Coastal Zone Management Section 309 Grant:

1997 Kelp / Reef Habitat Assessment

Final Grant Report
Contract No. 97-52

Prepared by

Bruce Miller
David Fox
Arlene Merems
Mark Amend

Oregon Department of Fish and Wildlife
Marine Program

December 31, 1997

This assessment was funded in part by the Oregon Departmen of Land Conservation and Development Coastal Management Program through a Section 309 Program Enchancement Grant from the Office of Ocean and Coastal Resource Managment, National Oceanic and Atmospheric Administration.

Coastal Zone Management Section 309 Grant:

1997 Kelp/Reef Habitat Assessment

Final Grant Report
Contract No. 97-82

Prepared by

Bruce Miller
David Fox
Arlene Merems
Mark Amend

Oregon Department of Fish and Wildlife
Marine Program

December 31, 1997

Contents

Acknowledgments

This project could not have been completed without the generous contributions from many individuals. In addition to the authors, our core dive team included John Schaefer, June Mohler, and Vicki Hoover Krutzikowsky. Divers from the Oregon Coast Aquarium also assisted in the sampling effort. Dr. Alan Shanks, Oregon Institute of Marine Biology, and Bob Hannah, ODFW, provided insight and review for the physical oceanographic section. Jim Golden, ODFW, provided useful review comments on the report. We would also like to thank the Port of Port Orford for logistical support. Special thanks are due to Bob Bailey for his continued support of our work.

List of Tables

List of Figures

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 nearshore reefs are in state waters, Oregon is responsible for managing these habitats to sustain their long-term use and productivity. Resource managers lack scientific information about the organisms and habitats on Oregon's nearshore (<50 m deep) rocky reefs. 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 change physical habitats for a variety of species. Detecting habitat 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. Thus, 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 1997 (year 3 of the study). The study area includes Blanco, Orford, Redfish Rocks, Humbug Mountain, and Rogue reefs. In 1996, studies focused on the relationships among fish communities and rocky reef habitats, estimating kelp bed biomass, and examining seabird use of kelp (Fox, et al. 1996). Kelp biomass was low and very limited in extent during 1996, precluding an evaluation of the impact of kelp harvest on associated fish communities. Kelp biomass was higher in 1997, providing an opportunity for limited experimental harvest and an evaluation of kelp harvest / fish community interactions. Although this evaluation was planned for 1997, a series of strong storms beginning in mid-September removed most of the kelp at Orford Reef, precluding experimental harvest and evaluation of harvest effects on associated fish communities.

This report includes estimates of bull kelp (*Nereocystis luetkeana*) biomass at Orford, Blanco, Redfish Rocks, Humbug Mountain, and Rogue reefs for 1997, and compares data on fish abundance collected in 1997 to data collected in comparable benthic habitat at Orford Reef in 1996. This report also provides a spatial and temporal view of water mass attributes at Orford Reef during 1997 based on results of 2 CTD surveys and a time-series of water temperature recorded at 3 offshore moored stations. The final section of the report is a kelp management analysis updated from Fox, et al. (1996).

1.1 Grant Tasks

A Coastal Zone Management Section 309 grant provided a portion of the funding for the 1997 kelp/reef work. This document and related reports summarize work performed under the grant. The grant outlined four work tasks:

Task A: Field Sampling Plan,
Task B: Reef Field Studies,
Task C: Management Analysis, and
Task D: Kelp-Reef Regional Ecosystem Analysis.

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

Task A, Subtask 1: Analyze 1996 field work - Fox, et al. (1996) presents the analysis of 1996 field work.

Task A, Subtask 2: Review and refine as necessary scientific research program for examining nearshore reef ecology - Our review dealt primarily with examining specific field methods and statistical study design. The "methods" subsections of sections 2 through 4, below, provide further detail on the sampling.

Task A, Subtask 3: Develop sampling design for 1997 work - The sampling design is reflected in the "methods" subsections of sections 2 through 4, below.

Task B, Subtask 1: Conduct field sampling - Section 2 through 4, below, describe the field sampling effort.

Task B, Subtask 2: Analyze data from field work and aerial photos - Section 2 through 4, below, describe the results of field and aerial photograph analysis.

Task C, Subtask 1: Prepare management analysis - Section 5, below, presents the management analysis.

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

Task D, Regional Ecosystem Analysis - A separate report scheduled for completion in June 1998 will summarize the results of this work task.

2. Kelp Biomass

2.1 Methods

The total biomass of kelp was estimated following methods used in the 1996 Kelp/Reef Habitat Assessment (Fox, et al. 1996). The biomass estimate is based on three main components; surface area of kelp on the ocean surface, kelp plant density derived from kelp canopy percent cover estimates, and weights of individual plants. For a complete description of the biomass estimate methods refer to Fox, et al. (1996) and Foreman (1975).

Kelp beds at Orford, Blanco, Redfish Rocks, Humbug and Rogue reefs were photographed on September 20, 1997, between 11:45 and 12:26 at an approximate tidal height of +1.3 meters under contract with Bergman Photography (Portland, Oregon). All specifications for the photography were the same as in 1996, with the exception of the camera focal length. The photographer used either a 6 or 12 inch lens, which allowed him to adjust flying altitude between 3,600 and 7,200 feet while maintaining a constant photographic scale of 1:7200. The flexibility in flying altitude allowed the pilot to compensate for changes in cloud cover and sun angle which can affect the quality of the photographs.

Kelp plant weights were sampled at Orford, Blanco, Redfish Rocks, and Humbug reefs on September 2 and 3, 1997. Rogue Reef was not sampled because of difficulty accessing the reef due to hazardous ocean conditions. At each reef sampled, an average of 10 plants were collected from up to 10 beds, providing a total of 102 plants at Orford and Blanco reefs, 99 from Redfish Rocks Reef and 80 from Humbug Reef. The blades and bulb of each plant, trimmed to 10 cm below the bulb, were placed in a basket to drain, then weighed individually. Plants were weighed using an electronic balance (Weigh-Tronix, Inc., Model QC 3265, Fairmont, Mn) set to display weights averaged over several seconds, to minimize the effects of vessel motion. Plant weights were compared between reefs to determine if data from multiple reefs could be pooled in order to increase sample size for the biomass estimate.

Kelp density was estimated by converting a percent cover estimate kelp canopy to density using the KIM-1 method developed by Foreman (1975). Canopy percent cover was obtained using a point-intercept sampling method similar to the 1996 methods (Fox, et al. 1996), with the exception of sampling rate. The sampling rate for this year's data was increased from 1 grid per .73 ha of kelp to 1 grid per 1.2 ha.

Surface area was obtained from the aerial photographs. The kelp beds were digitized from aerial photographs and incorporated into a GIS using similar methods as in 1996 (see Fox, et al. 1996). Individual maps were created for each photograph, then all maps were merged into one map, providing that horizontal control was adequate. Horizontal control was obtained using control points from the

1996 kelp photographs, 1993 rocky shoreline photographs, and USGS 7.5 minute Quadrangles. Horizontal control enabled the maps to be transformed from a no-projection metric (NPM) coordinate system to the Universal Transverse Mercator (UTM) projection. Surface areas of kelp beds at each reef were calculated in UTM for maps that had adequate control and in NPM for maps without adequate control.

We compared the three components of the biomass estimate (plant weight, percent cover, and surface area) between 1996 and 1997 to determine how these individual components varied with time, and how differences, if any, affected the biomass estimate. Analysis of Variance (ANOVA) was performed on the log-transformed data for plant weight and on the arcsin-transformed data for percent cover. Surface area and biomass estimates are not comparative statistically, but are presented in tabular form.

2.2 Results and Discussion

2.2.1 Kelp Plant Weight

Plant weights were log-transformed to meet the ANOVA assumption of normality. The ANOVA showed a significant difference between the means (p = 0.0002). The post hoc test, Scheffe's S test, determined significant differences between Blanco and Orford (p= 0.0261), Blanco and Humbug (p = 0.0019), Orford and Humbug (p = 0.0001) and Orford and Redfish (p = 0.0001). There was no significant difference in weights between Humbug and Redfish (p = 0.5717) and between Blanco and Redfish (p = 0.7826). Since Humbug is closer in proximity to Redfish and experiences similar localized currents and wave conditions to Redfish than to Blanco, we pooled weights from Humbug and Redfish reefs for the biomass analysis.

Rogue Reef was not sampled for plant weights so we applied data from Orford Reef to use for the biomass calculation, since these reefs are probably most similar. In 1996, the pooled weights of Orford and Blanco reefs used for the biomass estimate were also used to represent Rogue Reef weights. Table 2.1 summarizes the pooled plant weight data and associated statistics used in the biomass estimate.

Table 2.1 Mean pooled kelp plant weights and statistics for 1997. † and * denote how reefs were pooled.

Reef	Mean weight (kg)	Sample Size	Variance	Standard Error
Blanco	2.505	102	2.232	0.148
Orford	3.817 pooled *	102	8.988	0.297
Redfish	1.837 pooled †	179	1.199	0.082
Humbug	1.837 pooled †	179	1.199	0.082
Rogue	3.817 pooled *	102	8.988	0.297

2.2.2 Percent Cover / Density

Table 2.2 shows percent cover of kelp by reef. Percent cover and density was highest at Redfish Rocks. This is primarily due to the structure of the kelp beds. Redfish Rock plants tended to be in tighter, more discrete clusters, and beds were more easily definable, where as on other reefs, plants were more loosely associated, thus making defining beds more ambiguous. This is largely an artifact of our interpretation of what constitutes a kelp bed, and may need more refining in future assessments.

Table 2.2. Kelp canopy percent cover.

Reef	Mean Percent Cover	Sample Size	Standard Error of Percent Cover
Blanco	6.92	139	0.71
Orford	4.39	194	0.31
Redfish	12.34	44	1.83
Humbug	9.34	36	1.31
Rogue	3.36	37	0.49

2.2.3 Surface Area

Of the 26 photographs digitized, 8 had insufficient horizontal control for accurate transformation to the UTM projection. Inaccurate transformation distorts the shape and size of the beds which affects the surface area calculations. Transformation accuracy was generally within 15 meters, with 4 photos within 30 meters accuracy. Poor transformation was as much as 400 meters off in the worst case. Surface area calculations for beds with poor control were obtained from the NPM maps with an average error of 5%. Surface areas for the individual reefs are as follows: Blanco = 113 ha, Orford = 155 ha, Redfish = 36.6 ha, Humbug = 33 ha, and Rogue = 29.1 ha.

In order to display all kelp beds on the same map, individual photograph maps must be in the same geographic projection. After surface areas were obtained, the NPM maps were transformed to UTM and the beds were slightly repositioned for the purpose of graphic representation. The maps are presented in Figures 2.1 a,b, and c.

2.2.4 Kelp Biomass

The total kelp biomass for 1997 is 8,137 tons ± 2,234 tons (95% confidence interval). This amounts to 22 tons / ha (Table 2.3). The total harvestable biomass within the Oregon Division of State Lands experimental harvest lease area which consists of Blanco, Orford, Redfish and Rogue Reefs is 7,571 tons ± 2,052 tons (95% confidence interval).

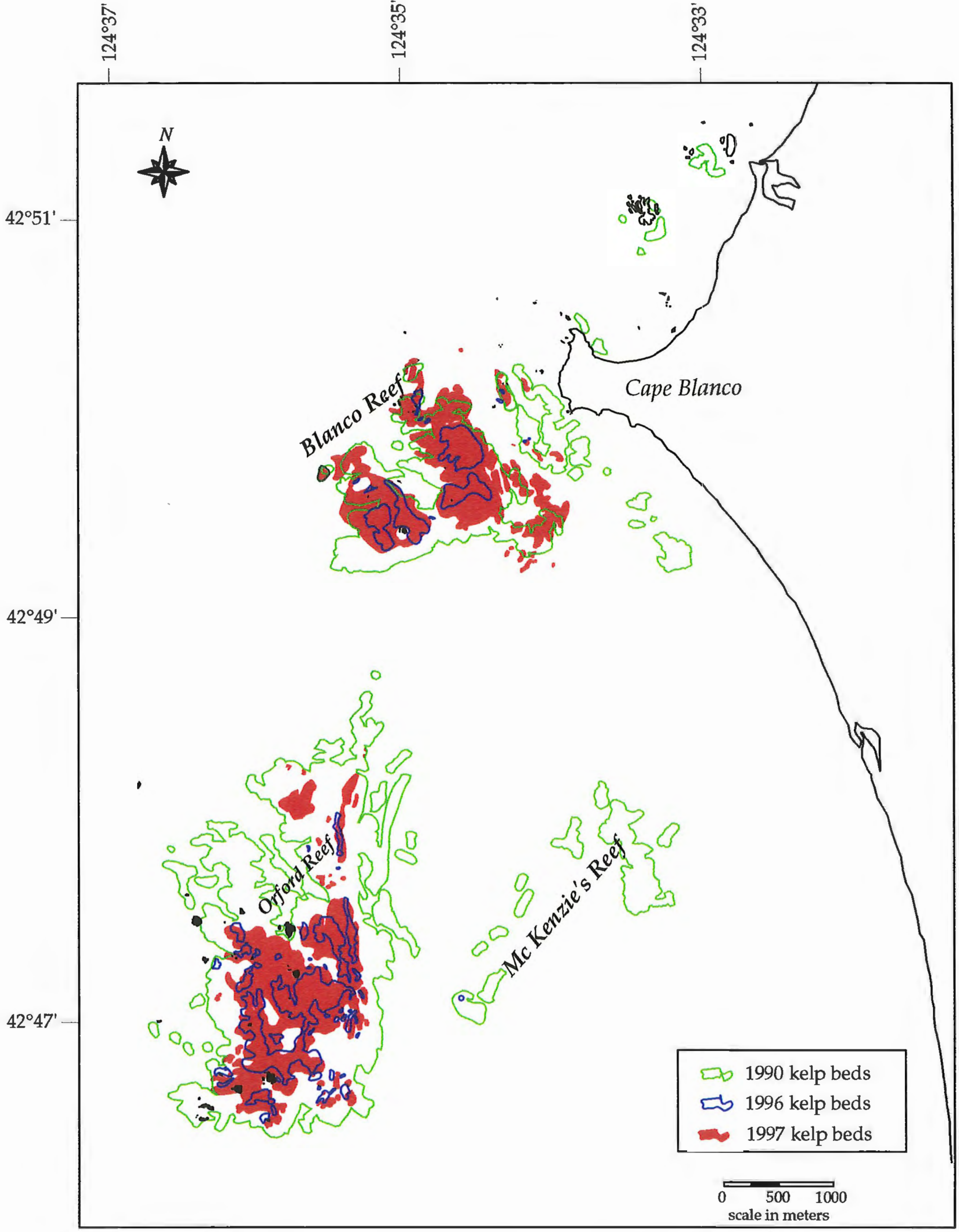


Figure 2.1a. 1990, 1996 and 1997 kelp beds on Orford, McKenzie's, and Blanco Reefs.

