Coastal Zone Management Section 309 Grant:

1996 Kelp/Reef Habitat Assessment

Final Grant Report
Contract No. 96-52

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December 31, 1996

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1. Introduction

Oregon is facing increasing pressures to develop the living marine resources of nearshore subtidal rocky reef areas, particularly off the south coast where community economies depend, in part, on a natural resource base. Much of the increased pressure has resulted from a shift toward nearshore reef fisheries due to the dramatic decrease in traditional salmon fisheries. Emerging or proposed marine resource uses include kelp (*Nereocystis luetkeana*) harvest, fisheries for previously under-utilized species, propagation or enhancement of sea urchins, abalone, and other species, and increased and diversified recreational uses.

Because the nearshore reefs are in state waters, Oregon is responsible for managing 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. We need to develop this information for making sound resource management decisions.

Effective management of kelp harvest, along with other rocky reef resource uses, requires an understanding of the natural processes in the reef ecosystem. Kelp harvest may affect future kelp production, and have secondary effects on organisms that depend on the kelp forest environment for habitat or food. Detecting these secondary effects requires knowledge of the relationship among structural and functional components of the ecosystem. While traditional species-specific research projects can contribute to this knowledge, a single-species research approach is inadequate to address all potential impacts of human activities, especially the important secondary effects. Research needs to be structured to examine ecosystem relationships.

We initiated a 5-year kelp/reef research project in 1995 to gather information necessary for managing kelp harvest and other nearshore reef uses. This report summarizes work completed during 1996 (year 2 of the study). The study area included Blanco Reef, Orford Reef, Redfish Rocks, and Humbug Mountain Reef, and Rogue Reef. Our 1996 research focused on examining the relationships among fish communities and their habitat, estimating kelp bed biomass, and examining seabird use of kelp beds.

This report presents a summary of 1996 work in six sections:

Physical Parameters
Kelp
Fish
Seabirds
Recommended Changes to Sampling Methods
Management Analysis.

1.1 Grant Tasks

A Coastal Zone Management Section 309 grant helped fund the 1996 kelp/reef work. This document and related reports summarize work performed under the grant. The grant outlined three work tasks:

Task A: Field Sampling Plan,
Task B: Field Studies of Kelp Harvest Impact Assessment, and
Task C: Management Analysis.

Each of the tasks were further divided into subtasks. The discussion below lists reports or report sections that summarize work on each grant subtask.

Task A, Subtask 1: Analyze 1995 field work - Our 1995 grant report describes the 1995 field work and presents some analyses. Appendix A, below, presents additional analyses.

Task A, Subtask 2: Design long-term program for examining nearshore reef ecology - We contracted with Dr. Deborah Brosnan to develop the long-term program. The program is summarized in "Dynamics of kelp (*Nereocystis luetkeana*) community, and impacts of harvesting on the community."

Task A, Subtask 3: Develop sampling design for 1995 work - Our July 8, 1996, grant progress report summarizes the sampling plan. The "methods" subsections of sections 2 through 5, below, provide further detail on the sampling.

Task B, Subtask 1: Acquire kelp aerial photos - Section 3, below, describes the aerial photography.

Task B, Subtask 2: Estimate kelp biomass - Section 3, below, presents the kelp biomass analysis.

Task B, Subtask 3: Conduct field work - Sections 2 through 5, below, summarize the field work.

Task B, Subtask 4: Analyze data - Sections 2 through 5, below, present data analyses.

Task C, Subtask 1: Prepare management analysis - Section 7, below, presents the management analysis.

Task C, Subtask 2: Prepare report - This report fulfills this subtask.

2. Physical Parameters

2.1 Methods

We recorded physical water attributes both temporally, using moored, continuously-recording light and temperature sensors, and spatially, using a CTD deployed periodically along transects. StowAway® light intensity and temperature data loggers moored at Orford Reef (42° 47' 1.2"N, 124° 35' 19.8" W) from August 1 to September 11, 1996 provided the continuously-recorded data. A set of meters fixed at 15.4 m depth recorded bottom conditions and an additional light meter attached to the mooring buoy measured ambient surface light. Similar meters placed at Redfish Rocks became detached from their mooring and lost during the course of the study. All meters recorded data once every 10 minutes. We used the program LogBook® to download the data and STATISTICA® (StatSoft, Inc.) to process the data.

We examined spatial variation in water attributes along transect lines on two dates, August 20 and 27, 1996. The transect lines ran north to south (approximately on a heading of 320°) and east to west (90°) across Orford Reef (Figure 2-1). Each transect had six to seven sampling stations located approximately 1 km apart. At each station we obtained water column profiles of conductivity (mmho/cm), temperature (°C), and pressure (decibars) using a Seabird Electronics® CTD (model SBE-19). Salinity measurements (in practical salinity units, or parts per thousand) and depth (in meters) were derived from conductivity and pressure readings, respectively. The instrument also measured underwater light levels using an attached Biospherical Instruments QSP-200® quantum scalar irradiance meter. The meter measured light within the 400-700 nm bandwidth, the portion of the light spectrum referred to as photosynthetically active radiation. The manufacturers calibrated all sensors prior to the field season.

We deployed the CTD by hand from the down-current side of the survey vessel, allowing the device to freefall to the bottom to ensure a consistent rate of descent and to minimize vertical movement due to vessel pitch and roll. Extra weight added to the instrument cage helped to keep the instrument vertical. We configured the CTD to record data on all sensors twice per second to obtain detailed vertical profiles of the water column during instrument freefall.

CTD data processing employed the application Seasoft® (ver. 4.012, SeaBird Electronics, Inc.). We used the program, Spyglass Transform® (ver. 3.02, Fortner Research, Inc.) to construct interpolated contour profiles of the physical variables. Satellite images of sea surface temperature off the Oregon coast and wind measurements from Cape Arago provided additional material to help interpret our data.

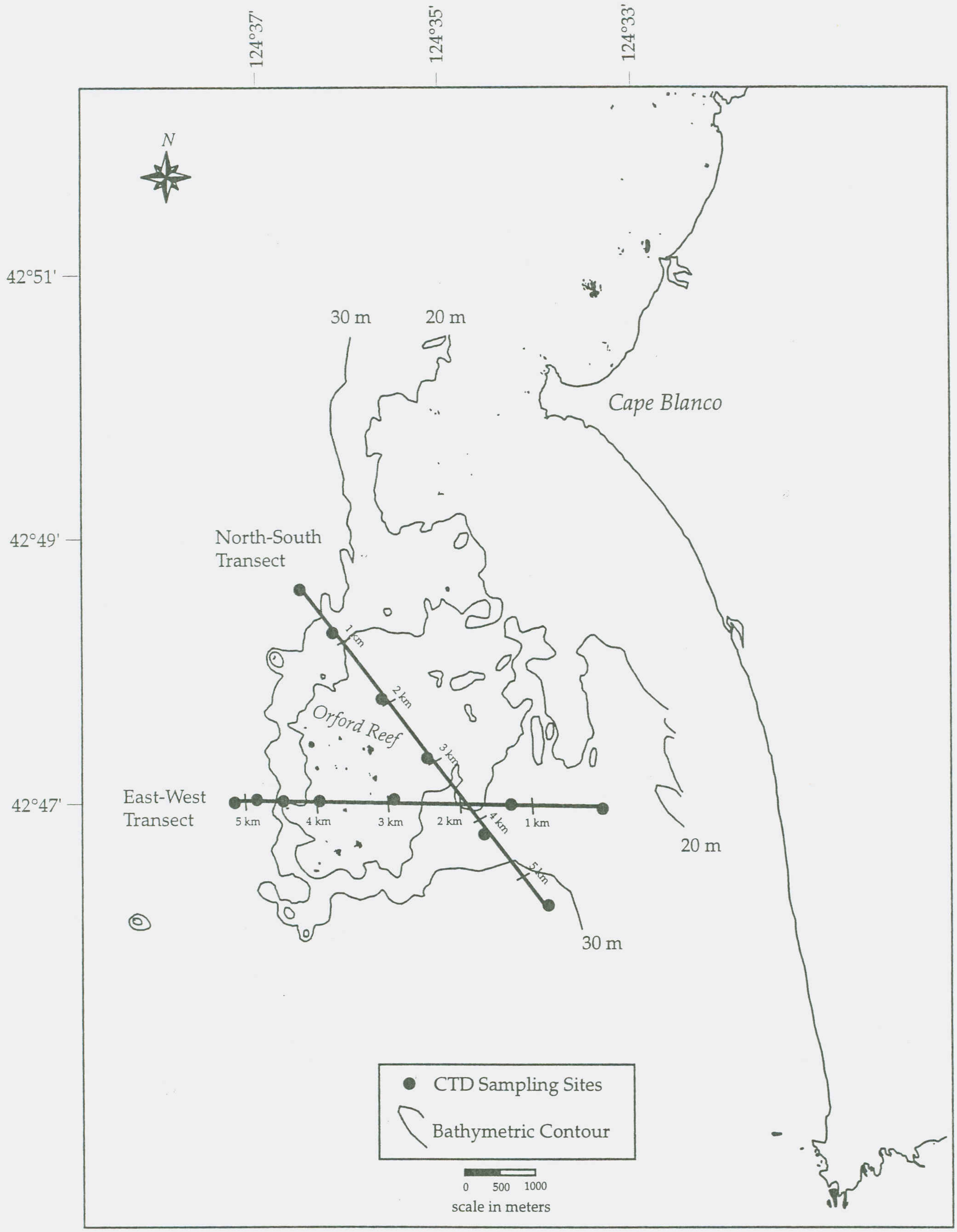


Figure 2-1. CTD transects and sampling sites on Orford Reef. Kilometer marks along the transects correspond to distances shown on Figure 2-6.

2.2 Results and Discussion

The temperature dataset from the moored instruments showed both daily, or shorter, fluctuations of about 0.5° C, and warm water events with changes of 2- 3° C over a few days (Figure 2-2). The short-term fluctuations were relatively regular and may have resulted from tidal changes. Tides can regularly alter the depth of the thermocline, resulting in observed temperature fluctuations from a instrument moored at a fixed depth. The warm water events near the end of the sampling period (Figure 2-2) probably resulted from changes in wind-driven nearshore water circulation. As winds blow southward along the coast, surface waters tend to move offshore and cold, deep bottom water upwells to replace the displaced surface waters. Winds blowing water northward have the opposite effect; warm, lower salinity surface waters move from offshore to the nearshore and downwelling may occur.

Wind data from Cape Arago's weather station (60 km to the north) and NOAA/NODC sea surface temperature satellite imagery provide evidence that the warm water peaks resulted from relaxation of upwelling. A period of north winds that lasted for a few days changed and blew from the south on August 25 (Figures 2-3 and 2-4). The speed of the south winds may have been enough to terminate upwelling and begin to establish a downwelling event. On August 22, the cold water masses at Cape Blanco and other localized upwelling areas extended southward (Figure 2-5) under the influence of north, upwelling-favorable winds. The absence of this flow on the upwelled water mass off Cape Blanco on August 27 (Figure 2-5) was likely due to a shift in wind direction. Upwelling intensity probably also decreased. While the image on August 27 (Figure 2-5) does not appear to show any obvious downwelling, the warmer surface waters that were residing offshore during upwelling appear to have moved toward shore.

Although upwelling-induced water movements provide a plausible explanation for the observed temperature changes, other explanations are possible. For example, Cape Blanco significantly interrupts longshore water movement, creating medium-scale gyres and other complex water structures. Movement of these water structures past fixed recording instruments would reflect as temperature changes. Longer term measurements are needed to more fully characterize local water properties.

Figure 2-6 displays the cross-reef temperature profiles recorded on August 20 and 27, 1996. The east-west transects are cross-sections of the prevailing longshore current; the north-south transects are side views of the longshore current. The plots of temperature indicate a reversal of structure between the two sampling dates (Figure 2-6). Warm, lower salinity water within the reef on August 20 becomes cold, higher salinity water on August 27. This is the reverse of the larger-scale temperature changes indicated on the satellite imagery (Figure 2-5).

The CTD transect data suggest that water passing Orford Reef may be trapped for some time within the reef before exiting. The profiles imply that cold, upwelled

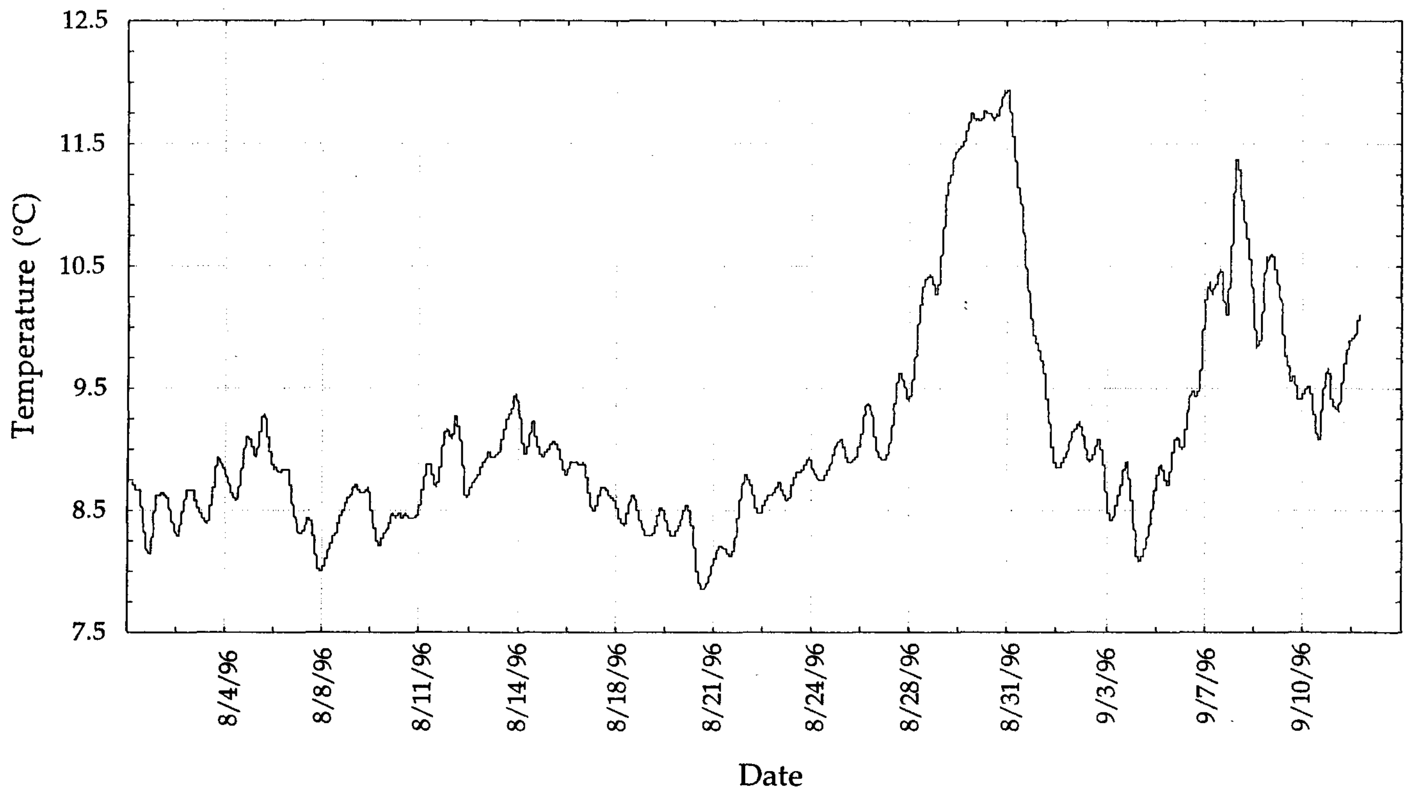


Figure 2-2. Temperature time series recorded from a moored data logger at a depth of 15.4 m on Orford Reef. Data are smoothed using a 50-point moving average.

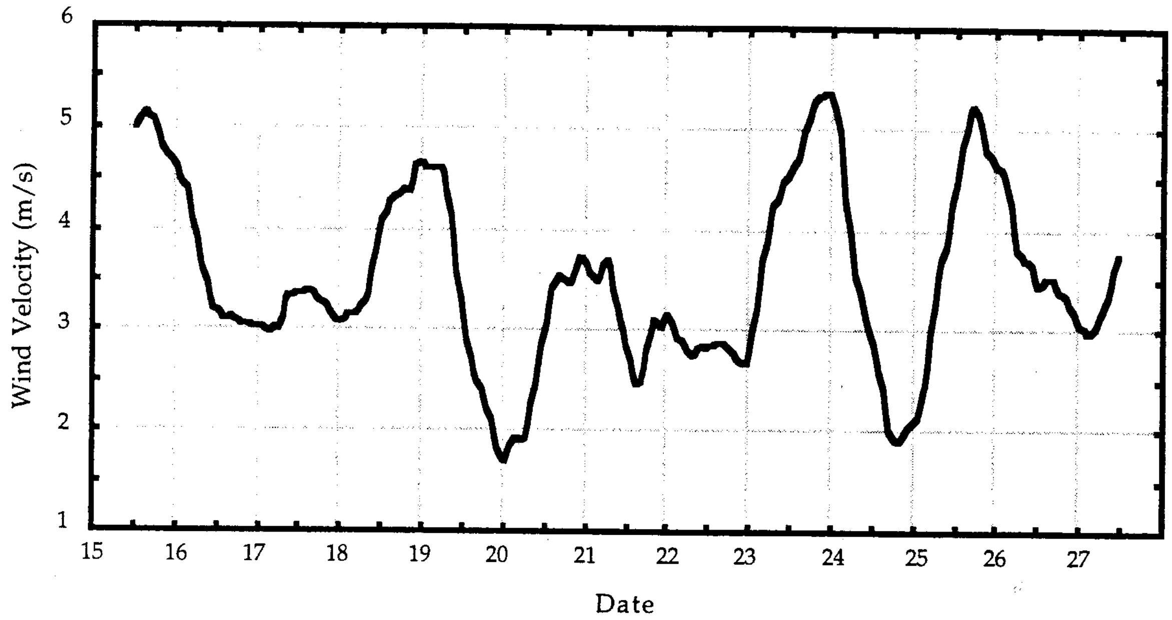


Figure 2-3. Wind velocity at Cape Arago. Dates represent days in August 1996. Data are smoothed using a 24-point moving average.

