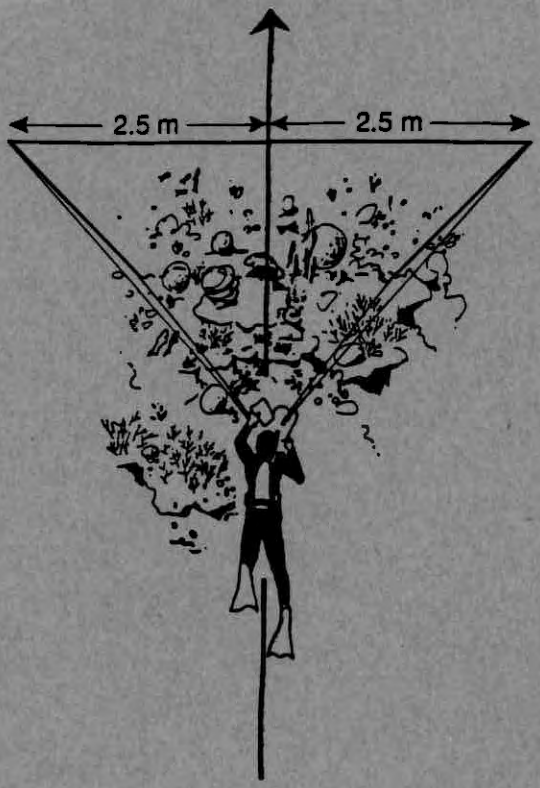
DYNAMICS OF THE KELP *Nereocystis luetkeana* COMMUNITY, AND IMPACTS OF HARVESTING ON THE COMMUNITY

Section 2.
RESEARCH DESIGN
AND
BIBLIOGRAPHY



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The Dynamics of the kelp *Nereocystis luetkeana* community and impacts of harvesting on the community:

Section 2 Research Design and Bibliography

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Dynamics of the kelp Nereocystis luetkeana community and impacts of harvesting on the community:

Section 2. Research Design and Bibliography

Executive Summary

1. The increased complexity of resource management in the coastal zone requires a more complex approach to research and management. Kelp and their associated communities are governed by a range of interacting physical and biological events. There is a need for basic information on the ecology of the bull kelp *Nereocystis luetkeana* which has received little attention, in comparison to *Macrocystis*. Important scientific questions that need to be addressed fall under three main categories: Community Aspects; Kelp Population Dynamics: Oceanographic/Biological Interactions. This report provides study designs to address some of these issues. In addition an interdisciplinary study on the relationship between economic viability and biological sustainability of kelp should be undertaken.

2. In this report we include sections on biological studies and monitoring physical parameters. The techniques to study fish dynamics differ from those used for benthic studies. However the design is set up so that integrated sampling can take place to minimize time and personnel efforts. At the end of each section, we include modifications or additions that can be made to the study to expand the range and scope. Throughout this report we have worked to balance design needs with logistical constraints, to produce a data set that will be biologically relevant and that can be analyzed statistically.

3. The impacts of kelp harvesting on fish composition and abundance. This design is set up to address the distribution of fish in kelp beds, and the impacts of harvesting on fish. We have included two main designs. The first design is based on a year of no harvesting. Under this scenario researchers carry out 100m transects at two sites (Orford Reefs and Rocky Point). At each site, 3 random kelp beds are designated as study beds, and researchers carry out 5 edge transects and 5 interior transects in each bed (100m from the center) (Total sample size 60 transects).

3. Subsequently we recommend one of two design options: Option A. requires control beds, and beds harvested at 10% of the bed. This study should be carried out at two sites, with 4 control and 4 harvest plots per site. In each bed, researchers carry out a before and after harvesting transect on the edge of the bed and 100m from the edge (interior). Total sample size is 64 transects. Option B is similar to option A except that there are two levels of harvesting 10% and 50% of the bed are harvested. These designs will test the effect of harvesting level on fish abundance, composition, and behavior.

3. Additional fish studies recommended are: 1. The role of kelps as a habitat for juvenile fish (including monitoring the recruitment of juvenile fish into kelp beds), and 2. A comparison of fish composition and abundance between the outer kelp beds and more protected beds near Port Orford.