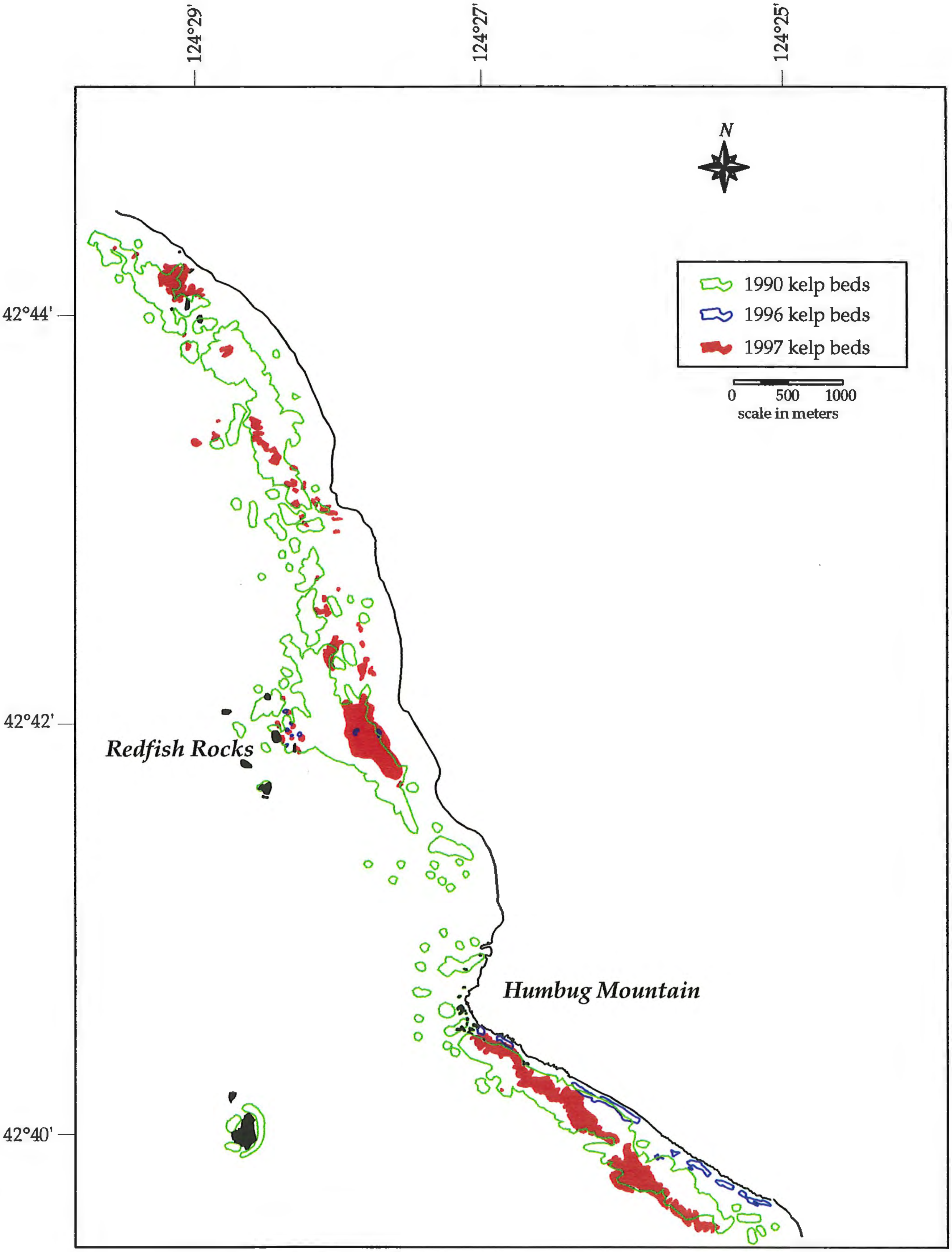


Figure 2.1b. 1990, 1996 and 1997 kelp beds at Redfish Rocks and Humbug Mountain Reefs.

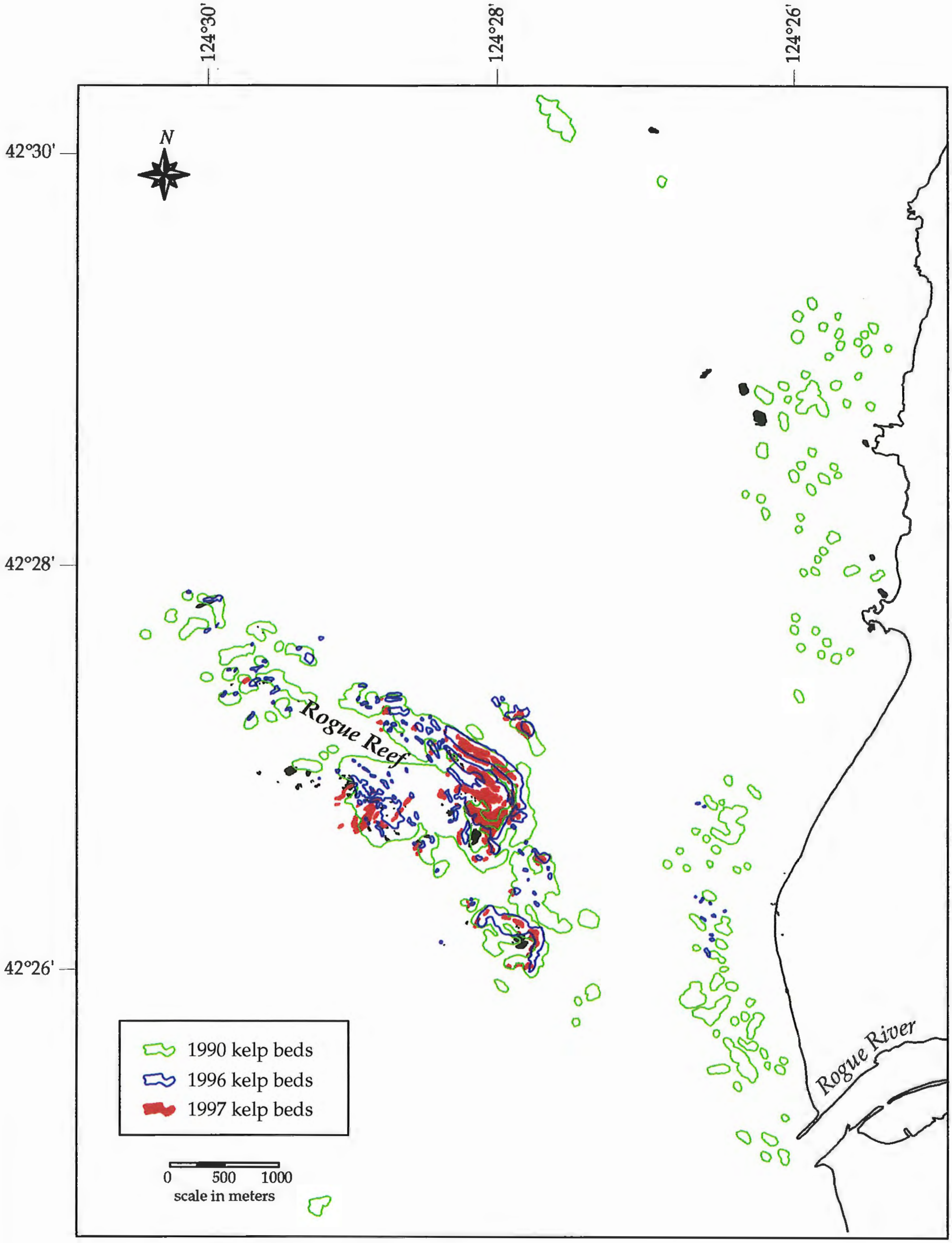


Figure 2.1c. 1990, 1996 and 1997 kelp beds on Rogue Reef.

Table 2.3. Kelp bed biomass.

Reef	Biomass (tons)	Standard Error	95% Confidence Interval	90% Confidence Interval	tons / ha
Blanco	2259	486	953	797	20
Orford	3900	1003	1965	1645	25
Redfish	743	115	226	189	20
Humbug	566	93	182	152	17
Rogue	669	189	370	310	23
Totals	8137	1140	2234	1870	22

2.2.5 Annual Variation

Table 2.4 compares the components of the biomass analysis between 1996 and 1997. Blanco and Orford had significantly lower plant weights in 1997 compared to 1996 based on results of ANOVA. (p=0.0001 and p=0.0053, respectively). Percent cover at both Orford and Rogue reefs was significantly lower in 1997 than 1996 (p=.0001 for both). Blanco and Redfish reefs appeared lower in 1997, though not significantly. Humbug had the only apparent increase in percent cover, also not statistically significant.

Table 2.4. Comparison of biomass estimate components for all reefs for 1996 and 1997. † denotes significant differences from the 1996 means.

Reef * Year	Mean Plant Weight (kg) unpooled	Mean Plant Weight n	Mean Percent Cover	Percent Cover n	Mean Density Plants/ha	Surface Area (hectares)	Biomass Estimate (tons)
Blanco * 96	5.04	44	8.99	42	8324	33.21	1717
Blanco * 97	2.51 †	102	6.92	139	7270	112.54	2259
Orford * 96	5.61	72	9.23	77	8446	65.60	3442
Orford * 97	3.82 †	102	4.39 †	194	5983	154.90	3900
Redfish * 96	2.19		25.17	6	16569	0.31	13
Redfish * 97	2.03	99	12.34	44	10031	36.58	743
Humbug * 96	not sampled	0	6.05	18	6828	13.54	574
Humbug * 97	1.60	80	9.34	36	8504	32.89	566
Rogue * 96	not sampled	0	14.13	99	10945	66.51	4522
Rogue * 97	not sampled	0	3.36 †	37	5455	29.13	669
	Average	Total	Average	Total	Average	Total	Total
1996	5.41	176	10.79	242	9243.02	179.18	10267
1997	2.97	383	6.33	450	6968.17	366.03	8137

While surface area is not statistically comparable, it can be expressed as the percentage increased or decreased from previous years. (Table 2.5). Kelp beds at Blanco, Orford, Redfish and Humbug Reefs had increases in total surface area from 1996, while Rogue Reef experienced a decrease. The increases were impressive; over

200% for Blanco, Orford and Humbug Reefs, and 118,000% for Redfish Reef. Rogue Reef decreased in area by 44%. Compared to 1990 amounts, only Blanco Reef was similar in total surface area. The other 4 reefs were smaller in size by 50% or greater.

Table 2.5. Kelp bed surface areas for 1990, 1996, and 1997.

Reef	1997 area (ha)	1996 area (ha)	1990 area (ha)	% change from '96
Blanco	112.54	33.21	100.9	+ 338.88
Orford	154.89	65.6	313.47	+ 236.13
Redfish	36.57	0.31	78.43	+ 11799.35
Humbug	32.88	13.54	46.63	+ 242.88
Rogue	29.12	66.51	77.74	- 43.80
Total	366.03	179.18	617.17	204.28

The total biomass estimate for 1997 is 8,137 tons; 79% of the 1996 estimate, despite the 200% overall increase in total kelp bed area for 1997. The lower biomass estimate for this year is directly attributed to lower plant weights and lower plant densities within the beds.