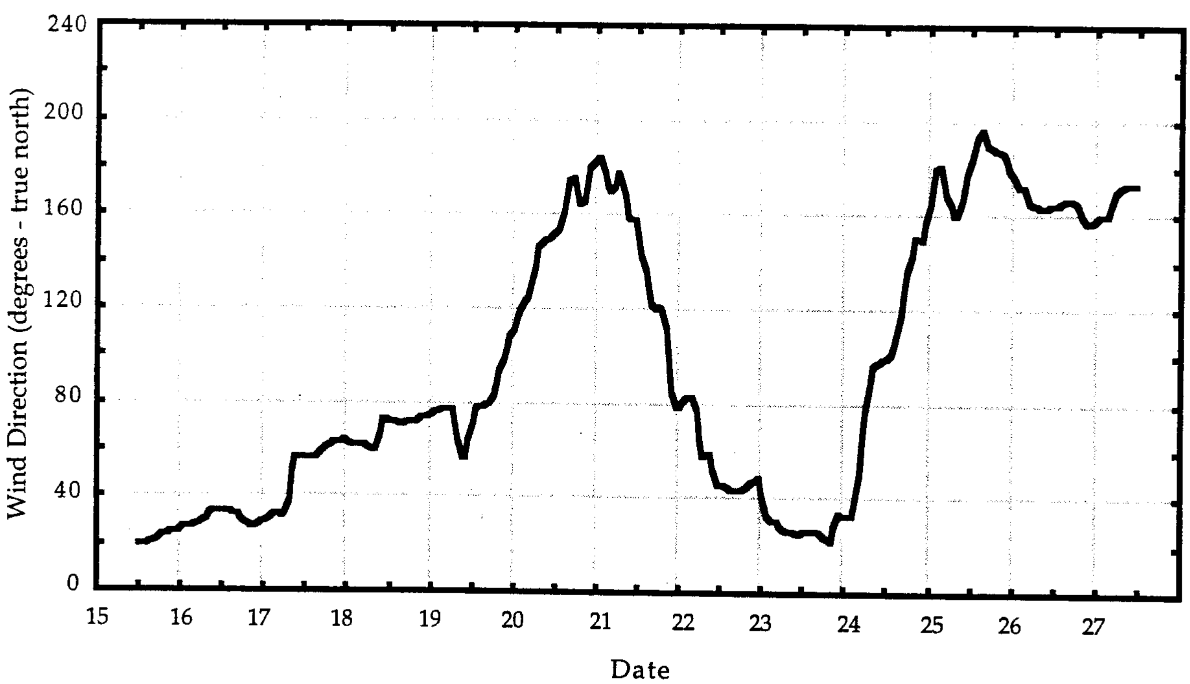
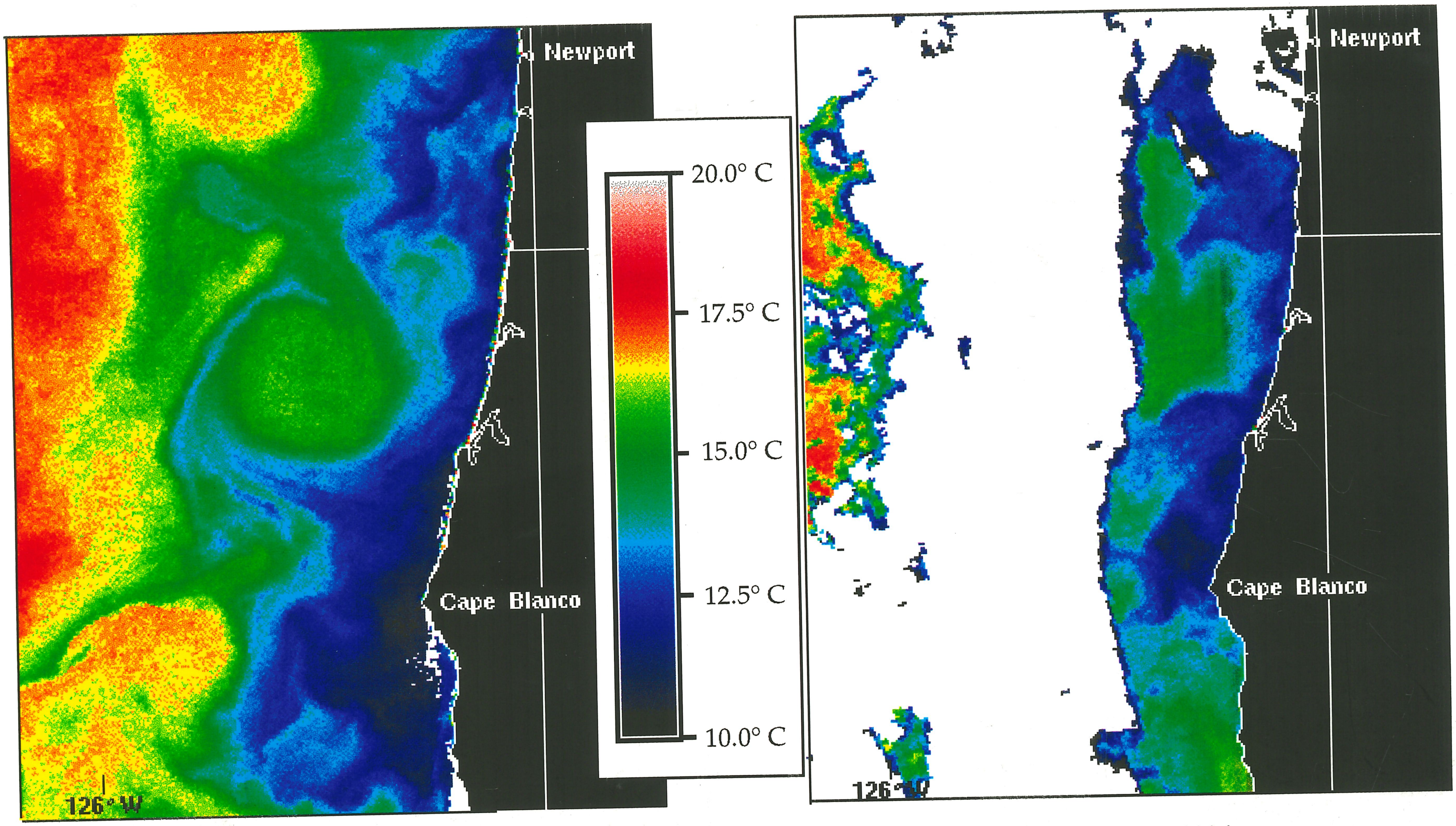


Figure 2-4. Wind direction at Cape Arago. Dates represent days in August 1996. Data are smoothed using a 24-point moving average.



August 22, 1996

August 27, 1996

Figure 2-5. August 22 and 27, 1996, satellite images of sea surface temperature. White areas on the images represent cloud cover.

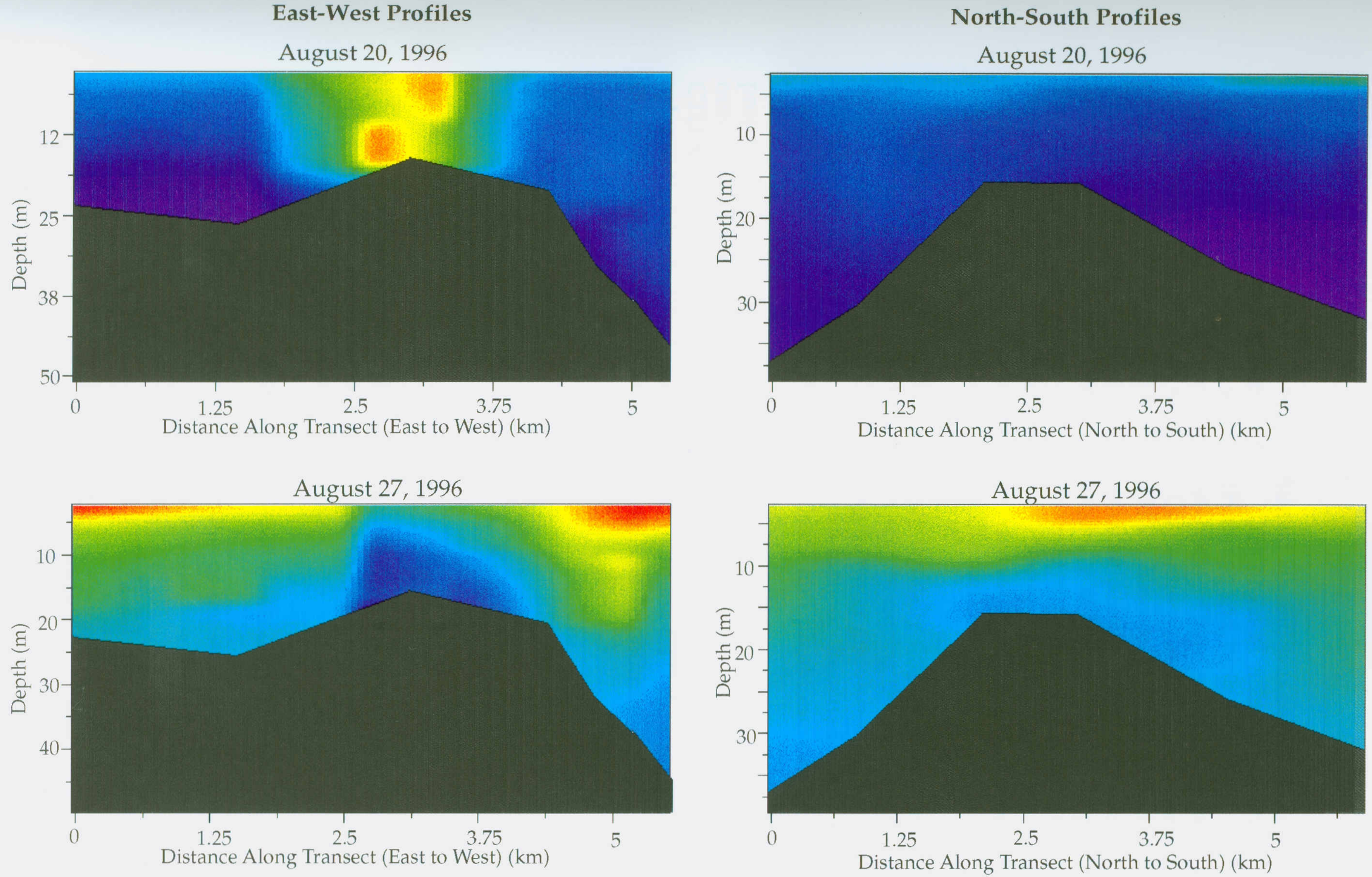
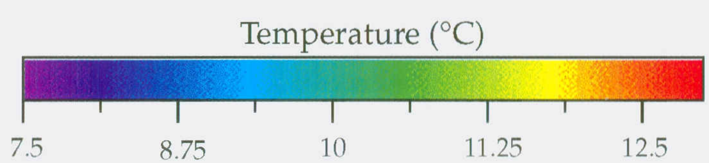


Figure 2-6. Temperature profiles derived from CTD transect data. The temperture bar to the right applies to all profiles.



water traveled around the reef on August 20, and was retained by August 27 when surrounding waters became warmer. This physical retention of water has been demonstrated in coral reef systems (Hamner and Wolanski 1988); not much is known about temperate reef water retention. There is evidence that giant kelp forests (*Macrocystis*) off of southern California slow the longshore movement of passing water (Jackson and Winant 1983). *Nereocystis* kelp extends down to about 20 m at Orford Reef. The east-west contour profiles show that the "retained" water only penetrates to about 20m. This might be evidence that the kelp beds slow down the water. However, since *Nereocystis* beds were not very extensive at Orford Reef this season, the bathymetric relief and offshore sea stacks may have contributed enough friction to slow the longshore current. Both factors should be considered in any future oceanographic sampling of the reef.

Nearshore waters off Cape Blanco typically display strong upwelling, with frequent supplies of cold nutrient-rich waters during the spring and summer months (Mann and Lazier 1991). A lag in water circulation or water retention may contribute to Orford Reef's biological production. Retained water over a reef system would increase residence time of nutrients and planktonic organisms. This could benefit kelp, invertebrates, and fish due to retention or longer residence times of propagules, larvae, and prey organisms. Further sampling of the waters inside and outside of Orford Reef would prove fruitful in testing a water-retention hypothesis. CTD casts and simultaneous plankton tows of the surface layer and the water column (using stratified tows based on real-time CTD data acquisition) would provide enough information to evaluate this hypothesis.

3. Kelp

3.1 Methods

A primary focus of the study was to develop data and methods for estimating total kelp (*Nereocystis leutkeana*) biomass in the study area. We computed kelp bed biomass using the following formula:

biomass (kg/bed) = plant weight (kg/plant) x plant density (plants/ha) x bed surface area (ha/bed).

The following formula provided estimates of the standard error of the biomass figures:

$$V_{(biomass)} = \{[(mean_{(weight)})^2 * V_{(density)}] + [(mean_{(density)})^2 * V_{(weight)}] - (V_{(weight)} * V_{(density)})\} * (\text{kelp surface area})^2$$

(Raj 1968). Where V denotes variance of the mean. The standard error is the square root of $V_{(biomass)}$.

We performed a re-sampling (bootstrapping) analysis to examine the validity of the standard error estimates and estimate confidence intervals using what is known as the "percentile method" (Efron 1982; Efron and Gong 1983). Like other re-sampling techniques, this method allows for estimating confidence intervals without making specific assumptions of the underlying distribution of the data. The procedure involved first creating datasets consisting of 500 mean weight and percent cover values by randomly re-sampling the original data, with replacement. A third dataset was created to represent the error in the regression relationship between kelp plant percent cover and density. This dataset consisted of a random normal distribution with a mean of 0 and a standard deviation equal to the standard error of the regression. The datasets were then combined randomly using the biomass estimation formula for a total of 250,000 iterations. The 2.5 and 97.5 percentiles of the large biomass dataset provide an estimate of the upper and lower 95% confidence intervals.

The discussion below outlines methods used to estimate each of the three parameters in the biomass estimation equation (above): plant weight, plant density, and kelp bed surface area.

We sampled both the upper portion of the kelp plant and whole plants to obtain an average weight per plant. From September 11-13, 1996, we collected a total of 171 upper plant portions from Redfish Rocks, Orford Reef, and Blanco Reef, and 40 whole plants from Redfish Rocks and Orford Reef. The upper plant portions were cut below the pneumatocyst (bulb) and bagged in plastic garbage bags so that they could be weighed individually. Divers collected whole plants by prying the holdfast from the substrate and securing groups of plants to a line and buoy. The plants were then brought onto the boat and individually bagged. Prior to weighing the upper portions of the plant, we trimmed each stipe to 10 cm below the base of the bulb. The whole plants were divided into top (trimmed 10 cm below bulb), stipe, and holdfast. We weighed each section separately, and measured lamina (blade) and stipe lengths.

Color infrared aerial photos provided the basis for computing kelp density and surface area. We contracted with Bergman Photographic, Inc., to fly 8 pre-planned flight lines, providing coverage of Orford, Blanco, Redfish, Humbug, and Rogue Reefs. The photos were taken with a forward-motion-compensating aerial mapping camera at a scale of 1:7200 (flight altitude of 3600'), on September 24, 1996, between 14:36 and 15:34, and at tidal levels ranging from +1.7 to +2.7 feet.

We estimated kelp plant density using the KIM-1 method (Foreman 1975, Foreman and Cabot 1979, Foreman1984). Generally, the method involves first estimating kelp canopy percent cover using a point-intercept method, and then converting the percent cover to density (plants/10m^2) using with the following regression formula:

Density = 3.745 + 0.5095 * % cover (Foreman and Cabot 1979).

The following formula provided an estimate of the standard error of the density values:

$$\text{Standard Error} = \sqrt{(0.5095)^2 * V_{(\% \text{ cover})} + \varepsilon}$$

Where V denotes variance of the mean (variance/sample size) and ε = average regression residual mean square.

A dissecting scope equipped with a 10x10 grid eyepiece provided the means to estimate percent cover. The grid was randomly positioned over a photographed kelp bed at a magnification of approximately 14x, and the total number of grid intersections overlaying any part of a kelp plant were recorded. The following formula provides an estimate of percent cover:

percent cover = (grid intersections overlaying kelp) / (total grid intersections)

The observer repeated this procedure up to a pre-determined sample size for each photograph, making sure to mark the location of each grid count to prevent overlap. The number of samples per photo were apportioned according to the total surface area of kelp; the sampling rate was approximately 1 grid per 0.73 ha of kelp. We performed the procedure twice to test if the method provided repeatable results.

Kelp bed mapping and surface area estimation followed a three-step procedure: interpreting aerial photos to define kelp beds, digitizing the kelp beds onto a GIS, and using the GIS to compute surface areas. The photos were interpreted to draw polygons around discrete clusters of kelp plants. Clusters of kelp plants separated by more than 0.2 in on the photos (37 m on the ground) were defined as individual beds. Single plants separated by more than 0.2 in from a main cluster were not encompassed in a polygon. We classified kelp polygons as either low density or high density according to the color and density of kelp on the photos (kelp is orange on color infrared photos). Low density polygons consisted of plants that appeared individually distinguishable, were light orange in color, or had blue water visible throughout the orange mass of plants. High density beds appeared dark orange and solid in appearance, representing overlaying plants, and had virtually no blue water visible within the orange mass of plants.

Digitizing the kelp bed polygons followed procedures to minimize errors in horizontal position and scale. One of three methods provided horizontal control for each photo:
1) establish control points on our GIS map using recognizable features such as rocks and road intersections that correspond to identical features on the aerial photographs,
2) if a photo had fewer than 4 common features, we "bridged" new control points from an adjacent photo with adequate control, using shared features in the area of photo overlap,

3) bridge control points from our 1993 rocky intertidal photos that had been previously horizontally controlled from USGS Orthophotos (used in the Humbug Mountain area).
Bridging reduces the positional accuracy due to the inherent error of the original control points plus any error in the bridged points. Once control points were established, photos were registered to the digitizer and polygons traced. To correct of x,y scale distortions inherent in any aerial photo, we transformed the digitized elements using an affine transformation algorithm executed by MapGrafix® software. The transformation analysis provided three statistics: 1) residuals, describing the error between the location of the control points and the corresponding points on the photo, 2) variance, describing the uniformity of error through all control points, and 3) transformation ratio, describing the amount of distortion that occurs along the x and y axis. Before completing the transformation we examined the statistics and rejected control points with residuals of than 13 meters.

