), including:

- adults generally stay in a relatively small area and are habitat-specific,
- they are very long-lived fish (up to 140 years in age for some species),
- they reach sexual maturity at a relatively late age (3-11 years, depending on sex and species),
- recruitment success is very sporadic (often 10 years or more between successful recruitment events), and
- they often occur in mixed-species assemblages.

Existing scientific information on nearshore reefs is currently inadequate to address new management needs. Data gaps occur at the population, species, and ecosystem levels. Examples of missing information include:

- stock assessments on most species of nearshore fish,
- adequate maps of the location, extent, and composition of reefs,
- reef-specific and coastwide demographic information on many of the harvested fish species,
- fishery monitoring on a reef-specific basis,
- fishery-independent indicators of reef "health", and
- a management model that accounts for both reef-specific differences and reef interconnectivity.

The Oregon Department of Fish and Wildlife, other state agencies, National Marine Fisheries Service, and user groups have initiated regional reviews of management methods and presently are seeking ways to improve fishery stock assessments and evaluate essential fish habitats. Reviews of existing and planned research are also being conducted to identify critical research needs and integrate research efforts. Marine Resources Program of ODFW has also initiated a process of re-organization and seeks to integrate research efforts across project boundaries. In 1998, the Marine Habitat Project coordinated with the Marine Recreational Fisheries Project in order to collect habitat information in conjunction with biological information on Seal Rock and Cape Perpetua Reefs.

4.2 Research Framework

Clearly, an integrated research framework is needed to develop scientific information required to meet new management challenges. Designing appropriate research for nearshore reefs begins with identifying management needs and translating those needs to research questions. Once the broad research questions are identified, specific research goals, objectives, and study plans can be developed to begin answering the questions.

Taking these first steps in developing a research framework will ensure all research is placed in a management-needs context, and that individual research projects can be integrated toward addressing common goals. The word "research" is used broadly here to refer to any type of information gathering activity on nearshore reefs (monitoring, inventorying, experimental research, literature reviews, interviews with experts, retrospective studies, etc.)

The following section presents the steps of identifying overall management needs, translating those into a series of management questions, and identifying the broad research questions that will provide a framework for addressing management questions.

4.2.1 Overall Management Need

The overarching management need is to maintain nearshore reef ecosystems so that they provide:
- natural functions and processes,
- sustainable fisheries, and
- aesthetic and recreational resources.

4.2.2 Management Questions

The following are examples of nearshore reef management questions:

1) What are the appropriate management measures to ensure sustainable fisheries on nearshore reefs?
2) How are nearshore fisheries affecting localized fish stocks on nearshore reefs?
3) What are the ecological effects of other (non-fishing) human activities on nearshore reefs?
4) How do natural environmental cycles affect fishery and other resources on nearshore reefs?
5) How do management actions on nearshore reefs affect the larger marine system?
also: How do management actions in the larger marine system affect nearshore reefs?

4.2.3 Broad Research Questions

An integrated series of research projects is needed to begin addressing the above management questions. Broad research questions that identify information necessary for management, provide an organizational context for a integrated research program. As an example, Table 4.2.1 lists research questions classed into 5 major categories, and indicates which management questions are addressed, which research is prerequisite to a particular question, and whether the research is best conducted at a regional or site-specific level. To be of direct use in designing individual research projects, these questions need to be further broken down into specific research objectives. Developing a complete framework, including a full list of research questions and objectives is beyond the scope of this report; this task would require the combined expertise of a diverse group of scientists, managers, and resource users. Oregon and California are currently proposing that NOAA sponsor an effort to develop such a research framework for nearshore studies.

Table 4.2.1. Examples of broad research questions and their relationship to management questions listed in Section 4.2.2.