There was some expectation that surface area alone might provide enough information to determine biomass, provided the other variables were fairly constant between years. However, based on these past 2 years' data, it is apparent that surface area alone cannot be used to estimate biomass. For the time being then the three variables, plant weight, plant density, and surface area, must continue to be sampled for annual biomass estimates. It is conceivable though that with the collection and analysis of multiple years data for kelp biomass and kelp dynamics, our ability to estimates these parameters without direct measurement may become possible, thereby enabling resource managers to estimate biomass with minimum economic investment over the long term.

3. Fish

3.1 Methods

Fish surveys were designed to determine kelp harvest effects on fish. The experimental design included three treatment (kelp harvest) plots and three control (no harvest) plots within areas of surface kelp east of the emergent rocks at Orford Reef (Figure 3.1). Control plots were included in the design to account for the time difference between pre- and post-harvest fish surveys. The plots measured 50 x 100 m with the long axis of each plot aligned approximately northwest-southeast, permitting fish transects to be aligned with the long axis of the plot and parallel to the predominant swell and current direction. Adjacent treatment and control plots had similar depths and bottom morphology.

Divers, equipped with SCUBA gear, counted fish along four 90 m benthic belt transects within each treatment and control plot. Transects started at various points along the southern edge (short axis) of each plot, and fish counts started at 5 m in from the plot edge. Transects within a plot were parallel, with adjacent transects no closer than 5 m. No more than 2 transects per plot were sampled in a single day. Fish surveys were only conducted when water visibility exceeded 3 m.

Two divers conducted each belt transect using a spooler and line marked at 10 m intervals. Fish were counted within an area 2 m wide, 3 m high and 3 m in front of the observer, and recorded at 10 m intervals along the transect. One diver recorded all fish species above the bottom within the count area, while the second diver concentrated on benthic habitat and counted only fish found on the bottom. On the return swim, one diver would swim along the transect line counting kelp stipes encountered within a 1 m wide belt, then record both stipe density and bottom morphology types (from a coded list) at 10 m intervals. The second diver followed behind to spool in the transect line.

In addition to the benthic transects, fish were also counted along three subcanopy transects within the same kelp beds comprising the treatment plots. Two divers were dropped near the upcurrent edge of a plot, or at either edge if there was no discernible current. Divers swam at approximately 5 m depth, just under the kelp canopy, along a fixed compass bearing for a total of 5 minutes. Length of each transect was determined by recording start and stop points using a differential-correction global positioning system (DGPS). One diver was responsible for maintaining depth and heading while the second diver counted all fish visible within a 2 m wide belt in front and above the count diver. Fish that were observed below the divers were not included in subcanopy counts. In all cases, these fish were associated with shallow bottom features (e.g. tops of pinnacles or ridges).

Fish counts within paired control / treatment plots were tested for equality with a two-factor analysis of variance, with treatment and plot being the factors.

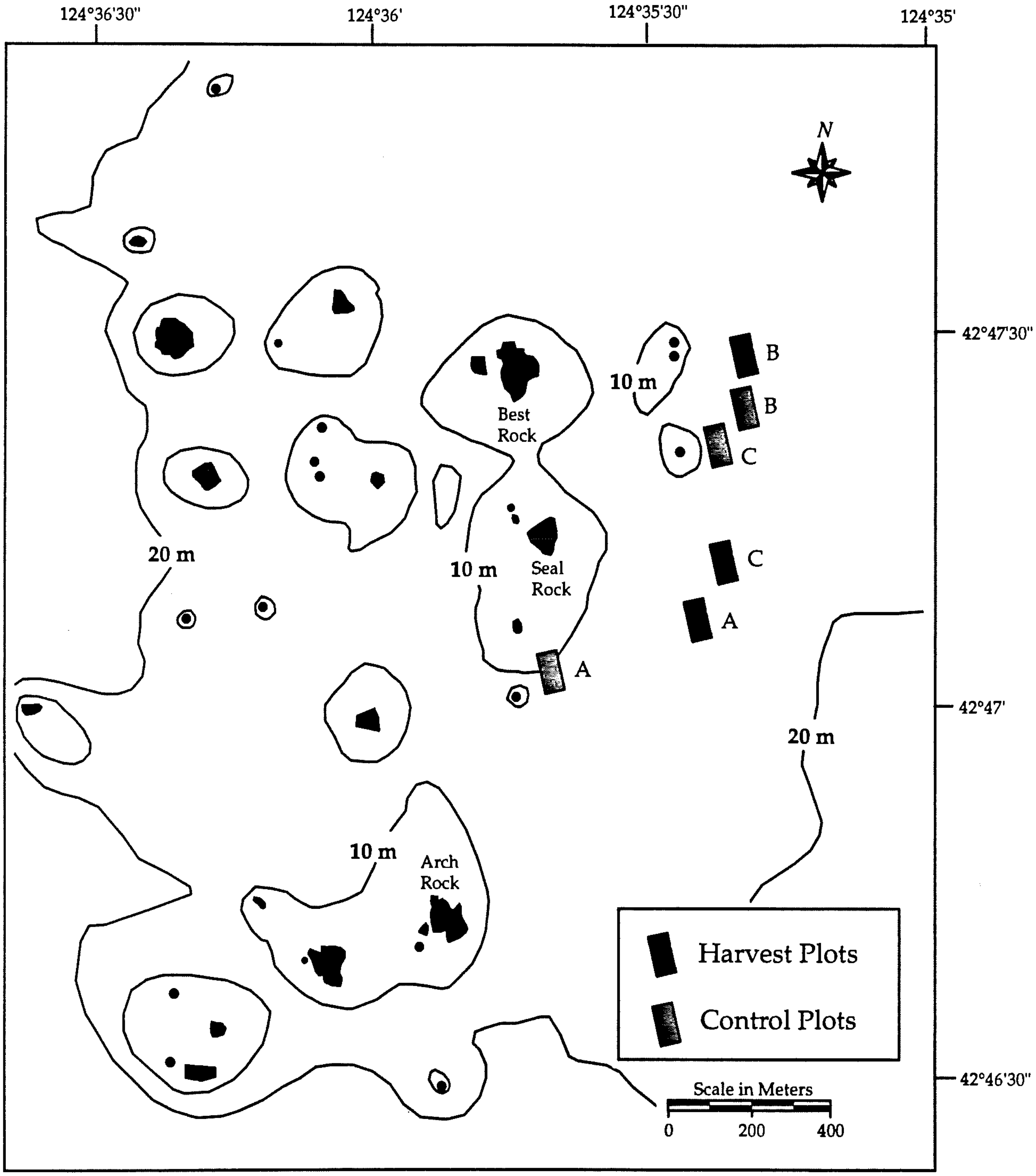


Figure 3.1. Kelp harvest and control plots used for the fish surveys, Orford Reef, 1997.

Because no kelp harvest occurred, due to storm damage to kelp beds, fish counts in the pre-harvest treatment and control plots were compared to counts made in similar habitats at Orford Reef during 1996, using a one-way analysis of variance. Comparison between years was also made with McKenzie Reef, which extends 1 - 2 km east of Orford Reef but may be considered part of the same reef complex.

3.2 Results and Discussion

The most abundant species encountered along benthic transects included black rockfish (*Sebastes melanops*) and kelp greenling (*Hexagrammos decagrammus*). Blue rockfish (*Sebastes mystinus*), china rockfish (*Sebastes nebulosus*), juvenile rockfish (*Sebastes* spp.), and lingcod (*Ophiodon elongatus*) were also common but occurred less frequently. Other species that occurred only rarely were striped surf perch (*Embiotoca lateralis*), red Irish lord (*Hemilepidotus hemilepidotus*), painted greenling (*Oxylebius pictus*), mossy warbonnet (*Chirolophis nugator*), and unknown species of sculpins (Cottidae). Cabezon (*Scorpaenichthys marmoratus*) were never counted on the transects but were observed off-transect or on the return swim and may have been attracted by the survey activity.

A two-factor analysis of variance was conducted on pre-harvest log-transformed counts of black rockfish and kelp greenling to test for differences between paired control and treatment plots. Because so few numbers of other fish species were encountered, species characterized as primarily bottom-dwelling (kelp greenling, lingcod, china rockfish) were also combined into a single category for analysis. There was no significant treatment effect for any category ($p= 0.71$ in all cases), indicating controls were valid for all treatment plots. However, plot effects were significant for black rockfish ($p < 0.001$), with all three plots different from each other.

Plots were initially chosen based on the presence of surface kelp. Analysis of bottom types following pre-harvest fish surveys revealed bottom types were not uniform between plots. Plots A and C were characterized by high-relief habitat, predominantly large boulders and steep bedrock ($>45^0$) over 1 m in height, with kelp holdfasts attached to both bedrock and boulders. Plot B was classified as predominantly low-relief habitat, primarily flat gravel/cobble bottom with occasional small and large boulders. Kelp holdfasts were only attached to the boulders in plot B. In 1996, fish surveys were stratified by high and low-relief habitat types. Comparisons of fish counts between years were made using these same strata; Plots A and C compared to transects within high-relief habitat in 1996, and Plot B compared to low-relief habitat. Because no difference was found between treatment and control plots in 1997, fish counts within paired plots were pooled for comparison with fish counts made in 1996.

Fewer black rockfish were found at high-relief sites in 1997 than in similar habitat in 1996, but differences were found both within and between years (Table

3.1). Plot A differed significantly from Plot C, but not from either reef site sampled in 1996, and Plot C differed from sites sampled in 1996 at Orford Reef but not McKenzie Reef (Bonferroni pairwise comparison probability, $p<0.05$, df=24). Blue rockfish were also much lower in abundance in 1997, but other species did not differ appreciably.

Fewer fish of most species occurred at Plot B during 1997 than were found at low-relief sites in 1996 (Table 3.2). Sites classified as low-relief in 1996 may have differed in other aspects, however. Sites surveyed in 1996 included transects characterized by low-sloping bedrock ($<45^0$) and small boulders, rather than predominantly gravel/cobble habitat found at Plot B. These slight differences in habitat, as well as absence of kelp and slightly deeper (3 - 5m) survey depths in 1996 suggest comparisons between years should be made with caution.

Kelp stipe density along transects ranged from 3.8 to 16.1 stipes/$10m^2$ but was as variable within paired treatment/control plots as between paired plots (Table 3.3). Most of this variability could be attributed to different densities of immature subcanopy kelp, often occurring as bundles of small stipes leading intertwined from adjacent holdfasts. There was no apparent correlation between kelp density and fish abundance within or between paired plots.

Few fish were observed along sub-canopy transects (Table 3.4). The only adult fish were black rockfish and there was only a single observation of juvenile rockfish. Because the kelp fronds provide such cryptic habitat, juvenile fish may have been under counted, if present.

Table 3.1. Mean density (no./100m^2) and standard deviation (s.d.) of fish species counted along belt transects within high-relief habitat at Orford and McKenzie reefs in 1996 and 1997. Sample size (n) refers to number of transects. Transect length = 80 m in 1996, 90 m in 1997.

Species	Orford Reef, 1996 High Relief, n = 6 No./100m2 (s.d.)	McK. Reef, 1996 High Relief, n = 6 No./100m2 (s.d.)	Orford Reef, 1997 Plot A, n = 8 No./100m2 (s.d.)	Orford Reef, 1997 Plot C, n = 8 No./100m2 (s.d.)
black rockfish	15.5 (15.4)	12.8 (14.0)	9.6 (7.4)	2.2 (4.7)
blue rockfish	2.0 (3.7)	6.6 (14.7)	0.08 (0.21)	0
china rockfish	0.83 (0.69)	0.42 (0.47)	0.76 (0.92)	0.14 (0.24)
juv. rockfish	7.1 (10.1)	4.1 (5.0)	2.2 (4.0)	3.4 (7.1)
kelp greenling	1.9 (1.5)	1.7 (1.3)	2.8 (2.2)	2.6 (1.4)
lingcod	0.10 (0.23)	0.31 (0.31)	0.15 (0.26)	0.31 (0.44)
cabezon	0.10 (0.23)	0.10 (0.23)	0	0
combined bottom species*	2.9 (1.3)	2.5 (1.2)	3.8 (2.4)	3.0 (1.5)

* Combined bottom species include china rockfish, kelp greenling, lingcod, and cabezon.

Table 3.2. Mean density (no./100m^2) and standard deviation (s.d.) of fish species counted along belt transects within low-relief habitat at Orford and McKenzie reefs in 1996 and 1997. Sample size (n) refers to number of transects. Transect length = 80 m in 1996, 90 m in 1997.

Species	Orford Reef, 1996 Low Relief, n = 6 No./100m2 (s.d.)	McKenzie Reef, 1996 Low Relief, n = 6 No./100m2 (s.d.)	Orford Reef, 1997 Plot B, n = 8 No./100m2 (s.d.)
black rockfish	5.9 (11.0)	8.1 (16.8)	0.08 (0.21)
blue rockfish	0	0.52 (1.16)	0
china rockfish	0.31 (0.48)	0.31 (0.48)	0
juv. rockfish	0.52 (0.76)	1.67 (2.16)	0.70 (0.91)
kelp greenling	2.1 (2.4)	1.3 (1.4)	1.8 (1.1)
lingcod	0.10 (0.23)	0.21 (0.29)	0.16 (0.27)
cabezon	0.10 (0.24)	0.10 (0.24)	0
combined bottom species*	2.6 (2.4)	1.9 (1.6)	2.0 (1.1)

* Combined bottom species include china rockfish, kelp greenling, lingcod, and cabezon.