We computed surface areas from affine-transformed polygons if four or more acceptable control points remained on the photos. When fewer than 4 good control points remained, the transformation resulted in a potentially high degree of x-y distortion of the polygons. We used the untransformed polygons to obtain surface area in these cases. We created kelp bed maps by merging the digitized kelp polygons with our existing GIS map of Oregon marine resources.

In addition to sampling kelp to estimate biomass, we also gathered samples to record sori development. The sori sampling involved cutting kelp plants just below the bulb, recording number of sori, number of blades, maximum blade length, sample weight, and bulb diameter. We sampled five plants per bed at a total of 10 beds from July 23 - September 13, 1996.

3.2 Results and Discussion

3.2.1 Kelp Plant Weight

The weight of the upper portions of the kelp plants provides the appropriate information for estimating harvestable biomass because only the portion of the plant at the surface is normally harvested. We first needed to determine the best way to pool kelp weight data in order to compute appropriate means and variances for use in estimating biomass. Should statistical tests show no difference in plant weights among beds, we could pool the data for mean kelp weight. Alternatively, if there were significant differences, we would need to keep the weights separate. We compared weights by bed and reef using analysis of variance (ANOVA) and Kruskall-Wallace tests. The ANOVA requires that data have a normal distribution and homogeneous variances. The plant weight data were positively skewed, with Redfish Rocks appearing to exhibit greater positive skewness than Blanco or Orford Reefs. The skewed data appeared to have been a result of sampling only plants large enough to reach the water surface. Sampling all stages of the plants would probably result in a normal distribution. Instead, sampling surface plants only truncated the lower part of the distribution, resulting in positively-skewed data. Log-transforming the data gave the best approximation of normality.

The ANOVA analysis of log-transformed weights by reef showed that Redfish Rocks plants were significantly lighter than those on Orford or Blanco Reefs ($p<0.0000001$), and that Blanco and Orford Reef plant weights did not differ significantly ($p=0.973$). The assumptions for homogeneity of variances and normality were violated, but not radically. The ANOVA of the log-transformed weights by bed was more complex. Redfish Rocks plants were still consistently lighter than those at Orford and Blanco Reefs (all $p<0.05$). Within Orford Reef, plants from bed #4 were significantly lighter than those from bed #5 ($p=.003$) and bed #6 ($p=0.0000075$). The assumptions for homogeneity of variances and normality were also violated in this test. Because the ANOVA assumptions were violated, we conducted Kruskall-Wallace tests by reef and bed to confirm the results. Differences by both reef and bed were highly significant ($p<.0001$), and mean ranks were consistently lowest for the Redfish Rocks kelp.

Based on the statistical analyses, we decided to pool Orford and Blanco Reef data, and keep Redfish Rocks plant weights separate. Because the Redfish Rocks kelp represented such a small portion of the total kelp (about 0.2%), we decided to use the pooled Orford and Blanco plant weights to represent Humbug Mountain and Rogue Reefs where no plant samples were taken. The biomass estimation used the following plant weight data:

1) Orford, Blanco, Humbug, and Rogue Reefs	Mean = 5.64 kg Sample Size = 111 Variance = 11.36 Standard Error = 0.32
2) Redfish Rocks	Mean = 2.19 kg Sample Size = 60 Variance = 2.35 Standard Error = 0.20

The 95% confidence interval for Orford and Blanco Reef kelp amounted to +/-0.633 kg, or 11% of the mean. A power analysis of the Orford and Blanco data indicated that a sample of 37 plants would still be expected to yield 95% confidence intervals of +/- 20% of the mean. Thus, sampling can be decreased if errors up to 20% are considered acceptable.

3.2.2. Kelp Plant Density

Table 3-1 summarizes kelp percent cover and density. Since this represented the first time our staff has performed this type of analysis, we conducted the percent

Table 3-1. Kelp (*Nereocystis leutkeana*) plant percent cover and density for two trials at estimating percent cover.

Reef	Mean Percent Cover	Sample Size	Standard Error of Percent Cover	Density Plants/ha	Standard Error of Density
Trial 1					
Blanco	8.99	42	0.85	8324	209
Orford	9.23	77	0.64	8446	151
Redfish	25.17	6	6.11	16569	1354
Humbug	6.05	18	0.90	6828	356
Rogue	14.13	99	0.94	10945	125
Trial 2					
Blanco	6.96	43	0.51	7290	223
Orford	9.95	84	0.64	8813	144
Redfish	12.62	6	5.44	10177	1224
Humbug	4.85	18	0.69	6214	349
Rogue	10.48	84	0.82	9084	147

cover estimates twice to ascertain if the procedure would yield repeatable results. An analysis of variance showed that, within a reef, trial 1 and trial 2 percent cover estimates differed significantly ($p = 0.0002$). The difference between the two trials suggests that further work is needed to test the repeatability of the density estimation methods.

3.2.3. Kelp Bed Maps and Surface Area

Kelp bed maps (Figure 3-1a, b, and c) show the location of kelp in the study area and Table 3-2 provides kelp bed surface areas. Nearly all of the aerial photos for Blanco, Orford and Rogue Reefs had horizontal controls within acceptable error limits. Only 4 photos had residuals greater than 10 meters. The transformation ratio was nearly 1:1 for most photos. Surface area differences between most affine-transformed kelp polygons and non-transformed polygons were less than 2%. Photos in the Humbug Mt. and Redfish Rocks areas were poorly controlled, resulted in a high degree of distortion. Surface area differences between affine-transformed kelp polygons and non-transformed polygons were about 45%. We assumed that the non-transformed maps gave the truest surface area calculations for photos with poor horizontal control. Affine-transformed polygons from these photos were incorporated into the map for display purposes, but surface area calculations in Table 3-2 were from non-transformed polygons. Table 3-2 also compares surface area of kelp beds in a 1990 survey with 1996. Total 1996 kelp bed surface area amounted to only about 29% of 1990.

Figure 3-1a. 1990 and 1996 kelp beds on Orford, McKenzie's, and Blanco Reefs.

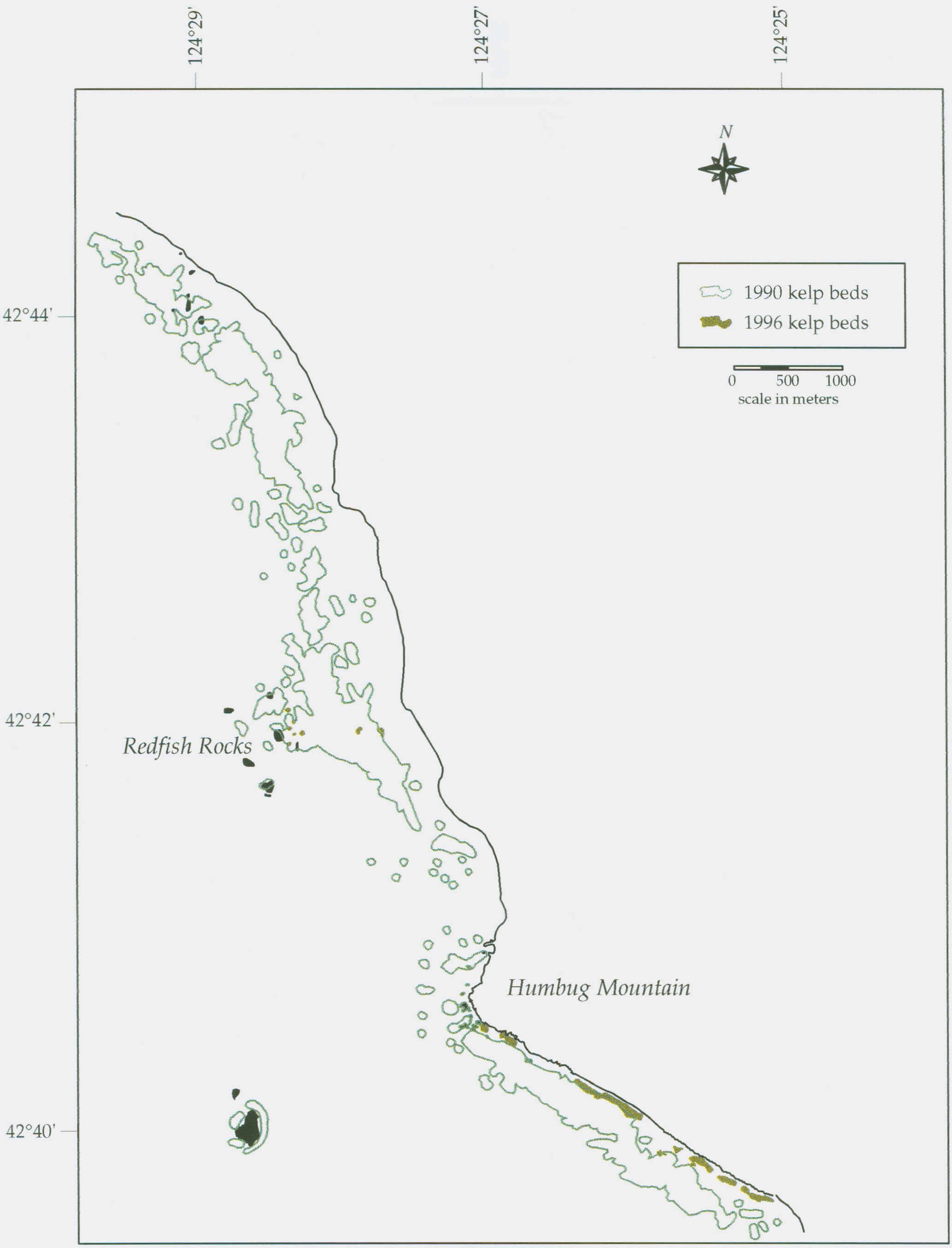


Figure 3-1b. 1990 and 1996 kelp beds at Redfish Rocks and Humbug Mountain.

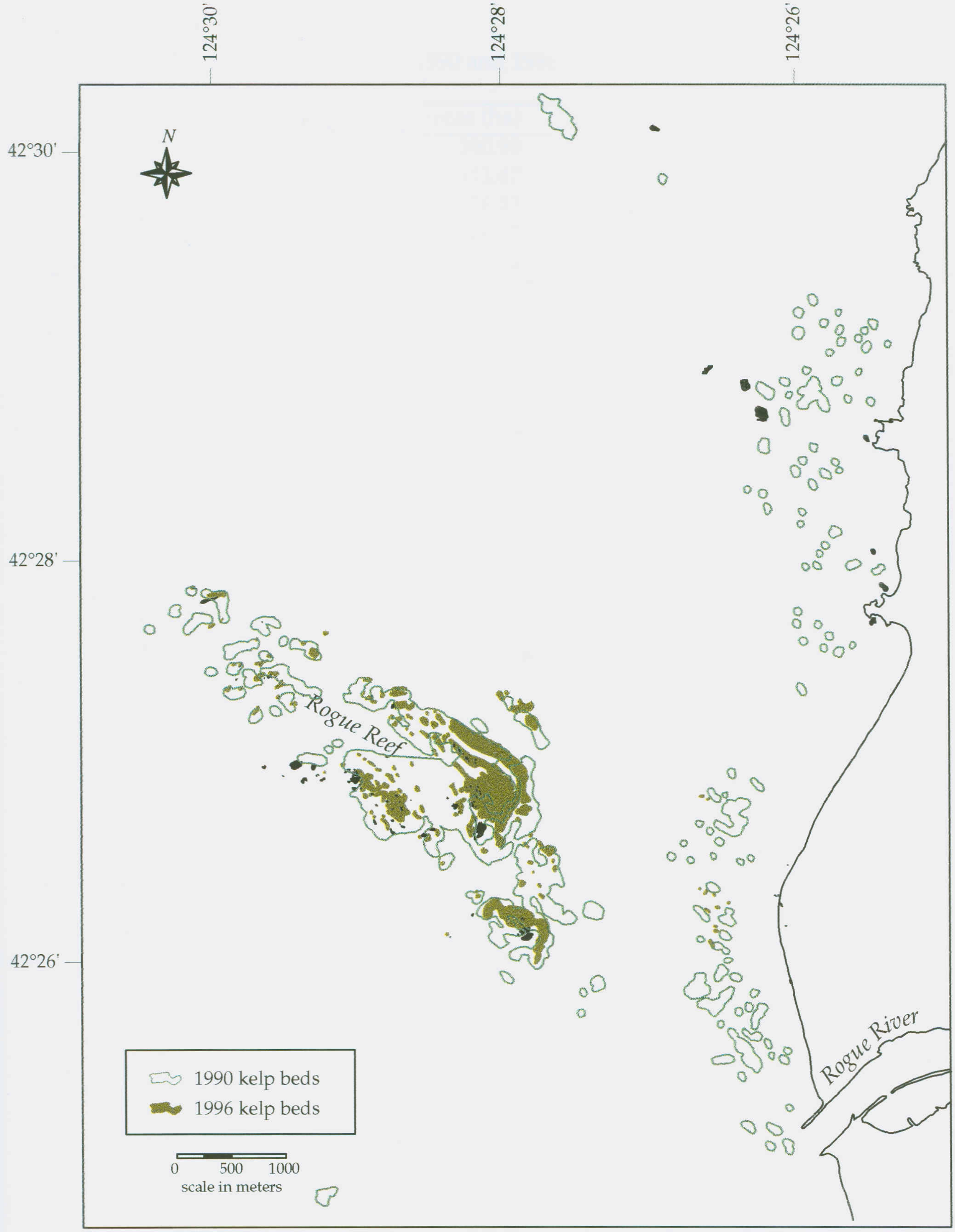


Figure 3-1c. 1990 and 1996 kelp beds on Rogue Reef.

Table 3-2. Kelp bed surface areas in 1990 and 1996

Reef	1996 areas (ha)	1990 areas (ha)	% of 1990
Blanco	33.21	100.90	32.9%
Orford	65.60	313.47	20.9%
Redfish	0.31	78.43	0.4%
Humbug	13.54	46.63	29.0%
Rogue	66.51	77.74	85.6%
Total	179.18	617.17	29.0%

3.2.4. Kelp Biomass

Table 3-3 and Figure 3-2 provide kelp biomass calculations by reef and trial. The total biomass and 95% confidence intervals of harvestable kelp amounted to 10,267 ± 1,678 tons for trial 1 and 9,376 ± 1,709 tons for trial 2. This represents an average of 55 tons/ha (Table 3-3). Of the five kelp areas studied, four (Blanco, Orford, Redfish Rocks, and Rogue Reefs) constitute the Oregon Division of State Lands experimental harvest lease area. The total biomass and 95% confidence intervals for those areas is 9,693 ± 1,659 tons for trial 1 and 8,856 ± 1,692 tons for trial 2.

The total biomass standard error of about 9% of the mean is relatively low for biological sampling. About 80% of the total biomass variance was due to the regression for converting percent cover to density. Only 13% and 7% of the variance resulted from plant weight and percent cover estimates, respectively. Therefore, increasing the sample size for weights or percent cover would do little to decrease overall variance. Also, since only a small portion of the total variance resulted from the percent cover estimate, the significant difference in percent cover between trials 1 and 2 did not result in significant differences in biomass estimates. The biomass 95% confidence intervals overlap broadly between trials 1 and 2 (Figure 3-2).

Before the above estimates can provide indicators of harvestable biomass, harvest efficiency needs to be accounted for. We did not conduct research on efficiency because no harvest was undertaken in 1996. Foreman and Cabot (1979) measured a *Nereocystis* harvest efficiency of 66-70% in British Columbia.

Table 3-3. Kelp bed biomass (Trial 1 and 2 refer to the two kelp percent cover estimates - see Table 3-1). Standard error and confidence intervals are based on re-sampling analysis.

Reef	Biomass (tons)	Standard Error	95% Confidence Interval	90% Confidence Interval	ton/ha
Trial 1					
Blanco	1717	289	565	475	51.7
Orford	3442	559	1096	920	52.5
Redfish	13	3	5	4	39.9
Humbug	574	125	245	206	42.4
Rogue	4522	567	1111	932	68.0
Totals	10267	856	1678	1408	57.3
Trial 2					
Blanco	1504	302	592	496	45.3
Orford	3591	562	1102	924	54.7
Redfish	8	2	4	4	24.5
Humbug	523	123	240	202	38.6
Rogue	3753	582	1140	957	56.4
Totals	9379	872	1709	1434	52.3

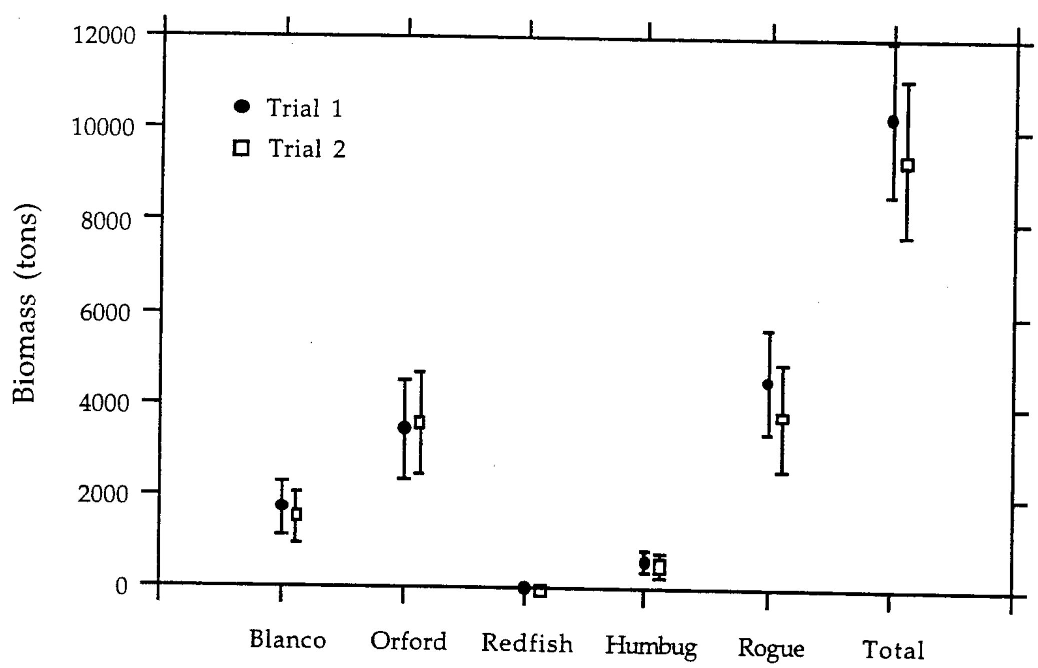


Figure 3-2. Kelp biomass estimates for trials 1 and 2. Error bars represent 95% confidence intervals.