4. Benthic Species Composition and Abundance: We recommend that the quadrat method be used to study changes in the benthic community. We use the same sites and transects as for the fish study above. Along each transect 3 x1m^2 quadrats are set up. Data are recorded using either photographs, or video. Some ground truthing will probably be required. Data analysis can be carried out by digitizing the images, and using an image analyzer to estimate percent cover. We have also included information on using Line Intercept Transect Method as an alternative data collection method.

5. Seabird surveys: Studying the density and distribution of seabirds at small scales is difficult. Therefor it is important that the study be designed to gather data appropriate for the scale of the work. In this report we evaluate three methods, line transect, extended point counts, and focal bird study. We recommend focal bird study as the method that will reduce variance and provide most useful information. A full design is included. In addition, if time permits, limited extended point counts may also be carried out.

6. Additional Benthic studies include 1. Studies that focus on key species or species of concern; and 2. The role of kelp beds in the dynamics of rocky shore communities (including bird communities).

7. It is also important to study the dynamics of the kelp population, and to understand how harvesting affects these dynamics. We have included some general designs for studying aspects of the population. It will be relatively easy to study reproduction and growth of plants in harvested and non-harvested areas. This type of study can also be carried out by volunteers (including kelp harvesters)

8. Oceanographic factors are likely to affect the dynamics of kelp, and the associated community. It is outside the scope of this report to develop a full oceanographic program. However, we have included some general questions that are important, and ways that these can be addressed.

9. It is important to monitor physical factors in addition to biological responses. We recommend that ODFW continue monitoring these parameters as part of the overall design.

10. Finally we present a protocol for field sampling. As this provides a good overview of the design, and how it operates in the field, we have included the table in this summary in addition to table 6 of the report.

Daily Field Research Protocol

As the boat arrives at the study site, the bird observer notes the presence of birds at the site, and records any observations including birds leaving the area as the boat approaches etc.

When the boat is anchored or stopped

Physical Oceanographic Data
Researchers collect physical oceanographic data using CTD, Secchi disk, light meters etc.

Divers enter water and collect oceanographic data at the bottom (temperature, depth, and any other information). Equipment including video cameras, transect frames etc. can be taken down to the bottom and anchored while fish transects are onging. This means that divers do not have to resurface to collect cameras or other equipment after fish counts are completed.

Community Sampling
Divers lay out 100m transects, and after waiting 5-15 minutes carry out fish transects. Divers return to permanent quadrat markers and either video, photograph or ground truth the plots.

Seabird and Other Studies.
While the divers are in the water, the bird observer continues with focal individual counts or with limited extended period counts.

If studies on kelp dynamics are ongoing e.g. reproductive status, data can also be collected while divers are in the water.

After Completion of community sampling (at the end of the first dive)

After the dive, researchers can either continue with bird surveys or move immediately to the next transects and plots to continue the fish and benthic surveys (and kelp population studies if they are underway).

When the day's diving has been completed, the additional bird focal studies can be carried out by visiting by visiting the undisturbed plots. (Note if time and boats permit, bird sampling can be carried out independently of dive studies).

Overview: Research Needs

The increased complexity of resource management in the coastal zone requires a more complex approach to research and management. We can no longer focus on a single harvested species and hope to address the complexity of ecosystem responses. Kelp communities are diverse and complex. Their abundance is governed by a range of interacting physical and biological events. In addition the ecology of other resource species (e.g. urchins) is integrated with kelp beds, and therefore it is important to study the system as a whole.

Below we discuss the information needs for management of *Nereocystis* beds. This list is derived from researching the available literature on *Nereocystis* and other kelp species, from communication with kelp biologists, and information from workshops especially the California Sea Grant sponsored workshop on kelp (McArdle, 1994). Following this, we present a series of experimental designs to gather information that can answer some of these questions.