Table 3.3. Kelp stipe density (mean and standard deviation, n = 4 per plot) at harvest and control sites at Orford Reef, 1997.

		Kelp Density (stipes/10m2)	
Plot	Treatment	Mean	Standard Deviation
A	harvest	4.3	0.8
A	control	16.1	4.7
B	harvest	11.2	5.0
B	control	4.3	1.5
C	harvest	8.7	3.8
C	control	3.8	3.9

Table 3.4. Fish counts from sub-canopy transects within treatment (pre-harvest) plots at Orford Reef, August 21 & 22, 1997.

Plot	Replicate	Transect Length (m)	Species	Total Count
A	1	345	black rockfish	3
	2	246	larval flatfish	1
	3	176		0
B	1	146	black rockfish	1
	2	154	black rockfish	1
	3	167		0
C	1	154		0
	2	147	juv. rockfish	1
	3	131	black rockfish	1

4. Physical Parameters

4.1 Methods

Orford Reef represents a morphologically complex coastal feature that has a potentially significant influence on alongshore and cross-shelf movement of nearshore waters. To study this influence, we investigated the temporal and spatial patterns of water temperature at Orford Reef during the summer season of aperiodic wind-forced upwelling and relaxation. We deployed an array of moored recording thermistors (Onset Corp., Poccassett, MA) that provided both a temporal and, along one axis, spatial record of water temperature. Surface (1m depth) and bottom temperatures were recorded at 15 minute intervals at 3 sites along a transect approximately perpendicular to the coastline (Figure 4.1). Recording thermistors were deployed on July 7 and retrieved on September 23 (offshore station) and October 14 (mid-reef and inshore stations), 1997. Thermistors were replaced at the mid-reef station to continue recording temperature. However, winter storms broke the buoy free, and the buoy and surface thermistor were recovered on the beach at Lincoln City, Oregon, approximately 150 miles to the north.

Because of the limited spatial scale of the moored array, on August 4 and September 3 we examined water temperature in greater spatial detail using a grid of 42 stations (Figure 4.1). The grid consisted of six stations, at approximately 1 km intervals along each of 7 transects that ran east to west across Orford Reef. We deployed a CTD (Seabird Electronics, model SBE-19, Bellevue, WA) at each station to obtain water column profiles of conductivity, temperature, and pressure. Salinity and depth were derived from conductivity and pressure, respectively. The manufacturer calibrated the instrument sensors prior to the field season. The CTD recorded data at 0.5 second intervals, and only data from the downcast were used for subsequent analysis. Contour profiles of physical variables were constructed using interpolation functions in the program Spyglass Transform® (ver. 3.02, Fortner Research, Inc.).

We also recorded sea surface temperature at the Port Orford dock (42° 44.3'N) and Cape Arago (43° 19.9'N) and obtained wind data recorded at Cape Arago (NOAA / NODC station CARO3; http://www.noaa.gov/BUOY/caro3.html) to help interpret our data from Orford Reef.

4.2 Results and Discussion

4.2.1 Overview of Wind and Temperature Data

Sea surface temperature recorded at Port Orford displayed a close correspondence to temperature recorded at Cape Arago. Both stations also responded in a similar manner to wind-forcing, as recorded at Cape Arago; wind from the north resulted in cooler water, while relaxation of north wind or wind from the south resulted in increased temperatures (Figure 4.2). These data suggest

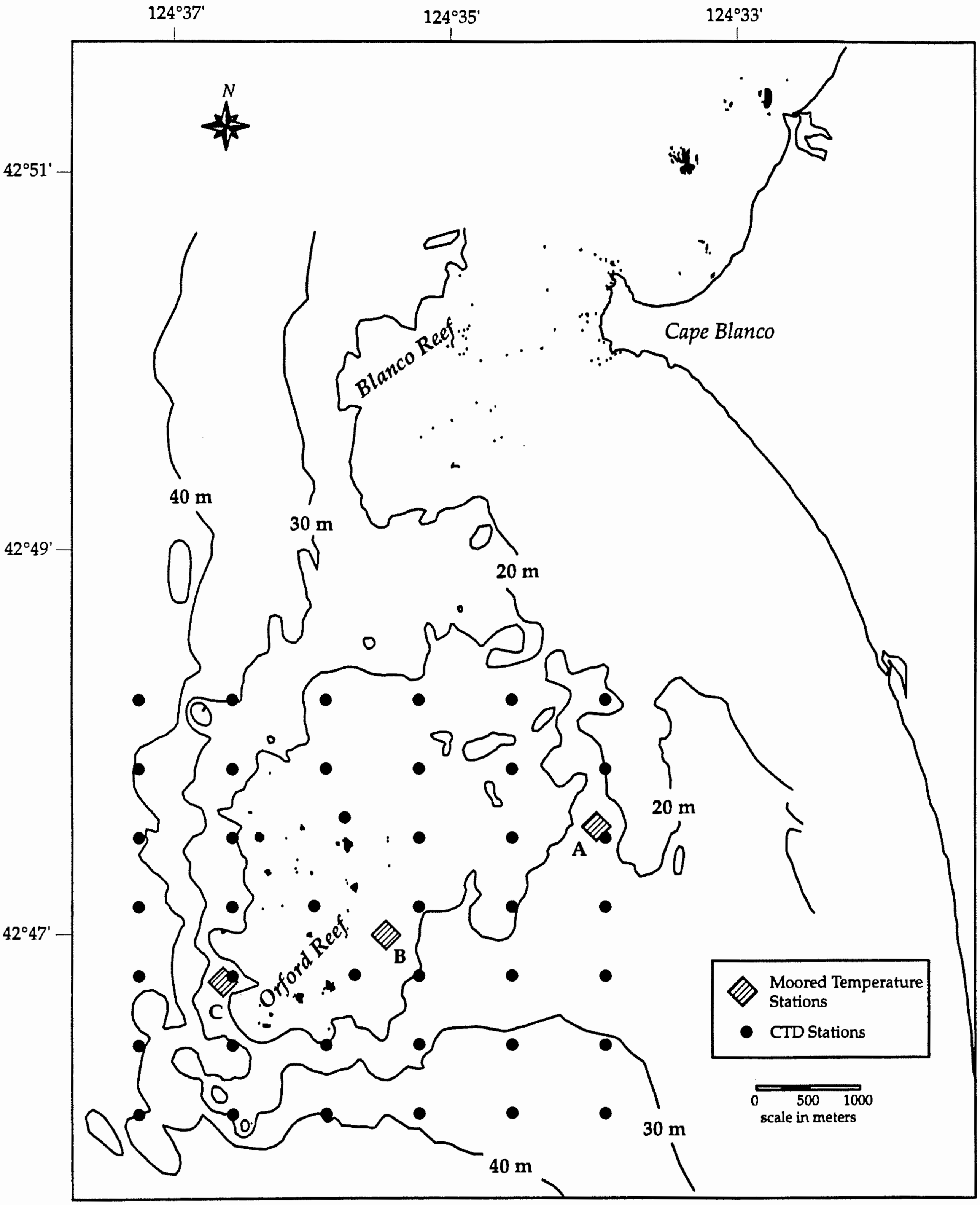


Figure 4.1. Moored temperature and CTD stations on Orford Reef, 1997. Temperature Station A (inshore buoy), 42° 46.565'N, 124° 36.972'W, depth 23 m; Station B (mid-reef buoy), 42° 46.976'N, 124° 36.449'W, depth 18 m; Station C (offshore buoy), 42° 46.722'N, 124° 36.595'W, depth 30 m.

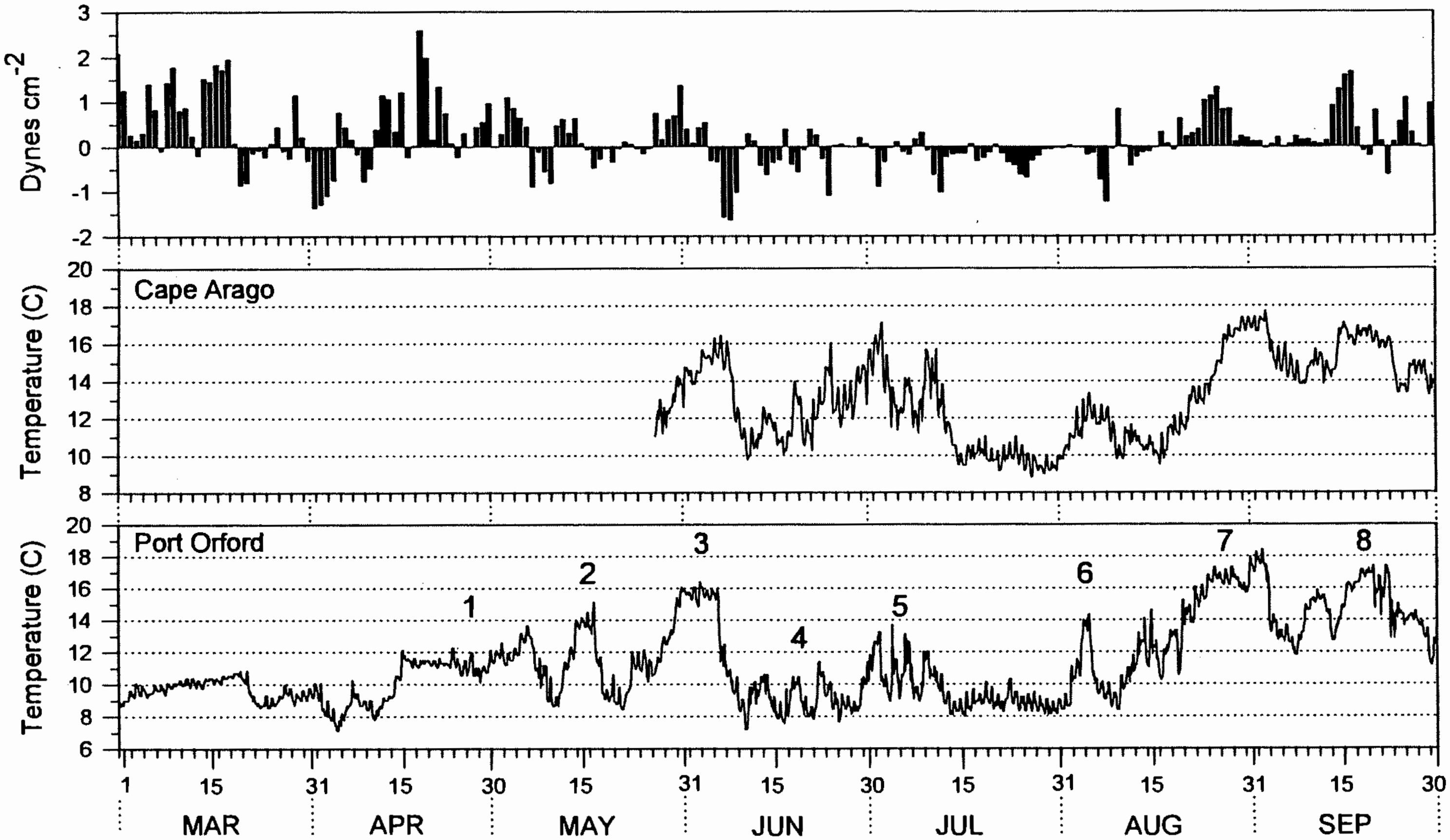


Figure 4.2. Daily mean alongshore wind stress and surface (3 m depth) water temperature at Cape Arago, and surface (2 m depth) water temperature at Port Orford dock in 1997. Wind stress recorded at Cape Arago Lighthouse (Gregory Point) C-MAN station (CARO3). Values > 0 represent northward (90° to 270°) wind stress, values < 0 represent southward wind stress. In order to calculate the alongshore component of wind stress, recorded wind direction was rotated 17° (clockwise) from true north. The alongshore direction past Cape Arago was based on a line drawn from the mouth of the Umpqua River (43°40' N) to Cape Blanco (42°50' N). This line is 17° magnetic. Declination at Cape Arago is 19°, thus wind data (reported in magnetic degrees) were rotated by subtracting 2° from the reported direction. Numbers 1 - 8 denote relaxation events referenced in text.

that wind-forcing and the response by nearshore water masses at Port Orford and Cape Arago are generally coherent, and that wind recorded at Cape Arago provides a reasonable proxy for wind-forcing at Orford Reef. The general coherence of wind, currents and sea level has also been noted at a broader regional scale within the California Current System (Strub, et al 1987; Huyer, et al. 1975; and others).