4. Fish

4.1 Introduction

The long-term sampling objective of the fish portion of the study is to test how kelp harvest affects fish populations. Since there was little kelp in 1996, test harvests were not conducted and there was no opportunity to directly examine harvest effects. Any sampling designed to examine fish-kelp relationships needs to also account for the relationships between fish and other important habitat parameters. 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. We took advantage of the lack of kelp harvest to test the relationships between fish and bottom habitat. These study results will provide needed information to help design future studies capable of separating kelp harvest effects from other parameters which influence fish abundance and distribution.

Sampling designs need to deal with functional scales at which organisms respond to their environment (Andrew and Mapstone 1987; Harris 1980). Our previous submersible research and similar research conducted by others has focused on fish distributional patterns relative to micro habitats (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). Most reefs off Oregon consist of a mosaic of different habitat patches at several scales. Although some fish show strong affinity toward one micro-habitat patch area (Matthews 1990a), many reef fish species utilize a range of available habitat patches within the mosaic (Ebeling and Laur 1988). Terrestrial ecologists have long known the importance of larger habitat scales in determining animal abundance and distribution (Harris 1984; Forman and Godron 1986; Noss 1990). The sciences of landscape ecology and conservation biology recognize the importance of describing ecosystem structure and function at several scales in order to gain a full understanding of the factors affecting organisms (Noss 1990, O'Neill, et al. 1986). As the principles from these disciplines are applied to the marine system, researchers and managers are recognizing new reasons to understand marine habitats at a number of scales (Norse 1993).

4.2 Methods

Our sampling design examined fish-habitat relationships at three spatial scales: micro-habitat (1's to 10's of meters), meso-habitat (10's to 100's of meters), and macro-habitat (1000's of meters). To examine meso- and macro-habitats, we set up a stratified sampling scheme based on a factorial design analysis of variance. The grouping variables (or factors) were reef (macro-habitat) and meso-habitat (the habitat described at the scale of a 80 m transect). Reefs included Orford, McKenzie's, Redfish, and Humbug, and meso-habitats included high relief and low relief bottom geomorphology. All sites were between 10 and 20 m deep to minimize the differences in fish communities due to water depth. The experimental design also had a reef x meso-habitat interaction term. The dependent variable in each analysis was log-transformed fish counts per transect. We sampled 6 transects in two meso-habitats on each of four reefs, for a total of 48 sampling sites (Figures 4-1 and 4-2). Where side-scan sonar maps were available, sampling sites were placed in areas of appropriate bottom relief. We assigned sampling sites randomly in parts of the Redfish and Humbug areas where side-scan sonar data were not available. The sampling design also provided fish and habitat data at the micro-habitat level (10 m transect segments) suitable for analysis using multivariate techniques.

Belt and video transects conducted by SCUBA divers provided the fish and habitat data. We dove from the R/V Shearwater in teams of two using standard SCUBA gear. The divers proceeded down the anchor line and deployed a spooled transect line outward from the anchor to perform sampling tasks. Each dive was broken into three main tasks: fish counting, benthic habitat filming, and quadrat filming.

Fish counts began at the boat anchor and were directed into the prevailing current. Each transect consisted of a belt 2 meters wide and included the water column above the substrate within the limits of visibility. The length of the transect, dependent upon diver air supply, was either 80 or 100 m. Transects were considered valid only when diver visibility was greater than 10 feet. One diver spooled out the transect line along a pre-determined compass heading while the other counted fish and recorded the data on a sheet mounted on the video camera housing. The spooling diver stopped at 10 m intervals to allow the observing diver to record fish counts from the previous 10 m segment, depth, and general bottom type. Once 80 m or 100 m was reached, the fish counts were concluded.

On the swim back to the anchor, one diver spooled in the transect line while the other video-taped the benthic habitat along the transect line. The diver with the video camera swam just ahead of the spooling diver at a height of 1-2 m above the bottom, directing the camera at approximately a 45 degree angle to the bottom. This filming style allowed the 2 m transect width to be covered on the footage. The filming diver would pause and aim the camera carefully at the 10 m interval markers, thus dividing the 10 m segments. This coverage ensured that the habitat data could be associated with the 10 m fish count segments during data analysis. The pauses at 10 m intervals were also used to video-tape 0.25 m^2 quadrats. The camera was held vertically approximately 0.7 m off the bottom during the pause. Periodically during the swim, the camera was panned from side to side to aide in the interpretation of bottom types and to document fish schools. After panning, the view began again at the point where it left the transect line.

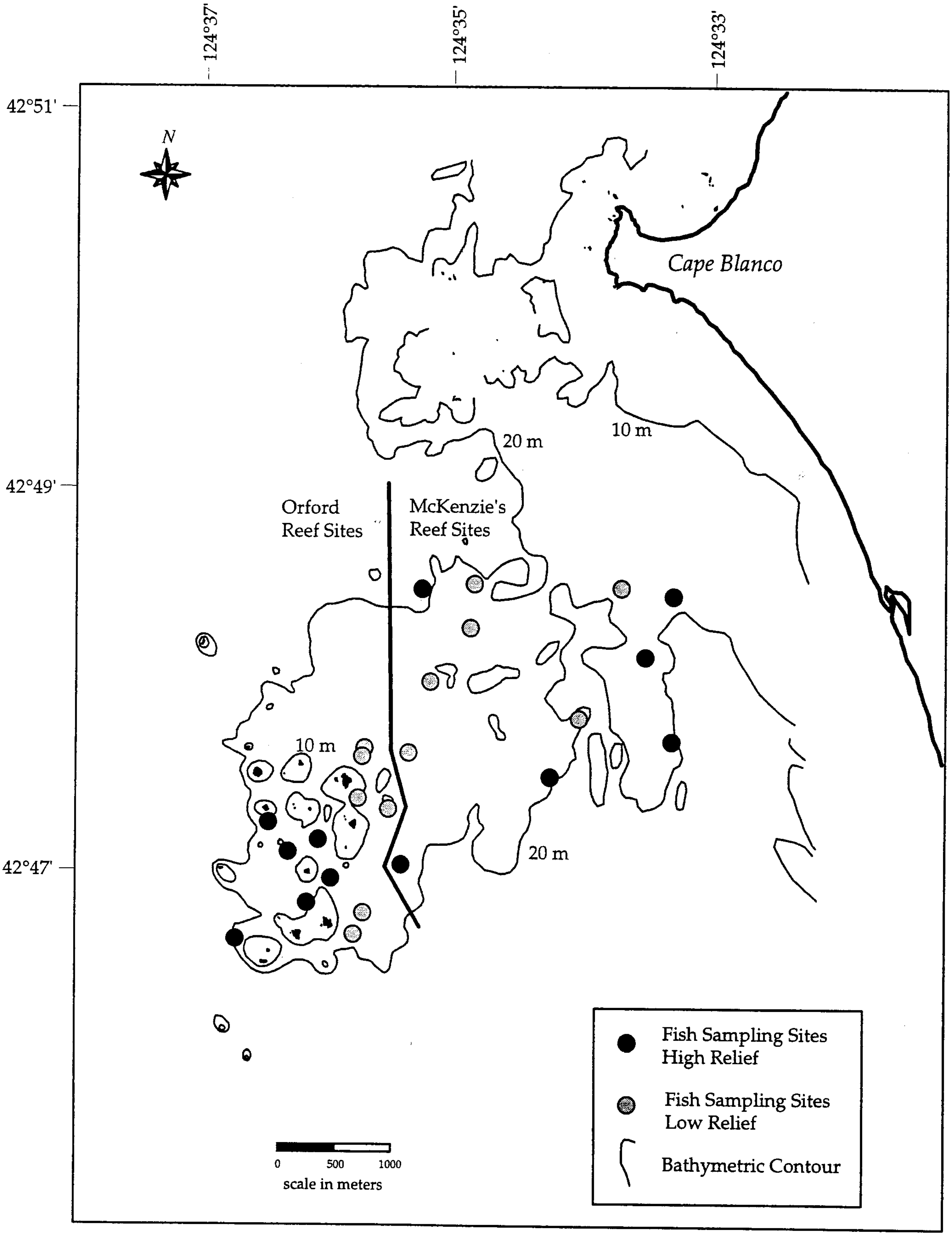


Figure 4-1. Fish sampling sites on Orford and McKenzie's Reefs.

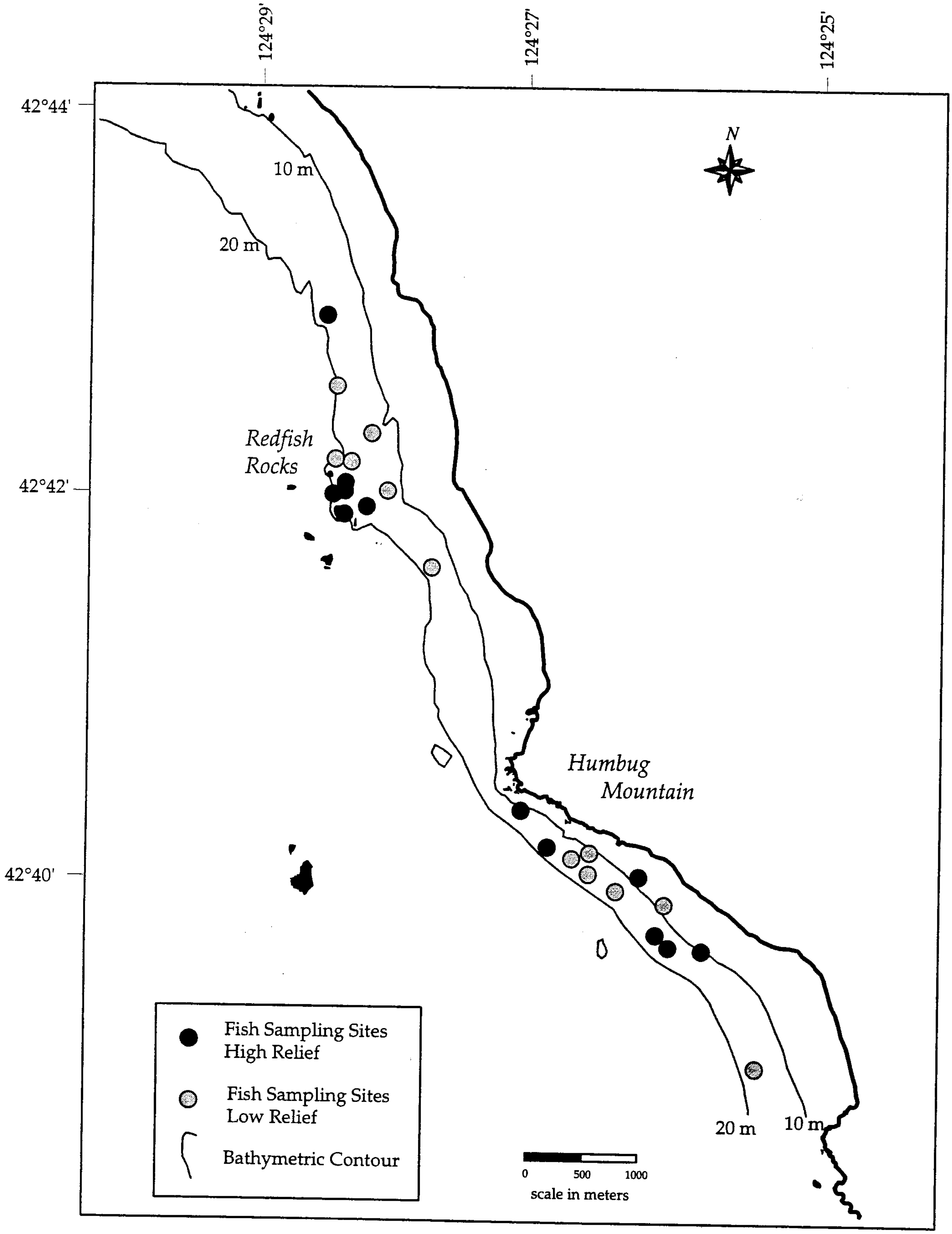


Figure 4-2. Fish sampling sites at Redfish Rocks and Humbug Mountain.

The video camera was equipped with two parallel laser sights (Laser Devices, Inc.) mounted 0.5 m apart. This helped in aiming the camera along the transect line, provided a scale reference in the video footage, and providing a reference to determine the 2 meter-wide belt transects.

The divers recorded visibility as they returned to the anchor. The video diver stopped at the anchor and held the camera with the white data sheet perpendicular to the returning spooling diver. Using the transect line, the spooling diver measured the visibility to the data sheet. After divers completed all work, they ascended up the anchor line. At the surface, data were immediately transcribed to permanent data sheets and divers' qualitative observations recorded.

We reviewed video tapes to identify bottom type along the transects based on a classification by geomorphology and sediment texture (Appendix B). Primary bottom type, secondary bottom type, and percent algal cover were recorded for each 10 m segment of a transect. Three groups of algal type were described for percent cover: subcanopy or understory, turf, and encrusting corallines. We also noted the presence and absence of conspicuous invertebrates along the 10m segments.

4.3 Results and Discussion

We recorded a total of 2,033 fish representing 20 species or groups (Table 4-1). The analyses focused on the most common species or groups including:

total fish,
total adult fish,
total rockfish,
total schooling fish,
total non-schooling fish,
black rockfish,
blue rockfish,
juvenile rockfish, and
kelp greenling.

The total fish data fit to a log-normal data distribution (chi-square goodness of fit $p = 0.50$). Log transforming the data with $\log(x+1)$ yielded a normal distribution (chi-square goodness of fit $p = 0.56$). To maintain transect length consistency between the 80 and 100 m transects, we only analyzed fish counts in the first 80 m of each transect.

Table 4-2 summarizes the results of the analysis of variance on the log-transformed fish counts by reef and habitat. The table also indicates how well the data meet the three primary assumptions for an analysis of variance: data normality, homogeneity of variance, and independence of variances. Chi-square goodness of fit tests confirmed a good fit to a normal distribution for log-

Table 4-1. Fish species observed during the 1996 SCUBA survey.

Common Name	Scientific Name
black rockfish	*Sebastes melanops*
blue rockfish	*S. mystinus*
China rockfish	*S. nebulosus*
canary rockfish	*S. pinniger*
yelloweye rockfish	*S. ruberrimus*
quillback rockfish	*S. maliger*
copper rockfish	*S. caurinus*
yellowtail rockfish	*S. flavidus*
vermilion rockfish	*S. miniatus*
juvenile rockfish	*Sebastes spp.*
kelp greenling	*Hexagrammos decagrammus*
rock greenling	*H. lagocephalus*
painted greenling	*Oxylebius pictus*
juvenile greenling	*Hexagrammos spp.*
lingcod	*Ophiodon elongatus*
cabezon	*Scorpaenichthys marmoratus*
wolf eel	*Anarrhichthys ocellatus*
spotted ratfish	*Hydrolagus colliei*
striped surfperch	*Embiotoca lateralis*
sculpin	family Cottidae

transformed data for all the species and groups except blue rockfish, juvenile rockfish, and kelp greenling. In all cases, the variances were homogeneous using the Hartley F-max, Cochran C, and Bartlett Chi-square tests. In all but one case, the variances and means were independent. Juvenile rockfish data showed a significant correlation between variance and mean ($r=0.93945$).

In most cases fish counts were significantly higher on high relief habitat than low (Table 4-2). In all but two cases, there was no significant differences among reefs. Blue rockfish counts were significantly higher at Humbug Mountain than Orford Reef. Kelp Greenling counts were significantly higher at Humbug Mountain than Redfish Rocks. There were no significant interactions between reef and meso-habitat.

The occurrence of higher fish counts on high relief habitat agrees with past submersible studies. This is most likely related to the greater structure and shelter provided by high relief boulder or bedrock outcrops. Kelp greenling showed no significant relationship with bottom relief. This agrees with our divers qualitative observations that kelp greenling seem to be ubiquitous on rocky reefs.

Table 4-2. Results of Analysis of Variance of log-transformed fish counts by reef and habitat. Reefs include Orford, McKenzie's, Redfish, and Humbug; meso-habitats include high- and low-relief bottom geomorphology. Assumptions for analysis of variance include data normality, homogeneity of variance, and independence of variances. n.s. = not statistically significant.

Dependent Variable	Difference Among Reefs	Difference Among meso-habitats	Interaction Term	Meets Assumptions: Norm-ality	Homog. var.	Ind. var.
total fish	n.s.	p=0.0007	n.s.	yes	yes	yes
total adults	n.s.	p=0.0008	n.s.	yes	yes	yes
total rockfish	n.s.	p=0.0003	n.s.	yes	yes	yes
total schooling fish	n.s.	p=0.0003	n.s.	yes	yes	yes
total non-schooling fish	n.s.	n.s.	n.s.	yes	yes	yes
black rockfish	n.s.	p=0.0012	n.s.	yes	yes	yes
blue rockfish	p=0.0442	p=0.0002	n.s.	no	yes	yes
juvenile rockfish	n.s.	p=0.0024	n.s.	no	yes	no
kelp greenling	p=0.0238	n.s.	n.s.	no	yes	yes

The homogeneity of fish densities among reefs surprised us, and has implications toward future sampling design. Sampling for kelp harvest impacts may not need to be spread among several reefs, thus allowing us to reduce total sampling effort, and/or increasing statistical power at a single reef. We need to exercise caution when using a single year's results to make this conclusion. There may be alternate explanations for the apparent lack of differences. For example, statistical power of the sampling may have been too low to detect differences among reefs. Also, the sampling technique may not have fully represented fish schools. Black rockfish schools appeared larger at Orford Reef, but since we only counted a 2 meter-wide swath, the count data may not have consistently differentiated large from small schools.

Another interesting result was the higher blue rockfish densities at Humbug Mountain than Orford Reef. It seems counter-intuitive that blue rockfish, a species more common waters deeper than our sampling, were more abundant at Humbug Mountain (an inshore area) than Orford (an offshore area). However, this agrees qualitatively with our 1993 sub cruise where we found more blue rockfish at Island Rock (near Humbug Mountain) than on Orford Reef. During our SCUBA transects, most of the blue rockfish at Orford Reef occurred as isolated individuals mixed with schools of black rockfish. At Humbug Mountain many of the schools consisted of nearly 100% blue rockfish with only a few black rockfish mixed in. Also, many of the blue rockfish at Humbug Mountain were small (less than 40 cm), indicating that the nearshore area at Humbug Mountain may provide habitat for younger fish.