There is a great need for basic information on *Nereocystis* and the bull-kelp forest community. *Nereocystis*, unlike its relative the giant kelp *Macrocystis*, has received little attention from biologists. However, with increasing commercial pressure on *Nereocystis* it is vital that we develop scientific information on the ecology of Nereocystis and its associated community. Important questions that need to be answered include:

Community Aspects:

Kelps are key species in the community, they provide a habitat and food for other species (Leaman 1980, Duggins 1982, Foster and Schiel 1985 and references therein), and there is a need for better understanding of the interactive relationships between members of the kelp bed community (McArdle 1994) specifically:

- What are the main interactions between kelp and associated species?
- What is the spatial and temporal distribution of associated species?
- What is the strength of the interactions between kelp and associated species, including fish (especially commercial species), birds, invertebrates, and other plants?
- Is the recruitment of kelp-associated species limited by spore or larval availability, or limited by the amount of available kelp habitat?
- How does the harvesting of kelp affect associated species in the community, including other commercial species such as fish and urchins?
- How important is kelp to the recruitment and survival of juvenile fish?
- Does productivity indirectly regulate the kelp community (e.g. Trophic Cascade Model)?

<u>Long term patterns</u>:

- What are the temporal and spatial fluctuations in the distribution of kelp bed communities? How does harvesting affect the patterns?

- What is the long term resilience of kelp bed communities to disturbances, including harvesting?

Interaction of biological and physical conditions

- How does the canopy affect water movement, light dispersal, and other factors, and how do these in turn affect the associated species living within the kelp bed?

Kelp Population Dynamics

- How does the recruitment and growth pattern of kelp vary spatially and temporally?
- What is the dispersal pattern of kelp spores?
- How does harvesting affect recruitment, growth, and reproduction of kelp?
- What is the current size of the kelp population and how does the size vary?

Oceanographic/Biological Factors

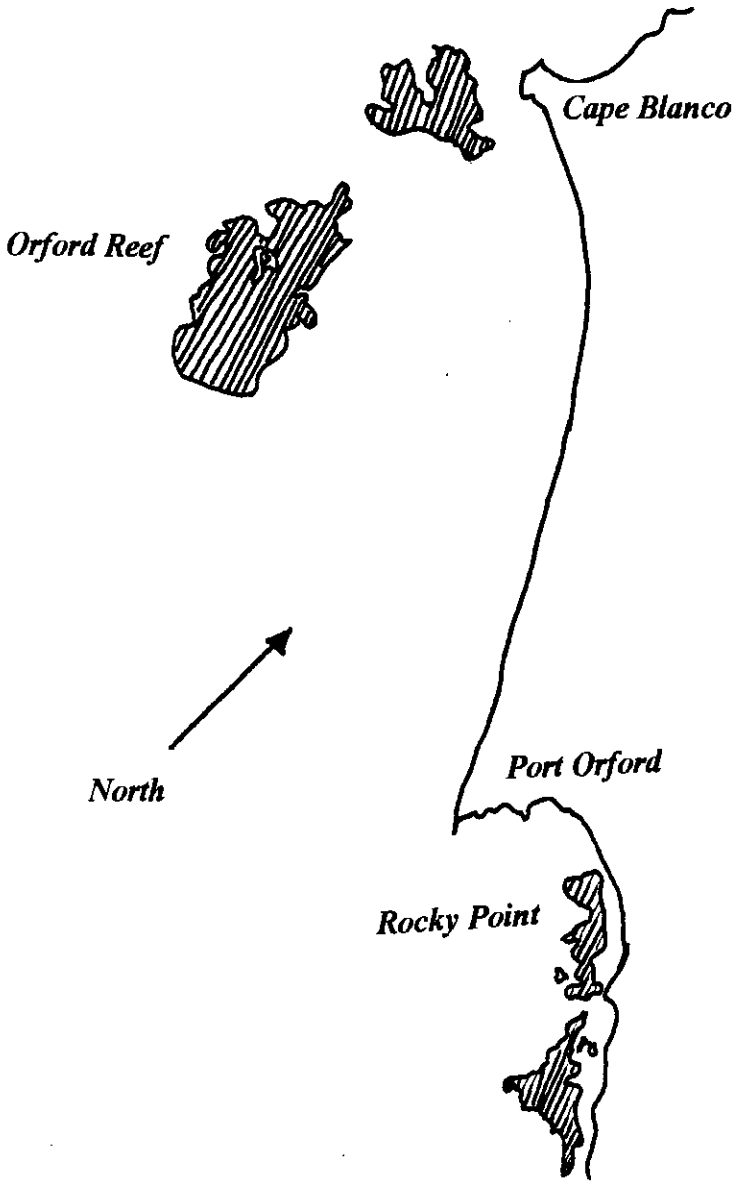
- Is there a relationship between ocean circulation patterns and spore and larval dispersal, settlement, and survival?
- Can ocean patterns be used to predict distribution and settlement patterns?
- What is the relationship between productivity and kelp abundance, and how does that influence the abundance of associated species?
- Can distribution and settlement patterns be detected and predicted by physical parameters (e.g. using satellite imagery , sea surface temperatures etc.)?
- Is there a relationship between large scale oceanographic events (e.g. El Nino events, the Aleutian Low) and settlement and recruitment patterns?