While the mechanism of wind-induced upwelling and decreased surface temperature is well understood (Smith 1981; Hickey 1979), the cause of increased temperature during the relaxation phase is less well understood. During upwelling, onshore subsurface flow of colder, more saline water creates inclined isopycnals that are shallower nearshore. The relaxation phase has been described as a cross-shelf advection of warmer surface water when winds relax or reverse, and the inclined and surfacing isopycnals are advected or relax dynamically toward a more level state (Smith 1968; Gill and Clarke 1974; Halpern 1976). In contrast, others have attributed nearshore warming in northern California (Send, et al. 1987; Wing, et al. 1995) and Oregon (Huyer, et al. 1974; Halpern 1976) to net solar heat flux and alongshore advection of warmer water from the south. Although both mechanisms may influence temperature at Orford Reef, there is a clear temperature response to wind relaxation or wind forcing from the south. Warm water events were associated with persistent strong wind from the south (Figure 4.2, e.g. events 1 through 3 and 6 through 8), as well as short, 1 to 2 day periods of southerly wind (events 4 and 5). Water temperature also decreased quickly in response to wind from the north. Temperatures began to decrease within one day of the onset of north wind and often decreased on the order of 2° - 5° C by the end of the second day.

Interpretations of wind and water temperature coupling should be made with caution during 1997. Satellite images (discussed below) showed a large, anomalously warm water mass off the Oregon coast during 1997, associated with a broader pattern of warming in the eastern Pacific. The warm water off Oregon was probably not directly linked to the 1997 El Niño (ENSO) conditions found further south, but resulted from local warming (A. Shanks, pers. comm.). Between June and September, nearshore winds were generally calm or from the south during several extended periods. These conditions prevented upwelling, forced anomalously warm water from offshore toward the coast, and caused nearshore warming from solar input. The warm-water layer found off Orford Reef was also thicker than is found during years with no influence from ENSO events, resulting in a deeper pycnocline. It is not clear how these factors may influence nearshore temperature response from wind-forced upwelling and relaxation.

4.2.2 Moored Temperature Data

Surface temperature recorded at the moored recording thermistors at Orford Reef and at the Port Orford dock followed a similar pattern, with some exceptions. During July 15 - 16, warming occurred at a tidal frequency over the offshore and mid-reef stations, but not the inshore station or at Port Orford (Figure 4.3). This period corresponded to wind-forcing from the north and cooler nearshore

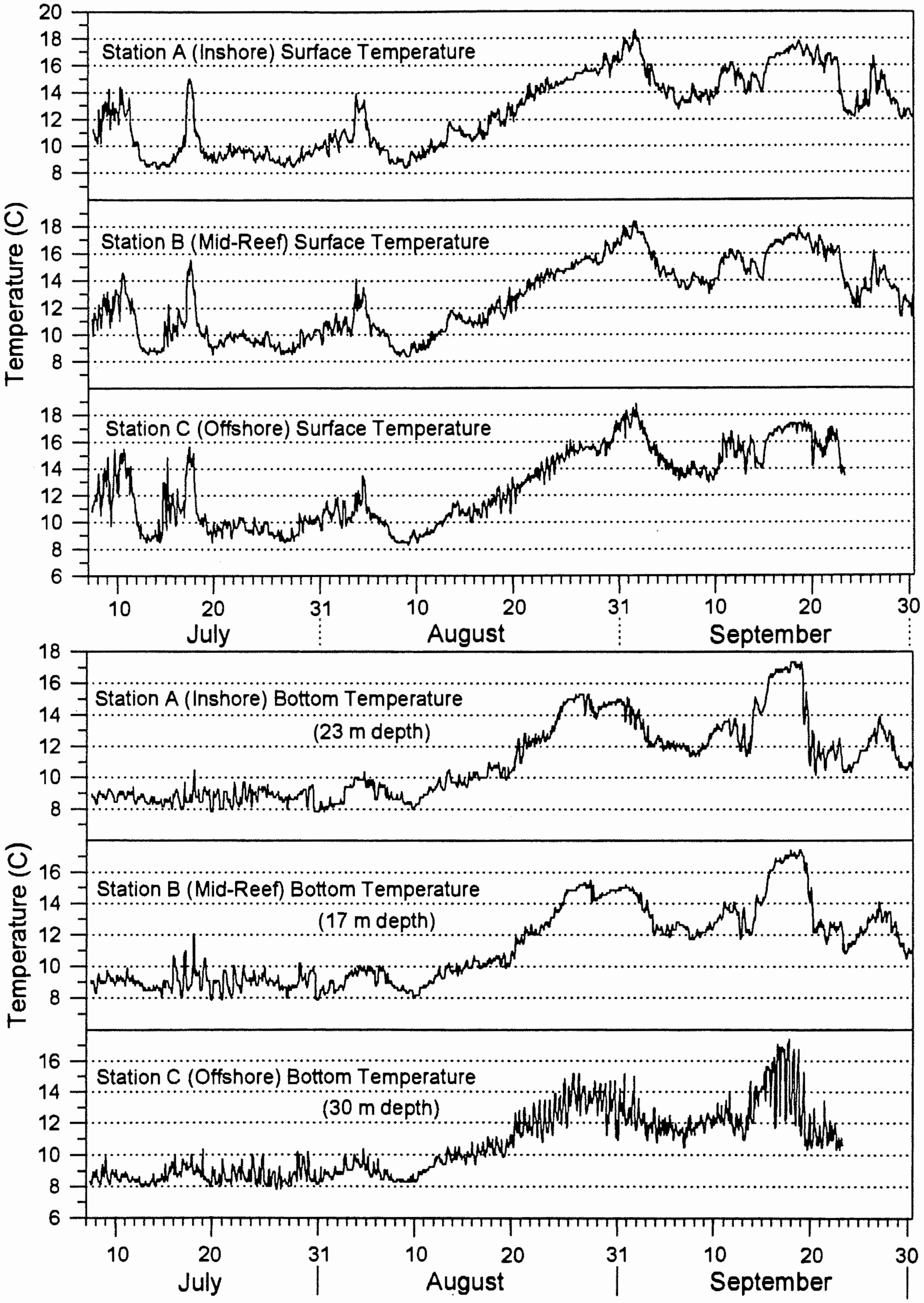


Figure 4.3. Surface and bottom temperature recorded at moored temperature stations at Orford Reef, 1997.

temperatures. Recently upwelled water resided over the nearshore stations, while cooler upwelled water oscillated with warmer offshore water at a tidal frequency at the offshore Station C. A single day of wind from the south on July 17 forced warm water over all 3 stations at Orford Reef (Figure 4.3), but this event did not reach the mainland at Port Orford (Figure 4.2).

Prior to mid-August, the pattern of bottom temperature was also similar at all three stations. Following mid-August, the offshore Station C differed from the other stations by displaying temperature variations of 2 - 5 C at a tidal frequency (Figure 4.3). Temperature decreased sharply to a minimum during the flood tide. During the period August 21 to September 22, when the highest temperature variation was observed (Figure 4.4), the temperature drop commenced an average of 2.6 hr. (s.d.=1.66) following the predicted low tide at Port Orford. After reaching the minima, temperatures either immediately increased or stayed at the minima for up to 4 hr. before increasing. The subsequent increase from the minima usually occurred after the high tide, but also occurred during the same flood period, before high tide (e.g., Figure 4.4, Sept. 15 - 19)

The low variation in bottom temperature prior to the mid-August warming event was probably due to the predominance of wind-forced upwelling during this period, resulting in a thick layer of cold water present over the bottom thermistors at all stages of the tide. After the water column warmed in mid-August, the sharp periodic change in bottom temperature may have been due to the position of the bottom thermistor relative to the thermocline. As the semidiurnal tidal waves progressed past the offshore station, displacing the thermocline upward relative to the thermistor, the temperature would decrease. During low tide, the thermocline would be displaced downward, leaving the thermistor in shallower, warmer water. However, evidence for this mechanism is equivocal. Vertical profiles of the water column on August 4 displayed relatively uniform temperature near 30 m depth at Station C and at the CTD station located 1 km west of Station C (Figure 4.5a). This was confirmed by the small variation in bottom temperature (9.2 - 9.4 C) at Station C during the tidal exchange framing the CTD survey. The thermocline on August 4 was found at 10 - 16 m depth. If the thermocline was located at similar depths during late July, vertical movement of the thermocline relative to the bottom thermistor could account for the 2 - 3 C variation in bottom temperature observed at the mid-reef Station B (17 m depth) in late July (Figure 4.3). In contrast, temperature gradually decreased to a depth of 40 m on September 3, with no distinct thermocline above that depth (Figure 4.5b). Bottom temperature at Station C varied by 0.5 C during the tidal exchange framing the CTD survey on September 3. Figure 4.5b shows that the expected temperature range at 30 m depth during a 2 m tidal exchange was no more than 0.2 C. This suggests some other mechanism may affect periodic (tidal) temperature variations at Orford Reef.

An alternate hypothesis for a sudden decrease in temperature at a tidal frequency is the pulsed delivery of subthermocline water by internal tidal bores. In California, Pineda (1991) attributed shoreward transport of water parcels and

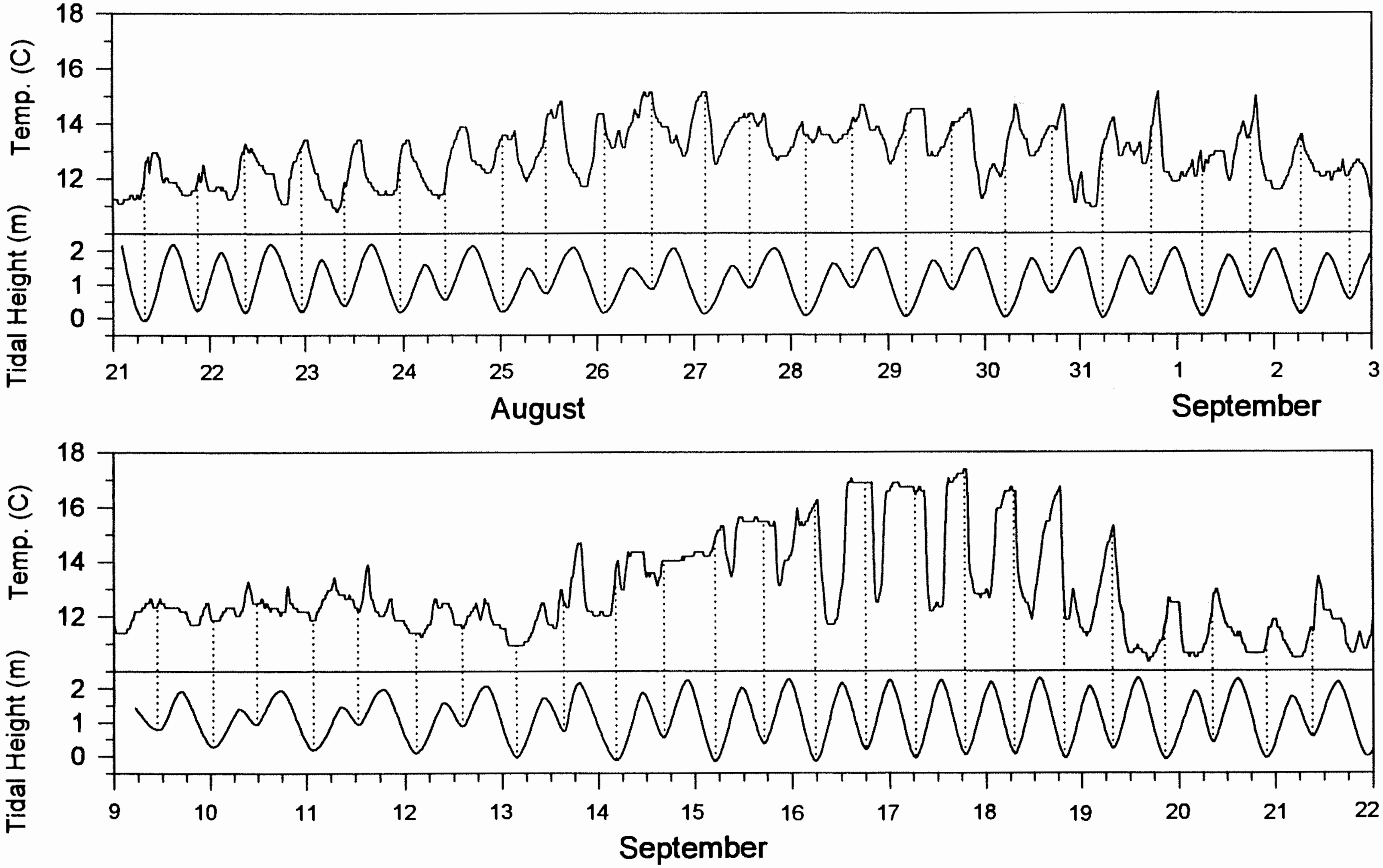


Figure 4.4. Bottom temperature at offshore Station C and predicted tides at Port Orford for the periods August 21 - September 3, and September 9 - 22, 1997. Vertical lines delineate low tide.