We regressed total fish density against average transect depth and visibility to test if these variables influenced our results. There was no significant relationship with depth. There was a significant, but weak, positive relationship with visibility ($R^2 = 0.130$; $p= 0.01189$). The low R^2 value indicates that visibility had little influence on the results. An ANOVA of visibility by reef and habitat showed a significant difference among reefs ($p=0.02651$), with Humbug Mountain having significantly lower visibilities than Orford Reef. There was no statistical difference in visibility between high and low relief habitats.

5. Seabirds

5.1 Introduction

Among the groups of organisms that may be affected by kelp harvest are several species of local and migrant seabirds. Common seabirds include: Cassin's auklet, rhinoceros auklet, Brandt's cormorant, pelagic cormorant, double-crested cormorant, red phalarope, red-necked phalarope, western gull, and marbled murrelet. At present, there is little information available on the ecological relationship between seabirds and the kelp forest or the relative importance of kelp beds to seabird populations. Existing information is primarily from a few food habit studies of seabirds in *Macrocystis* beds. In a 1992 ODFW seabird study which looked at the distribution of seabirds on Orford Reef, there were indications of seabird affinity for *Nereocystis* beds. Among these were higher densities of seabirds in kelp areas compared to non-kelp areas, and direct observations of birds feeding in kelp beds. Based on some preliminary findings and other observations by biologists, we feel there may be potential for kelp harvest to impose some disturbance to seabirds. Disturbances might include: displacement of feeding or resting birds, disruption of chick-rearing activities, and killing or displacing prey organisms. Similar concerns are shared by the Washington Department of Fish and Wildlife (WDFW) who recently began a study to determine the impacts of *Nereocystis* harvest on the federally listed marbled murrelet (Thompson 1996, personal communication). The general scope of this study is intended to characterize and understand seabird association with the kelp forest, and from this, determine if and how kelp harvest might disturb or impact seabirds.

This year's study was designed with two objectives: (1) determine the various forms of seabird activity in or around kelp and compare this between kelp and non-kelp areas, and (2) determine the location of seabird species relative to kelp beds.

5.2 Methods

5.2.1 Seabird Activity (Focal Bird Observation Method)

Seabird activity was monitored from shoreside locations rather than at sea to facilitate behavioral observation methods which require long periods of time at a fixed station. Two sites were chosen for the "within kelp" observations: the south side of Cape Blanco headland, and the bluff just north of Coal Point, due east of Redfish Rocks. Both sites offered good vantage points above the ocean and were areas where *Nereocystis* typically grows close to shore. We visited Nellie's Cove once at the end of the season because it was the only nearshore area that produced kelp and we wanted to have some observations of birds in kelp.

The observer used a 20-60x zoom spotting scope to observe bird behavior. A bird was selected for observation based on its position on the water relative to sun glare and sun direction, and for its proximity to shore so that magnification did not have to exceed 40x. The technique for observing involved watching an individual bird for a fixed amount of time and recording the type and duration of 13 discrete behaviors. The observer called out the behavior as the bird switched from one behavior to another. The data recorder entered the behavior code onto a hand-held computer data logger. Time was automatically recorded upon completion of entering a behavior code. A new time was recorded as each new behavior was recorded. The duration of each behavior would later be computed as the difference between consecutive times. A single bird was watched for a total of 5 minutes, upon which time another bird was selected and a new session begun. Observations were conducted shortly after dawn and before dusk, when birds were most likely to be on the water. Some mid-day observations were made as well to see if wind and glare were mild enough to warrant scheduling mid-day sessions. An observation session lasted about 3 hours. A sweep count of the area was done once or twice during the survey to record the species composition for the general area. These data were also recorded onto the data logger.

5.2.2 Seabird Location (Transect Method)

This survey was intended to associate bird location with respect to kelp, using transact survey methods similar to those employed by the WDFW study described above. We selected four survey areas; Orford Reef, McKenzie's Reef, Redfish area, and Humbug area. Prior to the survey season, transects were mapped on a GIS and overlaid with kelp data from a 1990 survey (Figure 3-1a), allowing placement of transects in areas expected to have kelp. The intention was for transects to meander in and out of kelp beds, at or near constant depth (within 20 feet). Locations and time of the actual transects were downloaded at 5 second intervals from the GPS onto a laptop computer. Depth was recorded by the boat operator every other minute.

The observation platform was the bow of the R/V Shearwater, a 25 foot aluminum, V-hulled boat. One or two observers sat on the bow, each looking on her side of the boat out 90° and forward to the center line of the boat to a distance of 100 meters. Recorded data included weather and environmental conditions, species identification and count, time of observations and the bird's position to kelp. These data were recorded into the datalogger by one of the observers or a dedicated data recorder if only one observer was present. Time was synchronized on the GPS and datalogger, allowing us to link species to geographic position (± 100 meters relative to boat position). Seabird locations would then be overlaid with this years' kelp location data (available from aerial photography) and other oceanographic data residing in our GIS. Species density and composition for each study area would also be calculated. Further analysis would include calculating percentage of bird species at various distances from kelp as a means for determining seabird association with kelp.

Equipment problems in the field, however, precluded most analyses. The downloading of the GPS data was rarely successful due to both the software and the hardware. Boat movement seemed to be the primary reason for the GPS software program failing and the computer losing power. When the program was running the data frequently transmitted incorrectly or inconsistently. Some records were repairable during post processing while others had to be deleted. When computer problems arose at sea, the alternate method was to have the boat operator record our location on paper every minute. This was a much less accurate method than required for analysis, but could provide a mechanism for testing the analysis itself.

5.3 Results

Two important phenomena occurred this summer that precluded a successful field season for the seabird study. The first was the lack of seabirds in the area. Early in the summer, large numbers of adult common murres and some cormorants died from starvation. This coincided with a delayed upwelling period which presumably attributed to the shortage of available prey species in nearshore water where nesting seabirds feed. Following the die off, USFWS reported that 80% of common murres abandoned their nests prior to hatching young (Roy Lowe, USFWS, personal comm. 1996). Many Brandt's and pelagic cormorants also suffered substantial nesting failure. These events are believed to have caused the early migration of the breeding colonies to their northern wintering grounds. Consequently, we saw few common murres in our study areas as compared to our 1992 survey on Orford Reef. The few common murres that remained were adults rearing chicks. Most of the other species typically seen were also considerably fewer in numbers than expected or observed in 1992. Cassin's auklets and rhinoceros auklets were absent from the reef during the 1996 survey.

The second important event was the absence of kelp plants in the early part of summer, and the substantially low number of kelp plants later in the season as compared with previous years. Consequently, the majority of the focal observations and at sea transects occurred in areas without kelp. These 2 significant events impaired our ability to examine seabird activity in kelp. Given these circumstances we changed our focus and used the opportunity to observe birds in a "kelp area" when no kelp was present, and to test the workability of the methods and equipment designed for this study.

5.3.1 Focal Bird Observations

Environmental conditions such as fog, wind waves, ocean swell, glare and sun direction also interfered with the observers ability to stay focused on a bird. Fog was a major deterrent, often limiting visibility to less than 200 feet at all shoreside sites. This frequently lead to canceling a day's survey. On some days it was possible to sample later in the day when the fog lifted, although there was concern about the variability associated with diurnal activity patterns of seabirds.

Almost all observations were of birds not in kelp, with the exception of one shoreside session at Nellie's Cove and one boat session on Orford Reef. We expected to see and have available for observation numerous Brandt's cormorants, pelagic cormorants, double-crested cormorants, pigeon guillemots and marbled murrelets, however, the number of birds and diversity of species present were surprisingly low. It is unclear if this was due to the premature departure of birds as described above, the absence of kelp inshore, or simply that the primary species of interest do not regularly inhabit the shoreline environment in sufficient numbers. A total of 30 birds were observed during our time at the sites (Tables 5-1 and 5-2). Of the 11 hours we spent at sites, only 3.25 hours was actual observation time. A great deal of the remaining 7.75 hours was spent waiting for birds to arrive in the study area. The small dataset did not lend itself to statistical analysis. Summaries of bird behavior and time allocation in kelp and not in kelp are presented in Tables 5-1 and 5-2.

Table 5-1. Observed behaviors, percent time allocation, and position to kelp for focal birds observed at kelp sites.

Species/ID	Position of bird to kelp	Behavior	Percentage of time of behavior	Total observation time (in minutes)
Double-crested Cormorant/1	kelp fringe	diving	79.6187	26.8496
	kelp fringe	surfacing/transition	1.7598	
	kelp fringe	paddling (one direction)	15.5935	
	kelp fringe	preening/splashing	3.0280	
Double-crested Cormorant/2	> 10 ft. away	diving	67.0338	5.1480
	> 10 ft. away	surfacing/transition	27.8543	
	interior of bed	surfacing/transition	5.1119	
Double-crested Cormorant/3	kelp fringe	diving	22.6604	5.4976
	kelp fringe	surfacing/transition	10.5569	
	kelp fringe	eating (swallowing)	5.0542	
	interior of bed	diving	45.5139	
	interior of bed	surfacing/transition	11.9954	
	interior of bed	paddling (one direction)	4.2193	
Pacific Loon/1	kelp fringe	diving	28.7915	5.4287
	kelp fringe	surfacing/transition	15.9840	
	kelp fringe	preening/splashing	55.2245	
Pacific Loon/2	> 10 ft. away	paddling (one direction)	100.0000	5.2210
Total Observation Time (in hours)				0.8024

Table 5-2. Observed behaviors and percent time allocation for focal birds observed at non-kelp sites.

Number of birds observed	Species	Behavior	Percentage of time exhibiting behavior	Total observation time (in minutes)
2	Common Murre	surfacing/transition	15.2283	11.8017
		preening/splashing	22.3341	
		paddling (one direction)	13.3471	
		diving	49.0905	
1	Double-crested Cormorant	surfacing/transition	15.3791	6.0121
		diving	84.6209	
6	Marbled Murrelet	vocalizing	0.3603	37.0037
		resting	13.4388	
		preening/splashing	24.9255	
		paddling (one direction)	37.9453	
		diving	13.7991	
9	Pacific Loon	surfacing	5.2497	46.2982
		resting	0.5742	
		preening/splashing	51.2925	
		paddling (one direction)	13.5241	
		paddling (multi-directional)	0.3064	
		head dipping in water	6.9920	
		diving	22.0610	
1	Pelagic Cormorant	surfacing/transition	16.9638	9.0362
		preening/splashing	6.3558	
		paddling (one direction)	5.2662	
		flying with fish/object	0.5020	
		eating (swallowing)	1.0823	
		diving	69.8300	
3	Pigeon Guillemot	surfacing/transition	14.0928	18.8266
		preening/splashing	4.1902	
		paddling (one direction)	32.4556	
		diving	49.2614	
2	Western Grebe	vocalizing	0.7572	10.5228
		preening/splashing	9.6944	
		paddling (one direction)	89.5484	
1	Western Gull	resting	2.3392	8.1003
		paddling (multi-directional)	37.4882	
		head dipping in water	52.6240	
		eating (swallowing)	7.5486	
Total observation time (in hours)				2.2633

Interpreting behaviors was a complex process. Behaviors such as diving, eating, and flying were easily recognized. Behaviors such as paddling, resting, foraging, and vocalizing were more ambiguous. A bird apparently paddling aimlessly may actually have been foraging in motion. A bird that appeared to be resting may have actually been quietly stalking its prey, waiting to strike. A bird dipping its head below the surface is not necessarily foraging for fish; it may be watching for predatory fish. For these reasons, we did not classify any behavior as "foraging", unless an object was seen in the bill. Since birds appeared to be constantly paddling on the water unless sleeping, paddling was the fall back category if no other behavior could be discerned. The "surfacing/transition" category describes the period when a bird surfaces after a dive but has not yet begun another discernible behavior. These periods were surprisingly long for some birds and seemed to coincide with the frequency with which they dived.

We observed a few episodes of successful foraging. On one occasion, a pelagic cormorant was seen swallowing some unknown object, possibly a fish. The same bird was later seen flying off with something in its bill. A western gull was also seen swallowing an unknown object. These incidents occurred at non-kelp sites. A double-crested cormorant was observed swallowing a fish at the kelp fringe after several bouts of diving in the kelp interior and fringe.

Focal animal studies on seabirds are quite challenging because seabirds can instantly leave the observer's sight through diving. It was sometimes possible to identify the focal bird upon surfacing if the focal bird was the only bird in the vicinity; however, seabirds often surfaced away from the location they dived, or surfaced in the vicinity of conspecifics, making it nearly impossible to know if you were watching your original bird or another bird who recently surfaced from a dive. In order to minimize the chance of permanently losing a bird to diving or flying, we only observed a single bird for a 5 minute period.

Five minutes seemed to be a sufficient amount of time to capture a bird's activity pattern while minimizing the chance of losing a bird to flying or diving as described above. About 70% of our observation sessions completed the full 5 minutes. It is possible, however, that an increase in observation time may provide a more thorough display of activity patterns without jeopardizing the completion of a session. The optimum observation time should be determined if further study of this type is warranted. Observer fatigue should also be a consideration of extended observation periods.

5.3.2 Seabird Location

Kelp growth was minimal during the period that we were conducting at-sea surveys. The greatest amount of kelp in the study areas was along the southeast and south sides of the emergent rocks of Orford Reef. There were a few small patches of kelp at Redfish Rocks, and a narrow linear patch along shore at Humbug Mountain. Less than 10% of all birds counted were in the vicinity of kelp. However, during the last week of the season, when kelp had increased at the surface, we observed 10's of adult and immature gulls feeding and vocalizing in the dense kelp mat near Arch Rock on Orford Reef.

The method of recording bird sightings on the electronic datalogger worked well when bird densities were low; data could be entered very quickly. This was important because the technique and analyses depend on capturing data instantaneously so that the bird and location data can be accurately mapped. However, when large densities of mixed flocks were encountered, or birds were in various positions relative to kelp, data entry took several seconds which would result in location and mapping error. The technique will need to be refined to correct this problem for future surveys.

Seabird densities on Orford Reef were calculated and compared to those of the 1992 survey (Table 5-3). All species or species groups were remarkably lower in August, 1996 than in August, 1992 for reasons discussed above.

Table 5-3. Seabird densities for 1992 and 1996 on Orford Reef.

Seabird Species or Species Grouping	Seabird Densities (birds/hectare)	
	1992	1996
Brandt's/Pelagic Cormorant	0.1593	0.0508
Double-crested Cormorant	0.0000	0.0000
Pigeon Guillemot	0.0720	0.0070
Common Murre	0.1440	0.0053
Cassin's Auklet	0.9081	0.0000
Rhinoceros Auklet	0.0551	0.0000
Marbled Murrelet	0.0138	0.0035
Red/Red-necked Phalarope	3.2113	0.0018
Gull species combined	0.0812	0.0754

6. Recommended Changes to Study Methods

6.1. Physical Parameters

1. StowAway brand temperature meters need to be moored in a protective case to keep them from being damaged or lost due to swell and currents.

2. A recording temperature meter should be moored 1 m below the surface to conform with oceanographic standards.

3. CTD transects provide an excellent way to characterize the water column across a reef. These should be repeated several times during the sampling season.

6.2. Kelp

1. We should devote an entire week to kelp plant weight sampling, rather than trying to combine it with SCUBA work.

2. Sori counts should begin early in the season, as soon as the first kelp surfaces.

3. Horizontal control on the kelp photographs should be improved by using differential GPS and/or placing buoys in know locations for inclusion on the photos.

4. We should perform sampling to verify the regression that relates kelp percent cover to density.

5. If harvest takes place we should conduct a study to estimate harvest efficiency.

6.3. Fish, Invertebrates, and Habitat

1. Video techniques should be modified so that the return video on the fish transects can be used as an invertebrate belt transect rather than a habitat type record. To accomplish this, the video diver needs to hold the camera at a near vertical position about 1 meter above the bottom. The divers can record habitat type rather than depend on the video to define bottom habitat.

2. Juvenile rockfish would best be sampled using separate transects that are both shorter that the 80 m fish transects and employ more rigorous diver searchers closer to the bottom.

3. We should try to keep the fish sampling season as short as possible to avoid problems with temporal changes in the community.

6.3. Seabirds

Seabird Activity:

1. Kelp should be less than 300 meters from shore if shoreside observations are to be successful. A shorter viewing distance would enhance the observers ability to track a bird by allowing the spotting scope to be set at a lower magnification. If kelp does not grow close enough to shore, focal bird observations should be terminated.

2. The data logger was the most efficient way that we tested to record behavior and duration. There was however, a slight delay between the actual recording of a behavior and the recording of the time. Using an electronic recording wand and bar codes for all data recording will increase efficiency of data collection.

3. Seabird behaviors should be better defined for more confident and accurate interpretations. Behavior categories may be slightly different for different species. This should be determined prior to the study.

4. Focal bird observations are costly. Factors such as low bird density, proximity of birds and of kelp to shore, disappearance of focal birds when diving, weather and oceanic conditions greatly affect the success of this study. We need to determine if the information we obtain and the time required to collect good data justifies future effort in this area.

Seabird Location:

1. The technique of using visual observations to determine if a bird was in or out of kelp was somewhat subjective. A more accurate technique would be to obtain aerial photographs of the survey area two or three times during the survey period, scan the photographs and incorporate bird and kelp location data into the GIS for an overlay analysis.

2. To ensure instantaneous recording of seabird sightings, we may choose to minimize the number of species of interest, and use an electronic wand and bar-codes to expedite data capture. We may also rely on other techniques as discussed in (1) above, for determining a bird's position to kelp. This would minimize the amount of data recorded at sea.

3. The technique of "meandering" transects in various directions caused some problems for the observers; in particular, glare due to the observer's position to the sun and strong head winds when the boat was faced into the wind which made for a shaky observer platform. Transects should be more consistent with regards to these conditions.

4. Transects should not be placed only in known kelp areas, but should traverse several miles of ocean to reduce bias toward the reefs and to strengthen analyses on habitat association. Also, we should not attempt to control for depth, but run transects more randomly and continuously record depth using a fathometer and overlay this data with bird and kelp data.

5. Orford Reef in particular has many obstacles that make maneuverability for this type of survey difficult including: (1) The sensitive nature of the area due to Stellar sea lion rookeries and nesting seabird colonies inhibits us from traveling through most of the interior area of the reef and (2) kelp is easily tangled in our twin outboard motors, causing them to overheat. In a "typical" year of dense kelp, it

would be impossible to maneuver through the area without constant entanglement in kelp and having to stop to clear the motors. This would severely interfere with the sampling design. A possible alternative is to drive the boat only around the perimeter of the general area of kelp and look as far as is practical into the center of the main kelp area. Another option is to construct a screen for the water intake ports on the motors that would prevent kelp from being sucked in.