Other aspects that need to be addressed include the relationship between the economic viability of kelp harvesting and biological sustainability. If harvesting is carried out in a biological sustainable way, will it also be economically ? This question is outside the scope of this report. It requires a multi-disciplinary approach to answer. However it is an issue that must ultimately be addressed by biologists, resource managers, fishermen, and economists.

Many of these questions require long term and integrated studies. In this report we have included designs that can be sampled indefinitely so that these types of studies can be carried out.

The study program in this report is designed to be carried out in some of the kelp beds off the southern Oregon coast (Figure 1), although these studies are applicable in many geographic areas. The main focus of the report is a design protocol that can be used by ODFW, and that can incorporate research projects by other researchers (e.g. other organizations, graduate students etc.) as was envisioned by CORE.

Figure 1. Kelp Bed Study Sites



Study Design: Community Aspects

Introduction

This section of the report details a study design to investigate the effects of kelp harvesting on kelps and the associated community. In section 1 we discussed the interaction web of kelp forests focusing on the trophic web, and the non-trophic web. That section highlighted the importance of studying the kelp forest as a whole, to determine how harvesting can directly and indirectly impact the community. For example, harvesting which leads to a reduction in herbivores, will in turn result in an increase in other algal species. Therefore it is important to monitor key aspects of the kelp community to gain a better understanding of kelp forest dynamics. This information can then be used to help managers make sound management decisions. We have focused our design on community wide responses. An advantage of this approach, besides those discussed above, is that if management attention shifts to a species of concern, information should be available on this species. It should also be possible to continue the methods described below to continue to gather information about a particular species of concern. Agencies may of course also want to include additional studies on the population biology of that species of concern also. For instance, if a benthic species or another kelp species becomes a species of concern, information gathered by permanent quadrat method should provide information on the abundance of that species, and changes in abundance in response to harvesting.

In this section we have included sections on biological studies, and monitoring physical parameters. The techniques used to asses impacts of fish differ from those used for invertebrates, and birds etc. However, the design is set up so that integrated sampling can take place to minimize time and personnel efforts. For instance, we describe methods to study the fish community using visual transect methods. The same transects can be used to study the effects of harvesting on the benthic community. We have designed this study to be comprehensive, however we realize that time and financial constraints may limit the studies that can be carried out. Therefore each study is designed to "stand alone" as a complete study, in addition to being part of a larger research program on kelp bed dynamics. In addition we suggest modifications to studies that can expand the range and scope of the study. For instance we have included a large section on studying the impacts of kelp harvesting on fish composition and abundance. We have included a modification to that study that would allow, for example, a graduate student to research the role of kelp in providing a habitat for juvenile fish. This is a smaller and more detailed study that may not be ideal for agencies at this time, but could provide valuable information on the role of kelps for commercial and non-commercial fish.