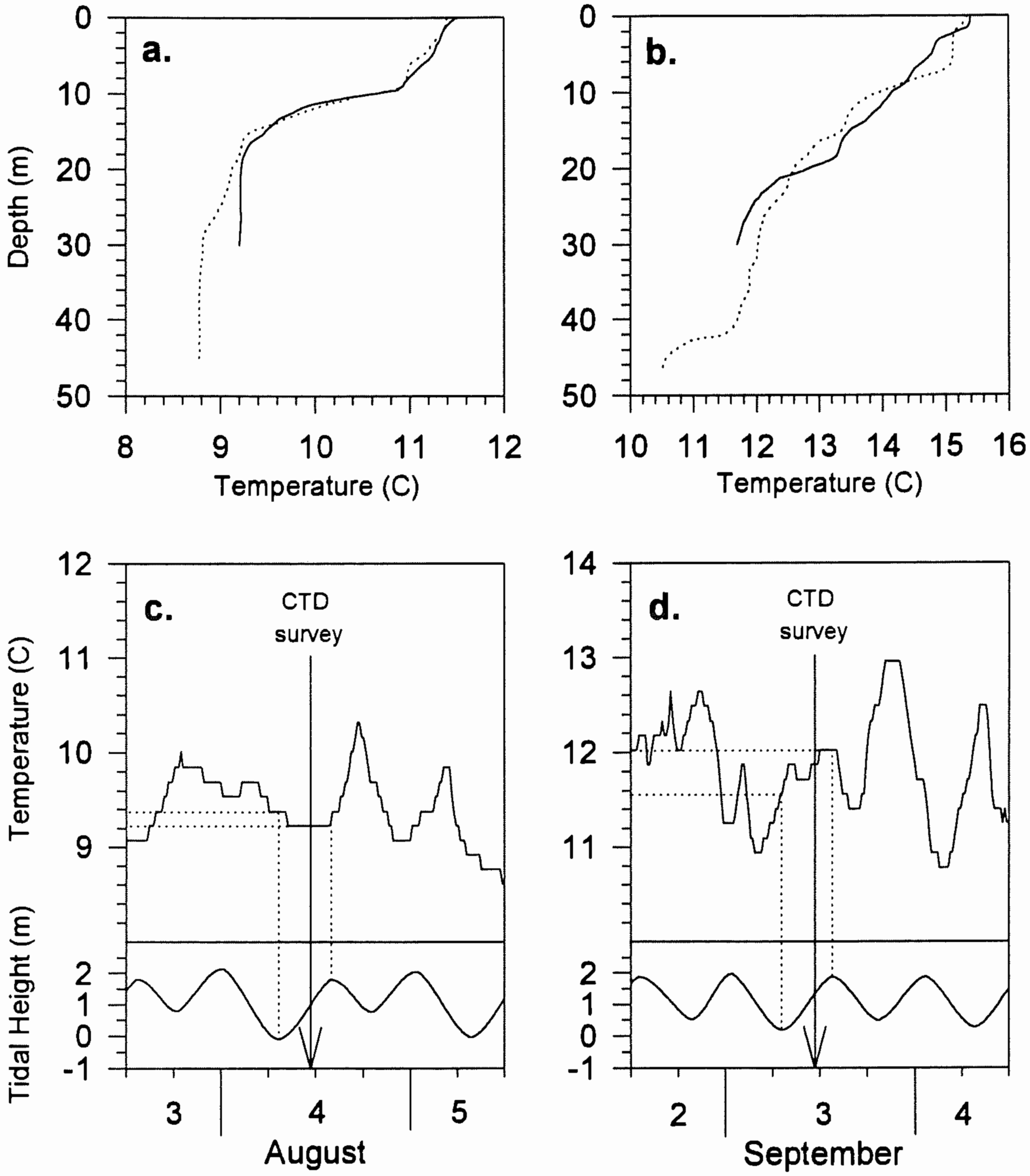


Figure 4.5. Vertical temperature profiles from CTD surveys and bottom temperature (30 m depth) at offshore Station C on August 4 and September 3, 1997. (a) vertical temperature profile at Station C (solid line) and CTD station E1 (dotted line), 1 km west of Station C, on August 4. (b) vertical temperature profile at Station C (solid line) and CTD station E1 (dotted line) on September 3. (c and d) bottom temperature at Station C and predicted tidal heights for the same period. Solid vertical line depicts time of CTD survey at Stations C and E1; dotted line represents range of bottom temperature at Station C during the tidal exchange framing the CTD survey.

planktonic larvae to internal tidal bores generated by breaking internal waves, which travel along the bottom. Leichter, et al. (1996) found that internal tidal bores caused high-frequency variation in temperature, salinity, water velocities and concentration of chlorophyll *a* at a coral reef in the Florida Keys. The arrival of bores on the reef slope was linked to a semidiurnal internal tide and was marked by temperature drops of up to 5.4 C in 1 - 20 min, with the largest drops associated with the spring tides. At Orford Reef, the highest temperature variations also occurred during the spring tides associated with the new or full moon on September 1 and 16, respectively (Figures 4.3 and 4.4).

Pulsed delivery of colder, subthermocline water could also account for the instances when sharp decreases in temperature were immediately followed by a sharp return to higher temperature within the same flood tide (Figure 4.4). As the internal tidal bore passes a fixed point near the thermocline, temperature drops, then increases as the water column returns to its former stratified structure. In contrast, the expected temperature response due to vertical movement of a thermocline (relative to a moored thermistor) driven by the semidiurnal tide would be a decrease in temperature during the flood tide and increase during the ebb.

It is possible both mechanisms may contribute to observed temperature patterns at Orford Reef. If pulsed delivery of subthermocline waters does occur at Orford Reef, this raises further questions on the influence of this mechanism on nutrient flow over the reef. In Florida, this mechanism significantly affected the temperature, nutrient, and particle flux regimes on the adjacent coral reef (Leichter, et al. 1996). The presence of kelp may modulate the flow of the intertidal bore onto Orford Reef . Jackson and Winant (1983) found that kelp beds dampen flow resulting from internal waves, with currents having less shear (more uniform vertically) within kelp beds than outside the beds.

4.2.3 CTD Surveys

CTD surveys provided a broader spatial view of water mass attributes. On August 4 relatively mixed water was found north of a front that extended approximately normal to the coastline on the south side of Orford Reef (Figure 4.6). A thin (< 5 m) layer of warmer surface water was found south of the front. The front line between these two water masses could also be seen from the survey vessel. This survey occurred at the end of a brief warming event measured at all 3 stations at Orford Reef (Figure 4.2, event 6). The source of this warm water is not clear. Satellite imagery for August 3 showed a discrete parcel of warm water between the shoreline south of Cape Blanco and cooler offshore water (Figure 4.7A). The cooler water offshore probably represented a remnant of strong upwelling that dominated the area between July 11 and 31 (Figure 4.2). Upwelling ceased in response to very weak wind forcing between July 30 and August 3, when nearshore warming occurred. The nearshore parcel of warm water detected by satellite imagery on August 3 and 4 may have formed in place from net solar input, or may have advected onshore as upwelling-favorable winds ceased or reversed. Regardless

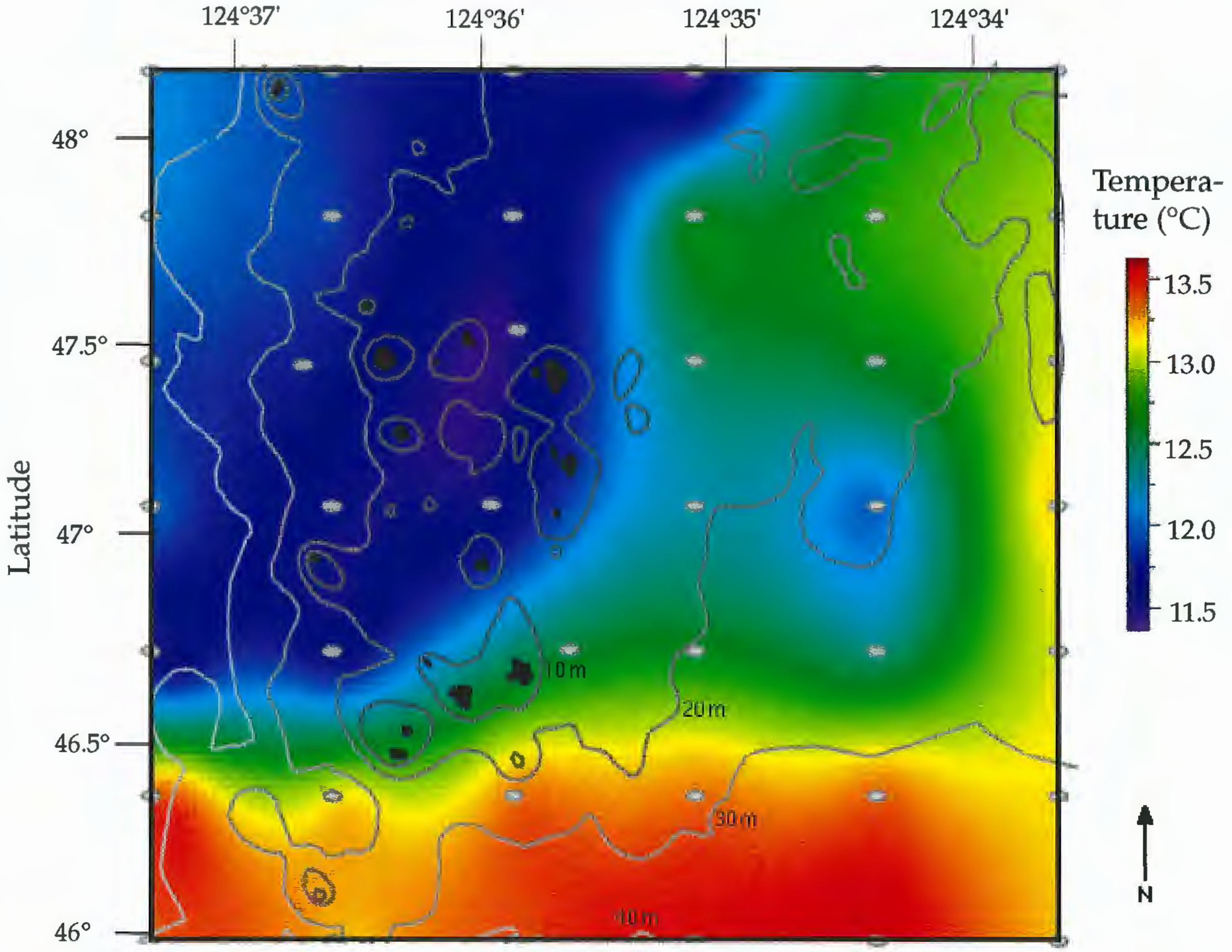
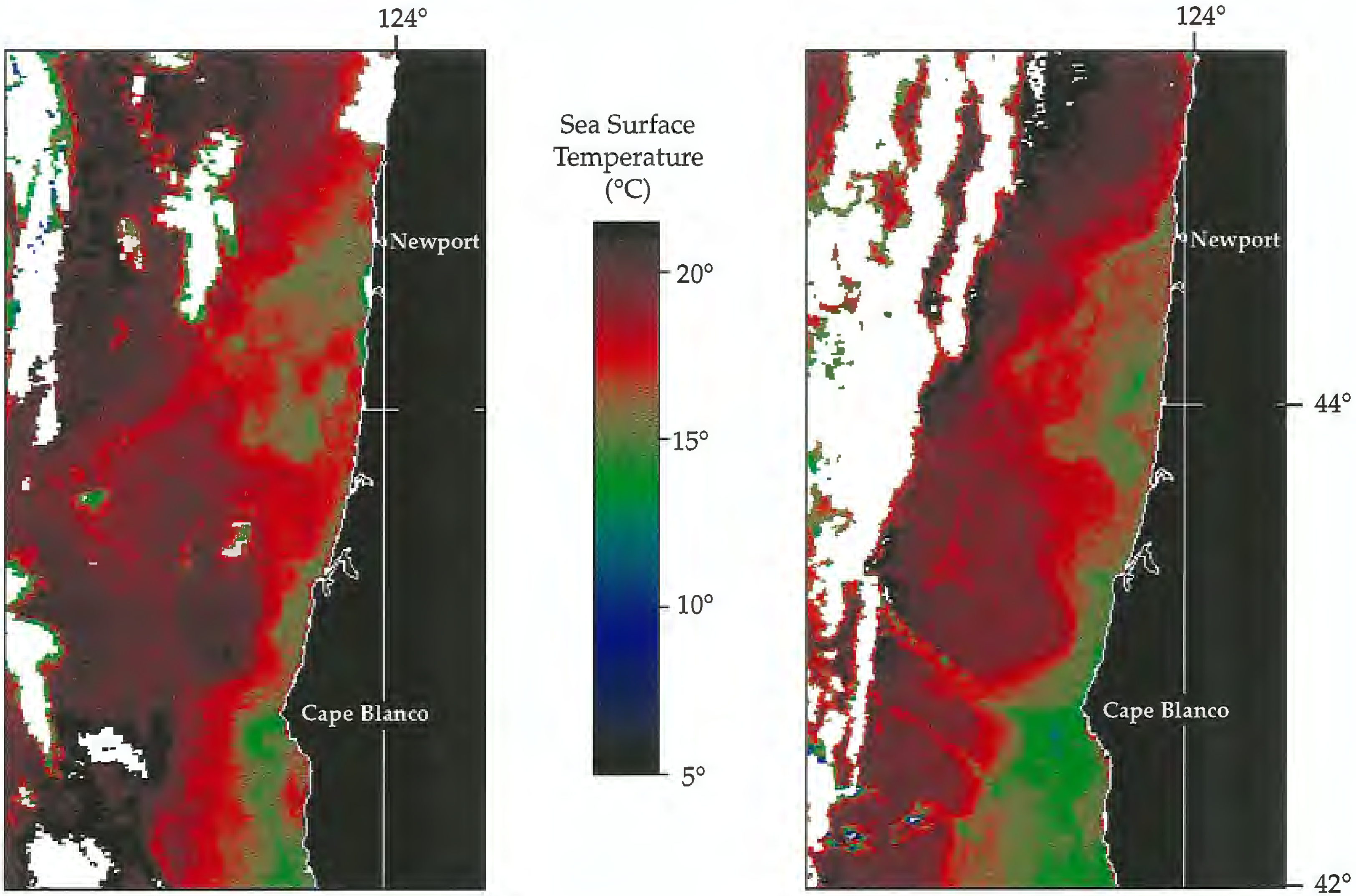


Figure 4.6. Surface water temperature distributions determined from CTD surveys at Orford Reef, August 4, 1997. Oval points depict CTD sample sites.