6. We need to upgrade our GPS and computer so that they work consistently at sea. Ideally, they should be compatible with one another so that bird data, location data and time data are downloaded concurrently. A separate GPS is need for navigation so one GPS can be solely devoted to downloading location data.

7. Management Analysis

7.1 Methods

The Kelp/Reef Habitat Assessment project is designed to collect needed scientific data and to work out practical details of harvest and management with the harvester and managing agencies during an experimental harvest phase. As a part of this year's management analysis we developed a set of management hypothesis, in the form of questions and possible answers, based on the programmatic objectives outlined in Oregon Coastal Management Program (1995).

While no harvest occurred in 1996, we evaluated events such as the timing of kelp production, production density, our ability to survey and produce biomass estimates prior to harvest, and the potential of experimental harvesting under the low kelp biomass observed, with the view of how it might potentially impact resources and the ability to manage a harvest plan.

7.2 Results and Discussion

7.2.1 Management Hypotheses

We set up the management hypotheses as a series of possible alternate answers to questions inferred in the programmatic objectives.

1) The first objective is to assess the adequacy of existing regulatory and other management programs for kelp/reef areas, resources, and uses. The implied question is: does the state have adequate resources to carry out a kelp/reef management plan, providing appropriate controls over harvest of kelp, while minimizing impacts of harvest on and use of other living marine resources and habitats? Answers to this question are broken into three parts with two alternatives for each part.

Biomass estimation

$A_{1\text{-}1\text{-}a}$ **Yes**: Existing state resources are adequate to evaluate kelp biomass on an annual basis, in cooperation with the harvester, and provide a timely estimate and field sampling plan in time for harvest.

Here, we assume that harvester and state agencies would share the cost of the survey.

$A_{1\text{-}1\text{-}b}$ **No** Additional resources are needed.

Here, one or the other or both have inadequate resources for timely estimates.

Ability to Harvest

$A_{1\text{-}2\text{-}a}$ **Yes** Kelp harvest (whether it occurs or not) and year-to-year management can be variable depending on timing of and amount of kelp production.

Here, we assume that the harvester and managers are flexible in ability to commit resources to estimate biomass and conduct harvest.

$A_{1\text{-}2\text{-}b}$ **No** Kelp harvest needs to be conducted every year at a threshold level to be economically feasible.

Here, we assume managers would have ability to be flexible in expending resources to do surveys, but harvester may not be able to maintain markets with highly variable kelp production.

Impact on Other Resources

$A_{1\text{-}3\text{-}a}$ **Yes**: Existing state resources are adequate to measure and evaluate impacts of kelp harvest on other living marine resources and habitats, and provide a timely recommendations resulting in appropriate modifications of kelp harvest plan.

$A_{1\text{-}3\text{-}b}$ **No**: Additional resources and/or a very conservative harvest strategy may be required.

2) The second programmatic objective asks us to describe needed program changes in state law, the Territorial Sea Plan, and agency regulations required to carry out a plan for kelp harvest along with other existing and future plans for mariculture, developing fisheries, sea urchins, commercial and recreational fisheries, recreational use, marine mammal protection, and marine minerals. The implied question asks whether or not the existing framework for management is adequate to incorporate and coordinate a new kelp harvest program with other uses within the Territorial Sea?

$A_{2\text{-}1\text{-}a}$ **Yes** Existing laws and plans are adequate to limit or prevent kelp harvest in areas of concern, should there be impacts on fish and wildlife resources, fisheries or on habitat.

Here, we assume that the Territorial Sea Plan would require interagency coordination so that protection of fish and wildlife resources would allow control over kelp harvest if required, even though kelp harvest is controlled by the Division of State Lands, and fish and wildlife resources are managed by the Department of Fish and Wildlife.

$A_{2\text{-}1\text{-}b}$ **No** Existing laws and plans are inadequate and need refinement in order to protect other natural resources and habitats.

3) The third programmatic objective seeks recommended management measures for commercial kelp harvest that can be carried out within existing agency authorities. The question here is will the present study provide the information needed to make these recommendations?

$A_{3\text{-}1\text{-}a}$ **Yes** The study design will be adequate to provide a recommendation on whether or not harvest should occur, how harvest should be conducted, and how agencies should implement and coordinate a harvest plan.

$A_{3\text{-}1\text{-}b}$ **No** The study design needs to be modified, or additional resources are required to answer the other information and programmatic objectives.

7.2.2 Management Analysis

Given the set of questions in section 7.2.1, we conducted a management analysis of the work accomplished in 1996.

Biomass Estimation (Programmatic Objective 1, Question 1-1 - Adequate Program)
Kelp production was low and late this year, as a result, the leasee did not harvest. Field sampling to collect plant weight data occurred from July 23 - September 13, 1996. Aerial photographs were taken September 24, 1996. Analysis of the data and biomass estimation did not occur until after winter storms commenced. The lateness of kelp production displaced the timing of survey work and biomass estimation. We conclude that these factors would not have permitted timely data for harvest. However, it appears this was due to nature of kelp production, not necessarily limitations of the program.

We can probably provide biomass estimates within 3 weeks of the receipt of aerial photos, assuming we have already collected the plant weight data. Assuming aerial photography occurs during peak kelp biomass in late August or early September, biomass estimates would be available no sooner than late September or early October. The timing of biomass estimation can be advanced by acquiring the aerial photography earlier in the season, prior to peak kelp biomass. This would yield underestimates of biomass and result in conservative harvest allowances.

Ability to Harvest (Programmatic Objective 1, Question 1-2 - Adequate Program)

The leasee cited poor production as the reason for not harvesting kelp in 1996. Assuming harvest could have occurred within the most productive beds measured, only 3,516 tons were available on Orford Reef and 4,137 tons on Rogue Reef. According to the experimental harvest plan, a minimum of 90 tons or 2.5% of the standing crop would have been harvested at Orford Reef. We conclude that this would have been a conservative amount for the purpose of experimental harvest and that harvest could have occurred if the timing of kelp growth had been more conducive to harvest.

The lease arrangement allows for negotiation of an additional amount that might be permitted beyond the experimental harvest. Assuming an experimental harvest of 10% or less, approximately 350 tons or less would have been available from Orford Reef or around 765 tons from Orford and Rogue Reefs combined. It is not known if this would be sufficient for economic feasibility.

Impact on Other Resources (Programmatic Objective 1, Question 1-2-Adequate Program)

While we were not able to measure the impact of kelp harvest on fish and bird populations, we were able to apply a sampling method that found significant differences in fish distributions with respect to bottom structure that were consistent between major reef areas. We conclude that habitat structure at one scale is likely to be more important than between-reef differences. If harvest is delayed again next year, at a minimum, the study design should incorporate sampling in kelp vs. non-kelp areas to see if there are significant differences in distribution of fish in and outside of kelp beds given a particular bottom type.

Bird observations were limited and somewhat anecdotal. When kelp did occur in dense enough quantities to form mats, adult and immature gulls were observed feeding in one dense mat near Arch Rock, Orford Reef. Survey methods need improving, and additional survey attempts will be required under conditions of higher kelp production and harvest to draw any conclusions about potential impacts of harvest on birds.

Program Changes Required (Programmatic Objective 2, Question 2-1)

Kelp leasing and harvesting is governed by Oregon Revised Statutes (ORS) Chapter 274, enabling the Division of State Lands (DSL) to lease submerged land for kelp harvesting. DSL does not have specific kelp leasing regulations but relies on administrative rules for aquaculture (OAR 141-82-032(5)). Statewide Planning Goal 19 and Ocean Resources Management Policy are dealt with under the Oregon Territorial Sea Plan. Interagency coordination between ODFW and DSL during the course of project was satisfactory, and for the purpose of the experimental harvest plan, no changes are recommended at this time.

Recommended Management Measures (Programmatic Objective 3, Question 3-1)

Additional years of biomass estimation and harvest impact evaluation are required prior to recommending management measures for kelp harvest. Some discussion among the leasee, DSL, and ODFW is recommended to determine minimum biomass for interest in harvesting as well as a minimum required for economic viability.

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Appendix A. Additional Analysis of 1995 Kelp/Reef Assessment Sampling

Introduction

Our 1995 grant report describes the 1995 field work and presents some analyses. We conducted additional analysis of the habitat video and fish data to help plan the 1996 sampling. This appendix summarizes the sampling methods and results.

Methods

Field Sampling

We conducted a series of belt transects to identify and count fish and to videotape bottom habitat. The transects were run both concurrently with urchin transects and separately as fish/video transects. In either case, the methods were the same, except the urchin/fish transects were 40 m long and the fish/video transects were up to 100 m long. Each transect consisted of a belt 2 meters wide and included the water column above the transect within the limits of visibility. Fish transects were considered valid only when diver visibility was greater than 10 feet. Visibility was estimated by the divers based on their experience and judgment.

Fish/video transects began at the boat anchor by clipping the transect line to the anchor. One diver spooled out the transect line along the pre-determined compass course while the other counted fish and recorded the data on a sheet attached to a clipboard. The spooling diver stopped at 10 m intervals to allow the observing diver to record fish counts from the previous 10 m segment and depth from the dive computer. Thus, the transect data were organized into 10 m transect segments.

At the end of the transect, one diver spooled in the transect line while the other video taped the bottom habitat along the transect line. We modified video procedures over the course of the field season to improve techniques. In our most improved technique, the diver with the video camera swam just ahead of the spooling diver, holding the camera at approximately a 45 degree angle to the bottom at a height of 1-2 m above the bottom. The video diver paused and aimed the camera carefully at the 10 m interval markers along the transect line to ensure these would be visible in the footage. This would allow the habitat data to be organized in the 10 m transect segments during post-processing. The video camera was equipped with parallel Laser Devices® laser trackers that helped in aiming the camera along the transect line and provided a scale reference in the video footage. Periodically, and at large rocky outcroppings, the video camera was panned from side to side to aide in the interpretation of bottom types. After panning, the view began again at the point where it left the transect line.

We attempted to capture juvenile rockfish at some sites to identify the species and test capturing methods. We tested slurp gun devises and a monofilament mesh tropical fish net. After capture, the fish were removed from the device by hand and placed into a diver goodie bag. Juvenile rockfish were identified based on meristic characteristics using Moreland and Reilly (1991).

Data Analysis

Data analysis methods included video review and interpretation, and data entry and analysis. Video tapes were reviewed to record the bottom types along the transects. We classified bottom types according to geomorphology and sediment texture (Appendix B). Primary and secondary bottom types were recorded for each 10 m segment of a transect. The 10 m segments used for the habitat data were the same as those used for the fish data.

The fish counts were entered onto a computer database and density data computed for each 10 m segment by dividing the count by the surface area sampled in the segment. Since all of the belt transects were 2 m wide, the total area sampled by each 10 m segment was 20 m^2. Density on a transect was computed by computing the mean value of the 10 m segment densities. The individual transect was the sampling unit for analytical purposes.

Fish data were analyzed to aid in determining optimal sampling design for future research. We first examined fish densities in relation to depth, transect length, and visibility using linear regression and analysis of variance (ANOVA) to determine if variation in densities could be related to these factors. We then applied statistical power analysis techniques to estimate optimal transect length and number of transect replicates. The data used to examine transect lengths and replicates included both the raw data collected during the field survey and databases created from the raw data using re-sampling techniques. The re-sampling procedure involved repetitively building new transects by randomly selecting from the pool of 10 m segment data collected on the transects. To attempt to control some of the spatial and transect size variance, we used re-sampling techniques to generate large datasets based on 13 transects from the Orford/McKenzie's Reef areas. The original transects were broken into 10 meter segments (total of 59 segments), then we built a large number new transects by randomly selecting 10 m segments, with replacement, from the original dataset. This allowed us to model statistical power using different transect lengths and sample sizes.

We explored sampling design considerations using the following data sets and comparisons:

1) total fish density and black rockfish density by transect using the raw data to examine effects of sample size on sample variance,
2) total fish density by number of transects segments using re-sampled data to examine the effects of transect length on sample variance,
3) total fish density by number of transects using re-sampled 100 m transects to examine the effects of sample size on sample variance, and
4) total fish density comparing transect length with transect replicates to examine their combined effects on sample variance.

To explore sample size optimization, we framed one or more of the following questions for each comparison listed above:

1) What is the minimum sample size (n) for estimating the mean within an error limit of δ? δ is expressed as a proportion of the mean (e.g., 20% or 0.2). The formula for estimating n is (Gonor and Kemp 1978):

$$n = s^2/(\delta^2)(x^2) \qquad (1)$$

where s^2 is the sample variance and x is the sample mean.

2) What is the minimum sample size (n) for estimating the mean within a 95% Confidence Interval of $\pm\ \delta$? δ is expressed as a proportion of the mean (e.g., 20% or 0.2). The formula for estimating n is (Cochran 1977; Gonor and Kemp 1978):

$$n = (t_{\alpha[v]})^2(s^2)/(\delta^2)(x^2) \qquad (2)$$

where $t_{\alpha[v]}$ is the value from the t-distribution for a significance level of α at v degrees of freedom; s^2 is the sample variance; and x is the sample mean.

3) What is the minimum sample size (n) for detecting differences of δ between two means? δ is expressed as a proportion of the mean (e.g., 20% or 0.2). The formula for estimating n is (Sokal and Rohlf 1981):

$$n = (t_{\alpha[v]})^2(2s^2)/(\delta^2)(x^2) \qquad (3)$$

where $t_{\alpha[v]}$ is the value from the t-distribution for a significance level of α at v degrees of freedom; s^2 is the sample variance; and x is the sample mean. The pooled variance used in a t-test is represented by $2s^2$.

4) What is the minimum sample size (n) for being P% certain of detecting differences of δ between two means? δ is expressed as a proportion of the mean (e.g., 20% or 0.2). "P" represents the probability of avoiding a type II error. The formula for estimating n is (Sokal and Rohlf 1981; Snedecor and Cochran 1967):

$$n = (t_{\alpha[v]} + t_{2(1-P)[v]})^2(2s^2)/(\delta^2)(x^2) \qquad (4)$$

where $t_{\alpha[v]}$ is the value from the t-distribution for a significance level of α at v degrees of freedom; $t_{2(1-P)[v]}$ is the value from the t-distribution for a significance level of 2(1-P) at v degrees of freedom; s^2 is the sample variance; and x is the sample mean.

All of the above analyses are based on sample variance and provide different approaches for examining how sample replication effects the variance.

Results and Discussion

Habitat

We reviewed and recorded habitat types from videos of 16 sampling stations at Orford Reef and Redfish Rocks. Table 1 summarizes the habitat types observed. Boulders comprised the most common bottom type in the videos, followed by bedrock, then cobble/gravel.

Fish

We surveyed 18 sites that had visibilities >10 ft, totaling 1000 m of 2 m wide belt transects. We recorded a total of 10 species or groups of fishes including black rockfish (*Sebastes melanops*), blue rockfish(*S. mystinus*), china rockfish(*S. nebulosus*), juvenile rockfish (*Sebastes* spp.), cabezon (*Scorpaenichthys marmoratus*), lingcod (*Ophiodon elongatus*), kelp greenling (*Hexagrammos decagrammus*), rock greenling (*Hexagrammos lagocephalus*), sculpins (Cottidae spp.), and wolf eel (*Anarrhichthys ocellatus*). Table 2 shows mean densities of the 7 most common species or groups based on all transects combined.

The density data from the belt transects had relatively high variances, probably due primarily to the patchy distribution of the fish. Other factors that could have contributed to the variance in our samples include:

1) samples were spread spatially within Orford Reef and between Orford Reef and Redfish Rocks,
2) samples were spread temporally from June through September,
3) samples were from different habitat types,
4) we were in the beginning of a learning curve for sampling fish; we may have been more proficient in later samples,
5) visibility varied among samples,
6) length of transects varied from 40 m to 100 m,
7) observers had different skill levels, and
8) degree of search effort varied among observers.

Table 1. Summary of bottom types observed on the videos of fish transects.

Bottom Types		# of 10 m	Percent
Primary (>50%)	Secondary (20%-50%)	Segments	of Total
Bedrock-Dominated Bottom			
continuous level rock	continuous level rock	9	8.9%
continuous level rock	continuous sloping rock	2	2.0%
continuous level rock	vertical or overhang	5	5.0%
continuous level rock	pebble	1	1.0%
continuous level rock	sand	1	1.0%
pinnacle	continuous level rock	2	2.0%
Bedrock Subtotal		20	19.8%
Boulder-Dominated Bottom			
large boulder	large boulder	4	4.0%
large boulder	small boulder	12	11.9%
small boulder	small boulder	7	6.9%
small boulder	cobble	13	12.9%
small boulder	sand	15	14.9%
Boulder Subtotal		51	50.5%
Cobble- or Gravel-Dominated Bottom			
cobble	small boulder	3	3.0%
cobble	sand	1	1.0%
gravel	small boulder	6	5.9%
gravel	cobble	6	5.9%
Cobble/Gravel Subtotal		16	15.8%
Sand-Dominated Bottom			
sand	small boulder	10	9.9%
sand	sand	4	4.0%
Sand Subtotal		14	13.9%
Total		101	100.0%

Table 2. Mean densities (#/ha) and 95% confidence intervals (C.I.) of the 7 most frequently observed fish.

Species or Group	Mean Density (#/ha)	95% C.I.
black rockfish	514	399
blue rockfish	61	80
china rockfish	26	24
juvenile rockfish	757	1459
cabezon	39	39
kelp greenling	57	60
lingcod	43	37

We used linear regression and ANOVA analyses to explore the relationship between combined species density and depth, visibility, and transect length. The results were all non-significant at the 95% level (Table 3). We consider these results inconclusive because sampling was not specifically designed to test the above factors.

We first used fish density transect data from Orford Reef, McKenzie's Reef, and Redfish Rocks to examine the effects of number of transect replicates on statistical power. Based on density of all species combined, a sample size of 14 would be required to generate standard errors within 50% of the mean (Figure 1a) and a sample size of 50 would be required to obtain 95% Confidence Intervals of ±50% of the mean (Figure 1b). Respective sample size requirements for black rockfish alone would be 10 and 40 (Figures 1a and 1b). The relatively high sample size requirement resulted from the high variation in the samples, which resulted, in part, from combining samples that consisted of both 40 m and 100 m transects. As demonstrated below, data from short transects such as 40 m are highly variable, thus elevating the estimate sample size requirements. Also, the relatively wide spatial distribution of samples may have contribute to the elevated variances.