	Research Question	Related Mgt. Question	Prerequisite Research	Regional (R) or Site Specific (S)
1	**System-Wide Inventory**			
1.1	What is the extent and distribution of rocky reefs in the nearshore environment?	1,4,5		R
1.2	What is the habitat composition of nearshore reefs?	1,2,3		R, S
1.3	What is the distribution of fish populations and assemblages on the nearshore reefs?		1.1	R
1.4	What are the characteristic invertebrate and algal communities of nearshore rocky reefs?	3,4	1.1, 1.2	R
2	**Focused Individual Reef Research**			
2.1	What is the total fish abundance on reefs?	1,2,4	1.1,1.2,2.2	R, S
2.2	What are the fish species-habitat associations on the reefs?	1-5	1.2	S
2.3	Are there differences in fish density and species composition on heavily-fished reefs vs. lightly-fished reefs?	1,2	1.2	S
2.4	Are there size / age composition differences on fishes in heavily-fished reefs vs. lightly-fished reefs?	1,2	1.2	S
2.5	What are the characteristics of other ecological relationships within the rocky reef environment (trophic relationships, etc.)?	1,3,4,5		R, S
2.6	What are the key factors that make a reef productive for fish?	1,2,4	2.1-2.5	R,S
3	**Fishery Research**			
3.1	What are the harvest levels on both a reef-specific and area-wide basis?	1,2	1.1	R, S
3.2	What are the demographic characteristics of selected species in the catch on both a reef-specific and area-wide basis?	1,2	1.1	R, S
3.3	What are the current and predicted future effort levels?	1,2		R, S
3.4	What are the most effective management models from a biological, social, and economic basis?	1,5		R
4	**Interconnections among Reefs and the Larger Marine System**			
4.1	What are the primary oceanographic factors influencing nearshore reefs?	1,3,4,5		R
4.2	Are heavily-fished reefs "re-stocked" through migration of adult or subadult fish from other areas? (or a more general question: What are the primary natural mechanisms of re-stocking fished reefs?)	1,4,5	1.1,1.3, 3.2	R
4.3	What are the transport patterns of nearshore fish larva?	4,5	4.1	R
4.4	What are the movement patterns of juvenile, subadult, and adult fish on nearshore rocky reefs?	1,2,5		R
5	**Monitoring**			
5.1	What are the best indices or indicators for monitoring reef "health"?	1-5	1.2,1.3,2.1,2.2, 2.5	R
5.2	What are the baseline values of the indices?	1-5		R
5.3	How have the values changed over time?	1-5		R

4.3. Applications of Reef Habitat Characterization in Nearshore Fisheries Management

Current ocean fishery management in the northeast Pacific relies primarily on information pertaining to individual species, including catch, abundance, and demographic information. Marine habitat information is now playing a larger role in fishery management as new requirements are placed on the management system (e.g., EFH provisions of the revised Magnuson Stevens Act), and as increasing fishing pressures push the management system toward a need for site-specific strategies. This is especially true in nearshore rocky reefs where the habitat is very finite and accessible, and where many species appear to have localized life styles.

Characterizing and mapping nearshore rocky reef habitats has a number of applications in research and resource management, including:

1) allowing reef areas to be subdivided along the coast in a biologically-meaningful fashion for research or management purposes,
2) providing a means to determine the area affected by a biological impact (from fishing or non-fishing activities) in proportion to the total habitat area available,
3) being useful for expanding habitat-specific fish sampling results to larger areas (e.g., expanding habitat-specific density estimates to reef-specific population estimates),
4) providing an ecologically-meaningful basis for stratifying biological sampling,
5) providing a standard for characterizing, describing, and comparing reefs,
6) providing a spatial context for analyzing and summarizing biological information, and
7) developing management systems that account for both site-specific and coastwide needs (e.g., a system of marine refugia, or a system of regulations based on the reefs' capacity to sustain fishing pressure).

Developing habitat information to the level required for the above applications requires a significant data gathering effort. First, a base GIS needs to be developed by incorporating available existing information on nearshore reefs, including bathymetry data, bottom characterization data, locations of kelp beds and offshore rocks, fishery catch and biological information, and information from fishers knowledgeable of local reef areas. Although this information will be useful to provide a basis for a nearshore reef GIS, its resolution will not be fine enough for most management applications. Specific surveys will be needed, requiring designing a survey methodology adequate for the types and scale of habitat information needed, designing an appropriate habitat classification system, and exploring fish / habitat relationships. Data gathering methods and conventions should be coordinated and consistent coastwide.

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