August 3, 1997

August 4, 1997

Figure 4.7. Satellite images of sea surface temperature; white areas represent cloud cover, August 3, 1997.

of the source, by August 4 only a small remnant of warm water remained against the coast, trapped by a developing upwelling system (Figure 4.7B). Water south of the front represents the edge of the warm water mass that was resident nearshore during the previous 3 days, and the cooler, more saline, mixed water north of the front represents recently upwelled water that was displacing the warm water mass.

A similar pattern of temperature distribution was observed on September 3, with warmer surface water found south of a front on the south side of the reef (Figures 4.8). This survey occurred during a cooling phase following a much larger and protracted warming event, but at higher temperatures than were found during the August survey. The water column over the entire survey area was more stratified but surface water was warmer and sub-surface water was colder south of the reef, resulting in stronger stratification south of the front. Although this pattern of physical attributes suggests a forcing mechanism similar to that observed on August 4, with warm water displaced by upwelled water, wind data from Cape Arago does not support this view. Strong south wind from August 20 through September 1 forced an extensive mass of warm water (14°- 18° C) against the central and southern Oregon coast (Figures 4.2 and 4.9A). Wind strength diminished between September 2 and 6, corresponding to a cooling trend in the water temperature, but the lack of north wind during this period suggests cooling could not be attributed to upwelling. It is probable that the cooling trend resulted from a combination of diminished winds from the south and alongshore flow; strong southwest wind forced 14°- 18° C water onshore prior to September 2, then as wind and onshore flow diminished, cooler (12°- 13° C) water moved south as an alongshore jet. As southwest winds increased after September 6, surface temperature increased again.

Both of the fronts that separated warmer and cooler water masses on August 4 and September 3 were aligned approximately perpendicular to the coastline. This alignment suggests displacement of water masses over Orford Reef occurred as alongshore flow. During field work at Orford Reef in 1997, currents were always observed to be alongshore. This is consistent with the typical seasonal pattern of a strong southward coastal jet during summer months (Huyer, et al. 1978). There is seasonal and spatial variation in this pattern around Cape Blanco, however. During May, Barth and Smith (1996) found that the coastal jet remains nearly straight as it transits around Cape Blanco, but during August when the upwelling circulation is more developed, flow is more spatially complex with jets and meandering eddies extending offshore from Cape Blanco. During summer months, Orford Reef, which extends south from Cape Blanco, is likely influenced by these spatially complex flow patterns.

4.2.4 Potential Role of Orford Reef in Dampening Alongshore Currents

During 1996, results of CTD surveys suggested that Orford Reef may function to alter alongshore or cross-shelf currents resulting in retention of water for some time over the shallower portions of the reef (Fox, et al. 1996). East-west transects

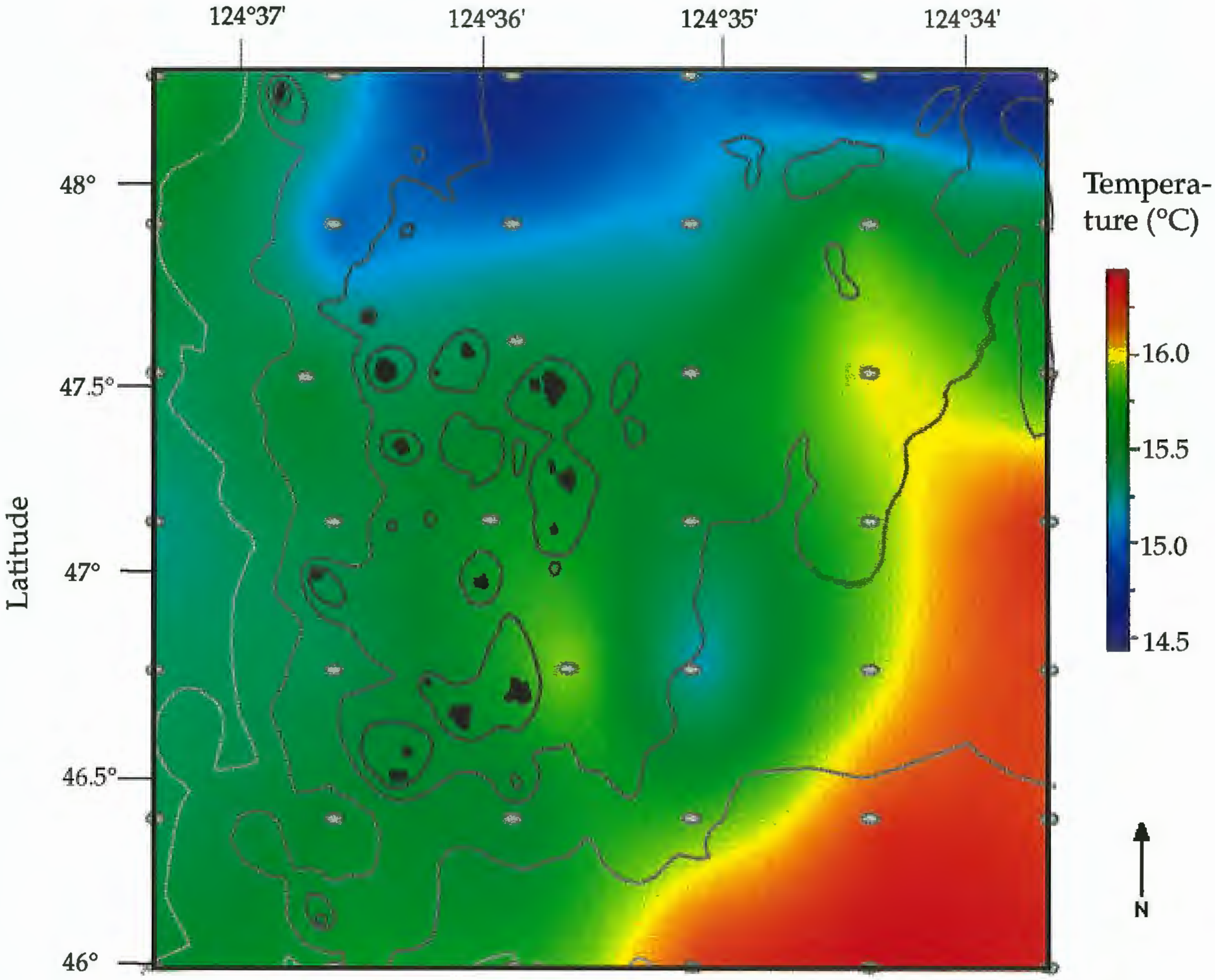
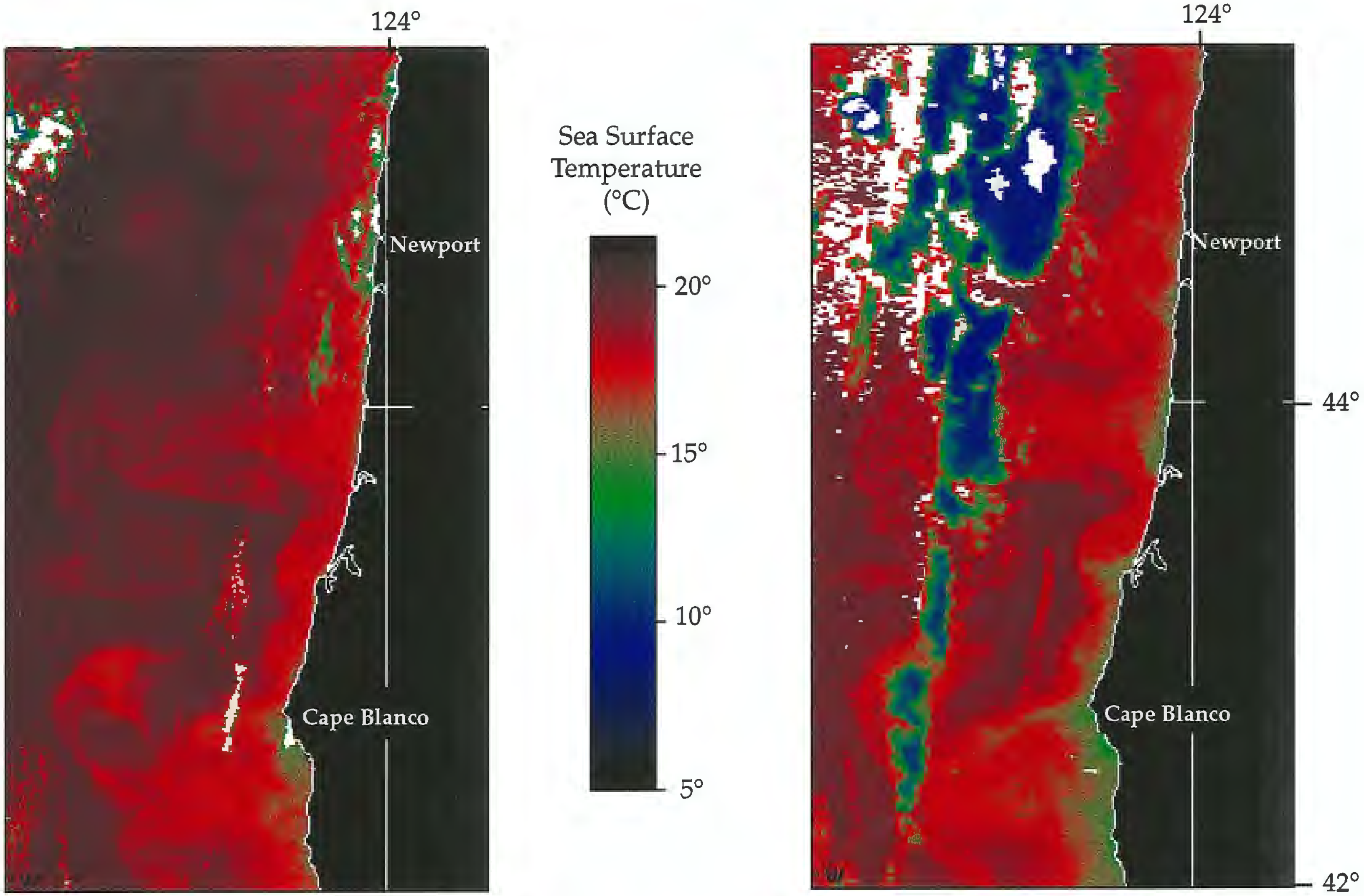


Figure 4.8. Surface water temperature distributions determined from CTD surveys at Orford Reef, September 3, 1997. Oval points depict CTD sample sites.



September 3, 1997

September 4, 1997

Figure 4.9. Satellite images of sea surface temperature; white areas represent cloud cover.

depicting water column profiles on August 20, 1996, showed a parcel of warm, low salinity water over the shallow portion of the reef and colder water inshore and offshore. One week later the reverse structure was observed. In 1997, the moored temperature buoys deployed at Orford Reef provided an opportunity to measure differential temperature response along a single axis.

Figure 4.10 shows the time lag for surface temperature response at the mid-reef Station B relative to the inshore and offshore stations for events corresponding to alongshore winds from the south (warming events) and from the north (cooling events) in which temperature changed 2.0° C across all three stations. Measurements of temperature response due to upwelling were limited in 1997 because of the general lack of north wind during the period the thermistors were deployed. Temperature response between stations was compared by choosing the time at which temperature first increased or decreased 2.0° C from a minima or maxima within the previous 12 hours. During five warming events, there was no consistent trend in temperature response between stations. The response lag during warming events at Station B ranged from 0.3 to -3.2 hr relative to the inshore and offshore stations. Temperature response was more consistent during cooling events; Station B displayed a positive lag of 1.1 to 7.7 hr relative to both inshore and offshore stations during three of four events.

If the positive time lag measured at the mid-reef station is a generally predictable response during upwelling, the delayed temperature response may be due to dampening of alongshore currents at this station relative to the other stations. Reef morphology may differentially influence the velocity of alongshore currents as they pass over different portions of the reef. Station B was closest to the shallowest portion of the reef, just east of the emergent rocks. This station was also located adjacent to subsurface and surface beds of kelp, while no kelp was found near the deeper inshore and offshore stations. The delayed temperature response at Station B during cooling events may be due to reduced alongshore flow of water over shallower portions of the reef, particularly in areas with kelp. Physical retention of water has been demonstrated for coral reef systems (Hamner and Wolanski 1988) and there is evidence that kelp (*Macrocystis*) beds off southern California slow alongshore currents (Jackson and Winant 1983).