Table 3. Results of the linear regression and ANOVA analyses.

Statistical Test	Regression R2	Regression or ANOVA P
regression of fish density with depth	0.0002	0.95
regression of fish density with visibility	0.04	0.42
ANOVA on transect length		0.27

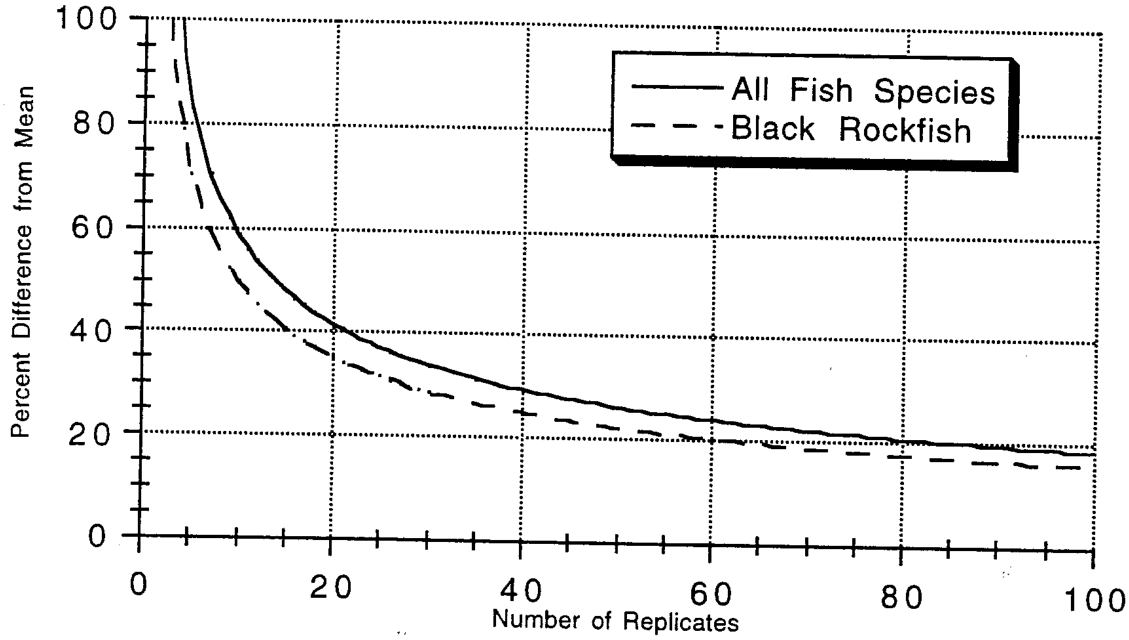

Figure 1a. Estimated standard error expressed as percent deviation from the mean as a function of number of transect replicates, based on transect data from all sampling stations.

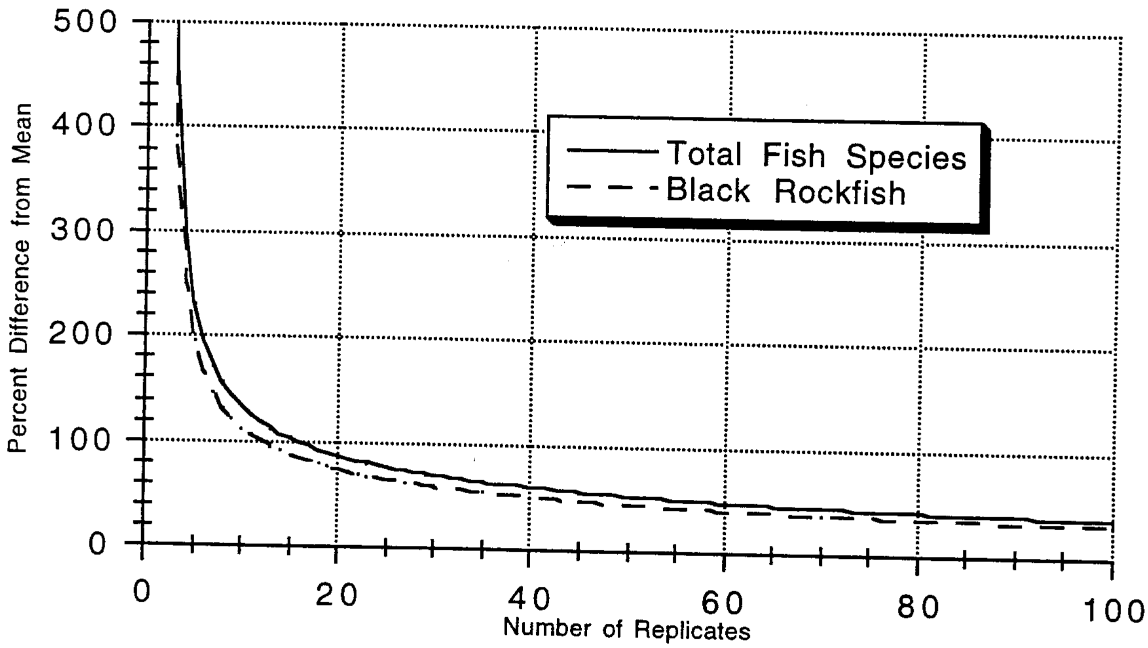

Figure 1b. Estimated 95% confidence interval expressed as percent deviation from the mean as a function of number of transect replicates, based on transect data from all sampling stations.

Use of transects generated from re-sampled data allowed us to further explore statistical power of the sampling while controlling some of the effects of spatial variance and transect length disparities. The power analyses based on re-sampled data need to be considered in light of the following:

1) the power analyses represent approximations only and are, in most cases, conservative,
2) the analyses assume that transects created from random combinations of 10 m segments will approximate actual transects, and
3) the density data are not normally distributed.

Fish were patchily distributed in our sampling area. When sampling patchy populations, precision of estimating the mean can be optimized by increasing the number of sampling units (Gerard and Berthet 1971). If we think of a transect as consisting of a number of 10 m sampling units, we can examine how sampling a successively greater number of 10 m segments affects the precision of estimating density along a transect. Increasing the number of 10m segments is analogous to increasing the length of the transect. Figure 2 shows the effects of increasing transect length on precision of estimating mean density. This figure was based on variance and mean total fish counts from the 59 ten-meter segments in the Orford and McKenzie's database. The curve begins to level off at 10 to 20 ten-meter segments (Figure 2), indicating that transect lengths of 100 to 200 meters would be most efficient at minimizing variance.

Using 100 m transects, we examined how statistical power is effected by varying the number of sample replicates. We randomly re-sampled our original dataset to create 1000 transects from all Orford and McKenzie's Reef data. Relative error in estimating the mean decreases with an increase in sample size (Figure 3). The decrease in error begins to slow at a sample size of 10 and begins to level off at a sample size of 20. The sample sizes for estimating means within a desired level of precision are lower than expressed in analogous graphs in Figure 1. These lower sample sizes result because variance is controlled in two ways: 1) the data are from a spatially less varied area (they do no include Redfish Rocks) and 2) all of the transects are 100 m in length rather than a mix of 40 m and 100 m transects. Figure 4 shows sample size requirements for statistically testing differences between means using re-sampled Orford/McKenzie's data. A sample size of 11 would be required to detect a difference of 50% between means at the 95% significance level (Figure 4).

In Figure 4, the chance of a Type I statistical error (incorrectly rejecting the null hypothesis when it is true - termed α error) is 5%. The computations do not address a Type II statistical error (incorrectly accepting the null hypothesis when it is false - termed β error). Figure 5 displays the relationship between sample size and detection differences incorporating a Type II error factor. The Type II error estimation factor is expressed as $t_{2(1-P)[v]}$ in formula (4) in the Methods section. For example, the curve labeled β=0.8 shows sample sizes required to have an 80%

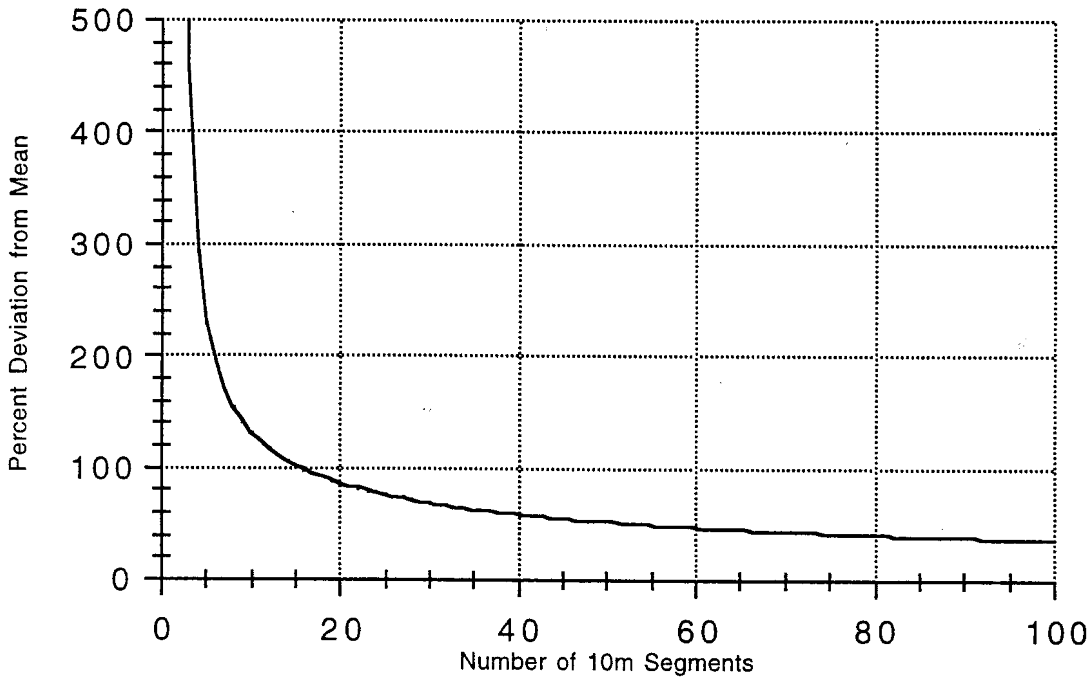

Figure 2. Estimated 95% confidence interval expressed as percent deviation from the mean as a function of number of 10 m transect segments. The data were derived by randomly re-sampling transect segment data from Orford and McKenzie's Reef.

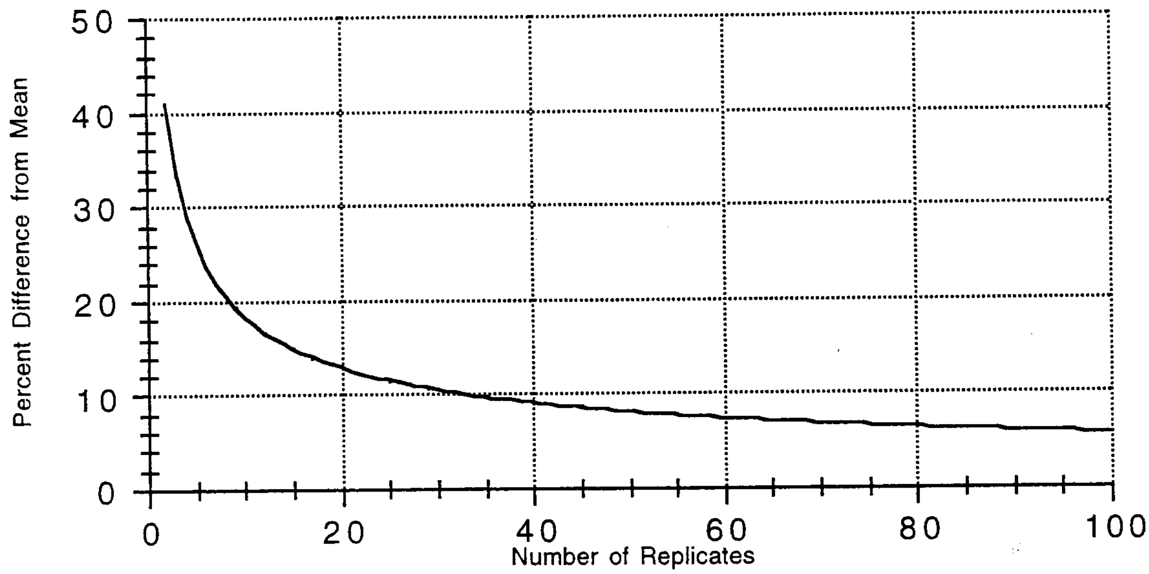

Figure 3a. Estimated standard error expressed as percent deviation from the mean as a function of number of transect replicates. This analysis is based on 100 m transects derived by randomly re-sampling transect segment data from Orford and McKenzie's Reefs.

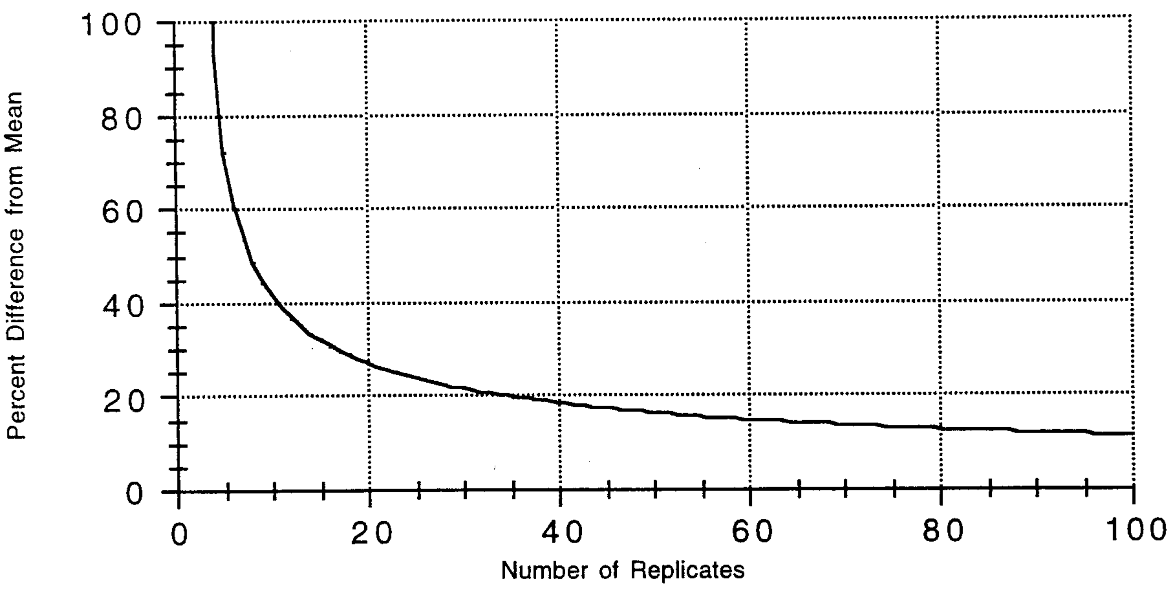

Figure 3a. Estimated 95% confidence interval expressed as percent deviation from the mean as a function of number of transect replicates. This analysis is based on 100 m transects derived by randomly re-sampling transect segment data from Orford and McKenzie's Reefs.

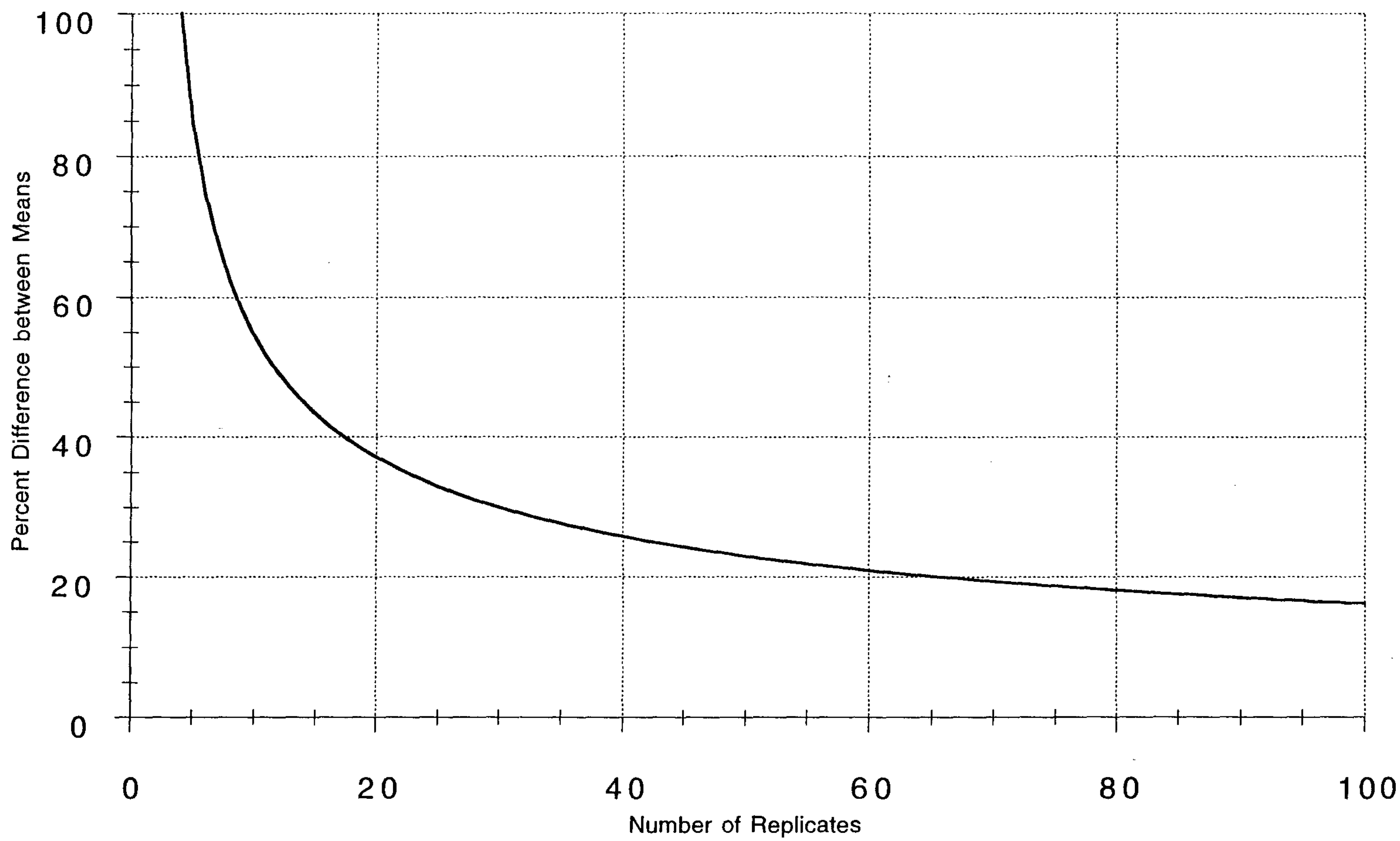

Figure 4. Estimated sample size requirements for detecting a difference between two means (expressed as percent of the mean) at an α-level of 0.95. This analysis is based on 100 m transects derived by randomly re-sampling transect segment data from Orford and McKenzies Reefs.

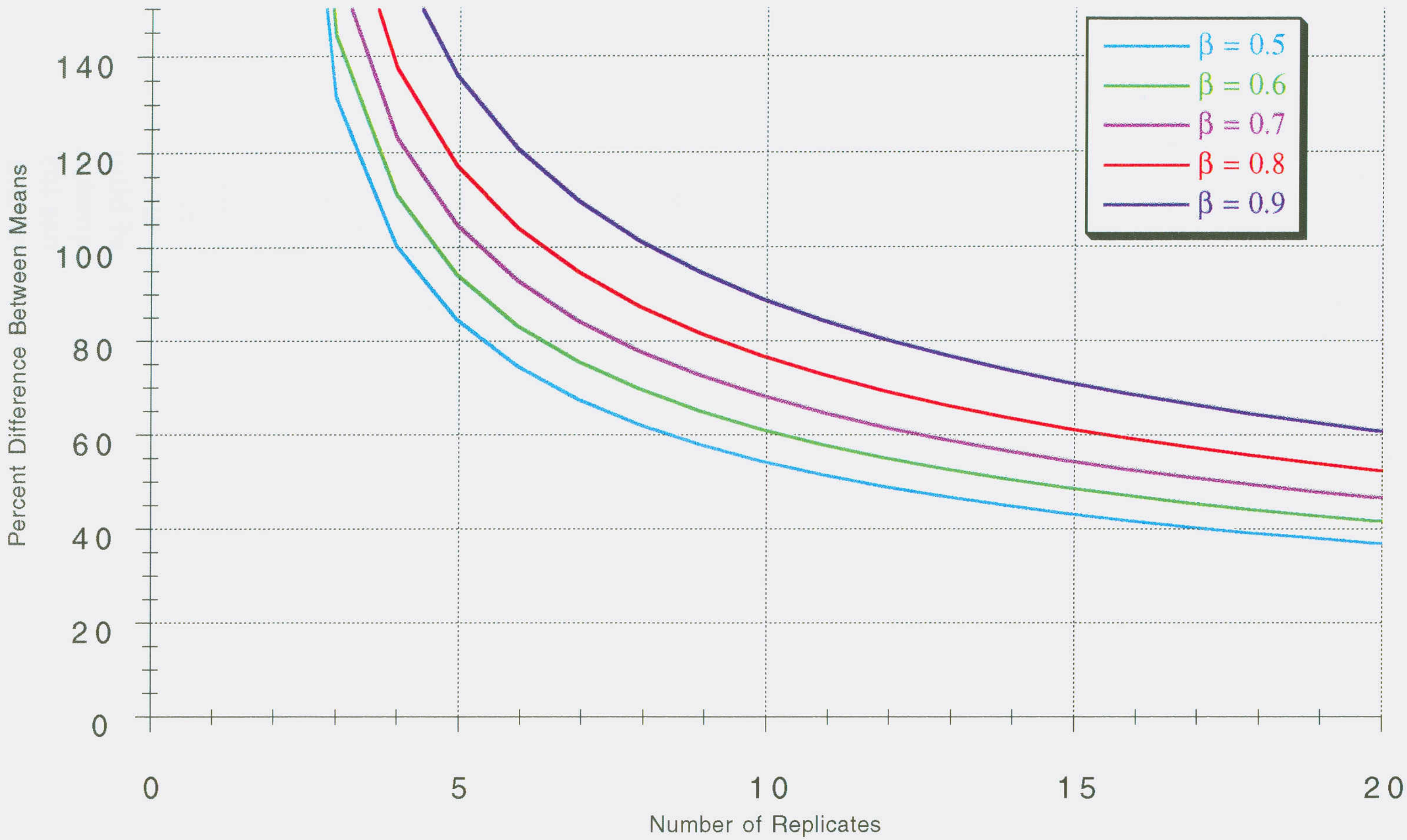

Figure 5. Estimated sample size requirements for detecting a difference between two means (expressed as percent of the mean) at an α-level of 0.95 and β-levels ranging from 0.5 to 0.9. This analysis is based on 100 m transects derived by randomly re-sampling transect segment data from Orford and McKenzies Reefs.

chance of correctly detecting a desired difference between means at the 95% significance level. In other words, if the null hypothesis is rejected, the chance of committing a Type I error is 5% and, if the null hypothesis is accepted, the chance of committing a Type II error is 20%. The curve labeled β=0.5 is the same as the curve in Figure 4 that does not incorporate an estimation factor for Type II error because, at a β of 0.5, the factor $t_{2(1-P)[v]}$ is zero (Sokal and Rohlf 1981).

Constructing an optimal sampling design requires combining the analysis of transect length and sample size with knowledge of what is practical and safe to execute while SCUBA sampling, and desired statistical detection limits of the study. Figure 6 shows the relationship between number of replicates and the detection differences between two means for 6 transect sizes: 10 m, 30 m, 50 m, 100 m, 150 m, and 200 m. As expected, the shorter transects require a larger sample size for a given detection level of differences between means. However, shorter transects also take less effort to complete. In a SCUBA survey, our unit of sampling effort is the individual dive. For Figure 6 to be useful in planning our sampling procedures the sampling requirements need to be expressed in terms of number of dives. Figure 7 shows the effect of transect size on detection limits based on number of dives required. The dive numbers were based on the following assumptions:

10 m transects - can complete 10 transects per dive
30 m transects - can complete 3 transects per dive
50 m transects - can complete 2 transects per dive
100 m transects - can complete 1 transect per dive
150 m transects - can complete 1 transect per dive
200 m transects - can complete 1 transect per two dives

At a sampling effort of 10 dives, 150 m transects are the most efficient, followed by 10 m transects. Transects of 100 m and 50 m are tied for third most efficient (Figure 7). The 30 m and 200 m transects are the least efficient.

The practicality and desirability of the different transect lengths also need to be considered before selecting an appropriate design. The most efficient transect length, 150 m, would be the most desirable if we could be certain of consistently completing transects of that length. This may be possible in shallow water surveys (less than 40 ft deep) but experience has show that using our standard ocean dive procedures, transect lengths of 150 m would often be impractical at the 50-80 ft depths typical of our sampling at Orford Reef. The next most efficient transect length, 10 m, could be desirable in some situations, but poses several potential problems in our sampling program. First, it is difficult to ensure each 10 m transect is an independent sample from the others on the dive. Clearly, simply dividing a 100 m transect into ten 10 m transects runs counter to statistical assumptions about independence of samples. California Fish and Game biologists in Monterey use 10 m transects in fish sampling work and have developed a method of increasing the independence of samples by swimming a distance from the end of one transect before beginning the next (Dave VenTresca, pers. comm 1996). They are able to

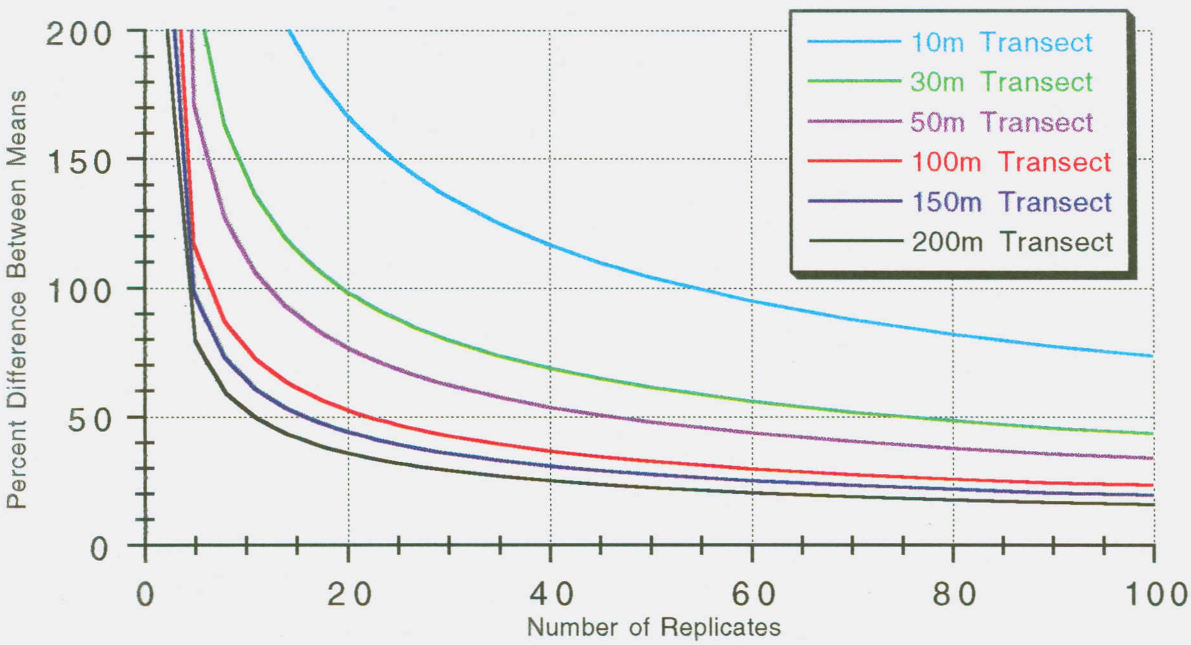

Figure 6. Estimated sample size requirements for detecting a difference between two means (expressed as percent of the mean) at an α-level of 0.95 and a β -level of 0.8 for transects ranging from 100-200 m long. This analysis is based on 100 m transects derived by randomly re-sampling transect segment data from Orford and McKenzie's Reefs.

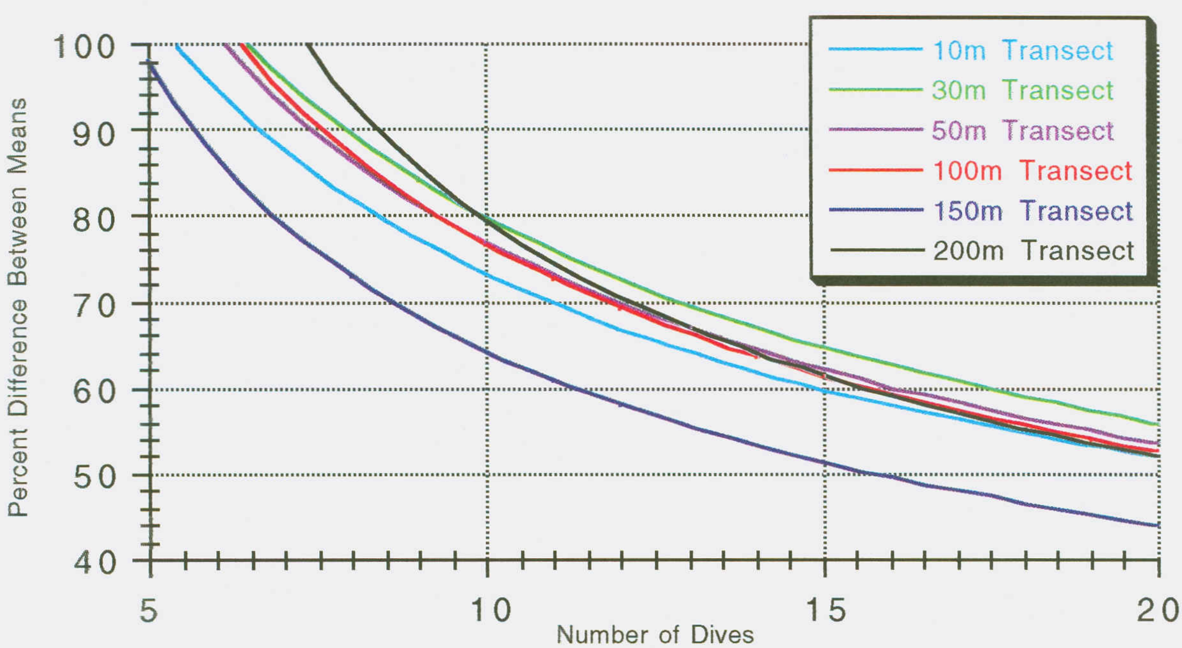

Figure 7. Estimated number of sampling dives for detecting a difference between two means (expressed as percent of the mean) at an α-level of 0.95 and a β -level of 0.8 for transects ranging from 100-200 m long. This analysis is based on 100 m transects derived by randomly re-sampling transect segment data from Orford and McKenzie's Reefs.

complete 15 transects per dive. The short transects offer them another advantage because the reefs they are sampling consist of patches of rocky habitat among sandy areas. Thus the small transects are less likely to move off of rocky habitat. The short transects, however, may not be desirable in our sampling program for three reasons. First, in our ocean diving, we prefer to maintain connection with the boat anchor using a transect line for safety purposes. The technique of separating the 10 m transects requires that this connection be lost, and would require an unconnected diver ascent and live-boat diver retrieval. Second, beginning the transect at the anchor line allows us to position our transects within the error limits of our GPS. Since some of our sampling will be within fixed plots of relatively small size, we require the capability of ensuring that we stay within the plot. Third, fish densities are often relatively low on the reefs we are sampling, thus short transects would result in many zeros in the data. For example, 49% of our 10 m segments had no fish. The large number of zeros causes the data, which are already skewed, to be more highly skewed. Having multiple zeros also causes the variance to be artificially low because the zeros do not vary widely from the already low mean density value. In fact, the apparently higher statistical power shown for our hypothetical 10 m transects may have resulted from artificially low variances caused from the high proportion of zeros. It may be possible to solve some of these problems by designing different transect methods, changing dive procedures, and relying on a dive tracker system for precision navigation; however, these changes may not be worth the small potential gain in statistical power. Therefore, the next most efficient transect length, 100 m, appears to be the best practical alternative for our sampling program.

We believe that the above analyses of statistical power are conservative and we will be able to detect smaller differences by controlling variances. The data used for this analysis covered a relative large area, were associated with several different types of bottom habitat and were spread out over several months. We can design studies to control this spatial, habitat, and temporal variability. Sampling for a study designed to examine kelp harvest impacts would be confined within relatively small plots (e.g., 200 m x 600 m, or 12 ha). We can presume that the variation in the fish populations within these plots will be smaller than the 250 ha area represented by our Orford and McKenzie's Reef samples. We can select treatment and control plots with similar bottom types based on the results of our side-scan sonar survey. Depending on weather, we may be able to condense the sampling to two or three consecutive weeks rather than the three month span of the sampling used for this analysis. Part of the variation in the data may have also resulted from differences in observer skill level. We were in the process of developing and learning methods during the 1995 work. We should be able to apply the methods more consistently in 1996.

Recommendations

Video Habitat Sampling

1) Obtain differential GPS capabilities to more precisely correlate our video data with the side-scan sonar data.
2) Before each dive, take a few seconds of footage of a sign board showing the sample/station number.
3) Apply the following video techniques consistently:
   - swim approximately 1 m - 2 m above the transect line
   - hold the camera at approximately a 45° angle toward the bottom. Install a bubble level on the camera housing for reference.
   - avoid tilting the camera from side to side
   - stop and pan at high relief features or sudden changes in habitat whenever possible. Always return the video to the same point on the transect line before proceeding.
4) Record incidental habitat observations on a data sheet immediately after each dive.

Fish Sampling

1) Measure underwater horizontal visibility with a Secchi disk to ensure visibility is adequate for fish transects and to gather data needed to test whether visibility biases our data.
2) Limit observations in our belt transects to a height of 2 m above the bottom. Typically, fish observed >2 m off the bottom are schools of blue or black rockfish. We should note the presence of these schools, but only count the fish within 2 m of the bottom.
3) While conducting the transects, look in crevices to ensure we are consistently counting juvenile rockfish and some of the larger fish that often hide in crevices (e.g., china rockfish, cabezon, wolf eels). We should use a light when searching the crevices.

Appendix B: Habitat Type Recording Form

Date:________ Tape Number:________

Location:___________ Video Count:________to_______

Dive/Transect Number:____________

	Bottom Habitat				Percent Algal Cover		
	Primary Habitat > 50%	Primary Modifier	Secondary Habitat >20 -<50%	Secondary Modifier	Subcanopy	Herbaceous	Turf
0-10m							
10-20m							
20-30m							
30-40m							
40-50m							
50-60m							
60-70m							
70-80m							
80-90m							
90-100m							

Mud (M): 0-0,0625mm
Sand (S): 0.0625mm-2mm
Pebble (P): 2mm-6.4cm

Cobble (C): 6.4cm-25.6cm
- Cobbles Bedded in Sediment (C1S)
- Cobble Not Bedded in Sediment (C1N)

Small Boulder (B): 25.6cm-1m
- Contiguous Boulder Field (B1)
  - Boulders Bedded in Sediment (B1S)
  - Boulders Not Bedded in Sediment (B1N)
- Non-Contiguous Boulder Field (B2)
  - Boulders Bedded in Sediment (B2S)
  - Boulders Not Bedded in Sediment (B2N)

Large Boulder (L): 1m-3m
- Contiguous Boulder Field (L1)
  - Boulders Bedded in Sediment (L1S)
  - Boulders Not Bedded in Sediment (L1N)
- Non-Contiguous Boulder Field (L2)
  - Boulders Bedded in Sediment L2S)
  - Boulders Not Bedded in Sediment (L2N)

Algae Cover
1 = 0-25%
2 = 25-50%
3 = 50-75%
4 = 75-100%

Continuous Level Rock (F): 0-45 degrees
- High Relief Continuopus Rock (F1)
- Low Relief Continuous Rock (F2)

Continuous Sloping Rock (R): 45-80 degrees
- High Relief Continuous Rock (R1)
- Low Relief Continuous Rock (R2)

Vertical or Overhanging Rock (V): >80 degrees
Pinnacle Top (T): Feature >2m
Crevice (K): Crack 1m-3m wide and >1m deep

[BOTMDATA]