The lack of a consistent positive temperature lag during warming events at the mid-reef station may result from variability in the direction from which warm water moves onshore. Winds with a strong west component may move water onshore as cross-shelf flow, while wind predominantly from the south may force alongshore flow from the south. Water may also warm from solar flux during calm periods.

Delay of alongshore currents and retention of water for even a few hours over shallow portions of a reef may have important implications for kelp recruitment. During summer months, the reproductive patches of sporangia (sori) on bull kelp blades break free and drift to the bottom to release the zoospores, which

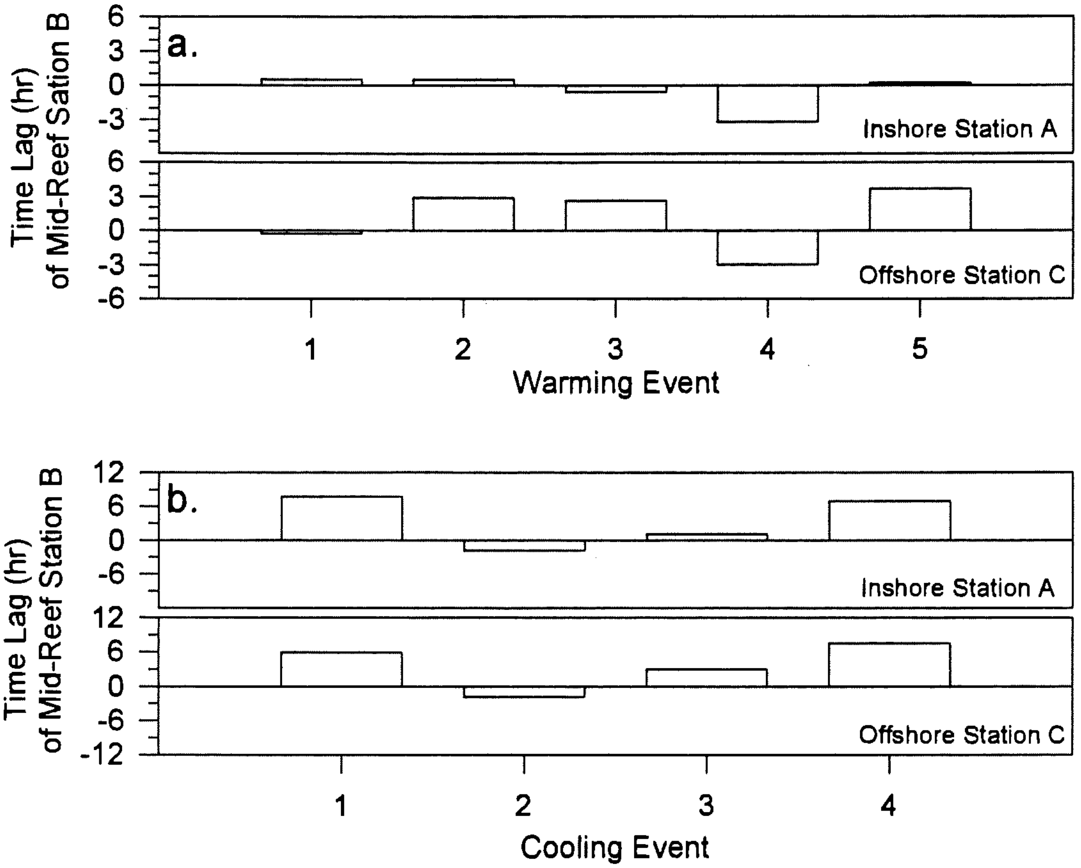


Figure 4.10. Time lag for surface temperature response at mid-reef Station B relative to inshore Station A and offshore Station C. Positive values indicate a temperature response occurred after the same response at the inshore or offshore station. Temperature response was defined as the time at which temperature first changed 2.0°C following a minima (warming event) or maxima (cooling event) during the previous 12 hours. (a) time lag at Station B during five warming events; numbers 1 - 5 correspond to events starting on July 8, 10, 17, August 3, and September 15, respectively. (b) time lag at Station B during four cooling events; numbers 1 - 4 correspond to events starting on July 10, 17, August 4, and September 22, respectively.

become the overwintering benthic gametophytes (Boney 1966; North 1971). The gametophytes must attach in suitable habitat (shallow, rocky substrate) in order to contribute to kelp recruitment the following spring. Although the relationship of kelp blade or sori drift to subsequent recruitment has not been documented, it is reasonable to hypothesize that retention of sori within habitat of the adult plant would enhance the number of overwintering gametophytes and survival of new recruits the following spring. A decrease in alongshore flow associated with complex shallow bottom and kelp forests should decrease export of kelp sori from suitable habitat.

5. Management Analysis

The Kelp/Reef Habitat Assessment project is designed to collect needed scientific data and to assist the harvester and managing agencies with the practical details of kelp harvest management. In 1996, 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) (Fox, et al. 1996). This section updates the management analysis based on 1997 research results.

5.1 Management Hypotheses

Management hypotheses consist of 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 and harvester resources are adequate to evaluate kelp biomass on an annual basis. Estimates can be provided in a timely manner to allow viable 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 when kelp production is low enough to dictate a harvest quota below the threshold level.

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 manage kelp harvest in a way that minimizes 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.

5.2 Discussion

Given the set of questions in Section 5.1, we updated our 1996 management analysis based on work accomplished in 1997.

Biomass Estimation (Programmatic Objective 1, Question 1-1 - Adequate Program)

Kelp biomass was slightly lower in 1997 than in 1996. This came as quite a surprise because 1997 kelp bed surface area was nearly double that of 1996. However, the average weight per plant in 1997 was about half that of 1996, accounting for the unexpectedly low biomass figure. The low plant weights may have resulted from warm water and low nutrients associated, at least indirectly, with the 1997 ENSO event. In addition to the wide year-to-year variation in parameters used in estimating biomass, there was also a wide spatial variation. While Redfish Rocks and Humbug Mountain reefs had much more kelp in 1997 than 1996, Rogue Reef had much less kelp.

The past two sampling years have reaffirmed our early supposition that kelp biomass cannot be approximated using kelp bed surface area alone. Two years with such dramatically different kelp bed areal coverage produced similar total biomass. As far as we can tell, both years were at the low end of what might be considered a typical year for kelp off the southern Oregon coast. More years of biomass estimation are needed to gain an adequate understanding of variation in the surface area, plant weight, and plant density relationships.

The cost of estimating kelp biomass amounted to $5,000 for the aerial survey and about $4,000 of ODFW staff and vessel time. Most of these costs were borne by our 1997 Coastal Zone Management Section 309 grant. ODFW would not be able to continue biomass estimation without outside support. Possible methods to reduce the cost include:

1) using less expensive remote sensing technologies to obtain images of kelp beds
2) using more automated methods to analyze the kelp images.

Alternate remote sensing technologies that may provide images suitable for biomass estimation include aircraft-borne multi-spectral scanners and satellite imagery. Researchers at Coastal Resources Associates, San Diego, are currently developing techniques to analyze multi-spectral scanning images for estimating kelp plant density in *Macrocystis* beds. Similar techniques may be applicable to high-resolution satellite images. Once techniques are developed, acquiring the images may be less expensive than aerial photography. However, costs for developing the techniques can be prohibitively high, involving relatively large, multi-year field studies. Developing more automated methods for analyzing the data could also reduce some of the staff costs associated with biomass estimations. For example use of a digital scale at sea in 1997 cut the time for sampling kelp weights in half. Scanning the photos and analyzing the images using image analysis software would cut the time required for estimating kelp density and surface area. However, this could require some initial staff time investment to develop the techniques.

Fox, et al. (1996) discusses a problem with the timing of biomass estimation and kelp harvest. In order to estimate peak biomass, aerial photography needs to be conducted in late August or early September. The earliest biomass estimates can be developed is early October, given time for photo processing, interpretation, and data work up. If harvesting is restricted to occur after a biomass figure is obtained, fall and winter storms may remove much of the kelp prior to completing significant amounts of harvest. If a harvester is allotted 10% of the peak biomass, harvesting after much of this peak crop disappears may result in removal of all, or a very large percentage of, remaining plants. Allowing some of the harvest to occur prior to storm removal may reduce late-season impacts. Further information on kelp growth and production, and dependence of fish on kelp habitat is needed to evaluate optimal harvest timing.

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

The lessee did not harvest kelp in 1997, so it was not possible to evaluate this objective.

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

We were unable to complete our examination of kelp harvest impacts because early September storms prevented the test harvest from occurring. During this year of poor kelp production, we found it difficult to set up the harvest/control plot experiment because of the limited kelp areas available to establish plots. We were limited to establishing all of the plots within the relatively small core kelp area on Orford Reef. The close proximity of the plots raised questions about the possibility of confounding the statistical results due to spatial autocorrelation among the plots. In addition, during low kelp years, kelp canopy sufficient for setting up the study does not appear until relatively late in the season. This leaves a tight time frame for completing the study prior to the onset of the first storms of fall. We recommend waiting for a year of relatively high kelp production prior to attempting the harvest vs. control plot experimental design again.

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. Although we recommend no changes to the statutes and rules, there needs to be increased coordination among ODFW, DSL, and the harvester during the course of project to ensure experimental harvest is conducted according to plans.

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. We should continue to pursue a study to examine potential harvest affects on the biological community, but only during a relatively high kelp year, and only after getting a pre-season commitment from all parties to participate in the study.

6. Literature Cited

Barth, J.A.; Smith, R.L. 1996. Coastal ocean circulation off Oregon: Recent observations of spatial and temporal variability. Submitted to "Estuarine and Ocean survival of Northeastern Pacific Salmon: A Workshop and Extended Abstracts", NOAA Technical Memorandum, NMFS, NWFSC.

Boney, A.D. 1966. A biology of the marine algae. Hutchinson Educational, London, pp 71-78

Fox, D.S.; Merems, A.; Golden, J.; Amend, M. 1996. 1996 kelp/reef habitat assessment. Newport, OR: Oregon Department of Fish and Wildlife, Marine Program. 61pp.

Gill, A.E.; Clarke, A.J. 1974. Wind-induced upwelling, coastal currents, and sea level changes. Deep-Sea Res 21:325-345.

Halpern, D. 1976. Structure of a coastal upwelling event observed off Oregon during July 1973. Deep-Sea Res 23:495-508.

Hamner, W.M.; Wolanski, E. 1988. Topographically controlled fronts in the ocean and their biological influence. Science 24:177-181.

Hickey, B.M. 1979. The California current system: hypotheses and facts. Prog Oceanog 8:191-279.

Huyer, A.; Pillsbury, R.D.; Smith, R.L. 1974. Observations in a coastal upwelling region during a period of variable winds (Oregon coast, July 1972). Tethys 6:391-404.

Huyer, A.; Pillsbury, R.D.; Smith, R.L. 1975. Seasonal variation of the alongshore velocity field over the continental shelf off Oregon. Limnol Oceanogr 20:90-95.

Huyer, A.; Smith, R.L.; Sobey, E.J.C. 1978. Seasonal differences in low-frequency current fluctuations over the Oregon continental shelf. J Geoph Res 83(C10):5077-5088.

Jackson, G.A.; Winant, C.D. 1983. Effect of a kelp forest on coastal currents. Cont. Shelf Res. 2:75-80.

Leichter, J.J.; Wing, S.R.; Miller, S.L.; Denny, M.W. 1996. Pulsed delivery of subthermocline water to Conch Reef (Florida Keys) by internal tidal bores. Limnol. Oceanogr. 41(7):1490-1501.

Moores, C.N.K.; Collins, C.A.; Smith, R.L. 1976. The dynamic structure of the frontal zone in the coastal upwelling region off Oregon. J Phys Oceanog 6 (1):3-21.

North, W.J. 1971. The Biology of giant kelp (*Macrocystis*) in California. Verlay Von J. Cramer, Lehre, pp 17-18.

Pineda, J. 1991. Predictable upwelling and the shoreward transport of planktonic larvae by internal tidal bores. Science 253:548-550.

Send, U.; Beardsley, R.C.; Winant, C.D. 1987. Relaxation from upwelling in the Coastal Ocean Dynamics Experiment. J Geoph Res 92(2):1683-1698.

Smith, R.L. 1968. Upwelling. Oceanog Mar Biol 6:11-46.

Smith, R.L. 1981. A comparison of the structure and variability of the flow field in three upwelling regions: Oregon, Northwest Africa and Peru. In: Richards FA (ed) Coastal Upwelling, American Geophysical Union, Washington, DC, p 51-53.

Strub, P.T.; Allen, J.S.; Huyer, A.; Smith, R.L. 1987. Seasonal cycles of currents, temperature, winds, and sea level over the northeast Pacific continental shelf: 35N to 48N. J Geophys Res 92(C2):1507-1526.

Wing, S.R.; Largier, J.L.; Botsford, L.W.; Quinn, J.F. 1995. Settlement and transport of benthic invertebrates in an intermittent upwelling zone. Limnol Oceanogr 40(2):316-329.