The Effect of Kelp Harvesting on Fish Composition and Abundance

Kelp beds provide habitat, food, and a refuge for fish (section 1). Activities that remove kelps can have a negative effect on fish abundance (Leaman 1980). However, we

have little quantitative information on the strength of that effect. It has been suggested that juvenile fish, particularly rock fish depend on kelp for a habitat (see Foster and Schiel 1985). Therefore kelp removal is likely to reduce the abundance of these fish. This is turn can affect other species in the community, and because some of these species are commercially important, kelp harvesting may indirectly affect the commercial fish harvest. However, until more quantitative studies are carried out, we have little information to predict whether or to what extent kelp harvesting will affect fish populations. This study is designed to provide quantitative information that will help answer this question, and provide a more predictive model that can be used in management.

Specifically this study is designed to address the following questions:

- What are the main interactions between kelp and associated fish species?
- What is the spatial and temporal pattern of distribution of associated fish species?
- What is the strength of the interactions between kelp and fish (especially commercial species)?
- How does the harvesting of kelp affect associated species in the community, including other commercial species such as fish?

This study can also provide some information on:

- Is the recruitment of kelp associated species limited by recruitment or habitat availability?
- How important is kelp to the recruitment of juvenile fish?

Kelp harvesting may affect the trophic interactions in the bed (section 1). Smaller beds may not support as many herbivores or predators, (including birds that feed among the kelp fronds). Changes in light regimes, as a result of harvesting, may make parts of a kelp bed unsuitable for predators or prey, or may alter the outcome of competition among species. Kelp beds have edges and interiors that differ in physical parameters. For instance the interior of large kelp beds are subject to less wave action than the exposed outer edges. Harvesting will increase the edge:interior ratio and this can affect the behavior of fish and other species. Increasing the edges of a kelp bed decreases the refuge effect of the interior regions. Therefore any predators that move into the kelp bed to forage may now be depleting a greater proportion of the prey. Interior species may suffer higher predation or be driven out.

Fish that are closely associated with kelp should show changes in abundance and distribution in response to harvesting. However this effect, and our ability to detect a response, may be confounded by the recruitment dynamics of the fish themselves (Sale 1975, Booth and Brosnan 1995). If fish are recruitment limited, then available habitat will not be saturated. Under this scenario, harvesting kelps may have little impact on fish densities. However, if fish recruitment is habitat-limited, then reducing the available habitat by removing kelp will lead to reductions in fish populations. We know little about the dynamics of fish recruitment into kelp beds off Oregon, and so quantitative predictions are not possible at this stage. However, the design below will provide information on whether kelp fish in Oregon are recruitment or habitat limited.

The experimental design for fish is designed to test the effects of kelp harvesting on the composition and abundance of fish. The design includes a first year sampling design to develop baseline information on fish abundance and composition, and to compare density and composition between edge and interior parts of the bed at two sites.

Predictions

- If kelp is unimportant to fish, then harvesting will have no effect on fish density or composition.
- If kelp forests are saturated with fish, then harvesting is likely to initially increase fish density especially around the edges. Over time the density of fish will decline to below pre-harvest levels through competition.
- If kelp forests are not saturated with fish, then harvesting is likely to increase fish densities in the kelp beds as displaced fish move into non-harvested areas, and densities will remain at this higher level.

Study design

The density and patchy distribution of fish makes it difficult to detect differences in fish abundance and distribution unless there is a major effect, or unless replication is large. For instance, in an ODFW study in 1995, 49% of sampling transects were zero (Long et al 1996). In order to detect a difference between harvested and control sites, we recommend a transect length of 100m for all fish transects. Experimental design must also be balanced with accessibility of the study sites (heavy swells and poor weather can make diving impossible), and the amount of time a diver can safely spend sampling in 18-25m of water on a regular basis. ODFW have concluded that 75 dives per season are close to the maximum number of dives possible, and this does not account for training dives (5-10 dives), or for extremely poor weather. We have structured the number of replicates and sites to give maximum replication and scientific information given the constraints of the working environment.

Below we present a research program for studying the effects of harvesting on fish in kelp beds. The design assumes that there will be no harvesting in the first year, and that harvesting will take place annually thereafter. Therefore the first year's activities are designed to gather information in a standardized way, that can be statistically analyzed, and will be used as the basis for subsequent years research and management. However, if harvesting occurs in year one, then the design for year 2 and subsequent years are immediately appropriate. Designs for the second and subsequent years are to study the extent of the harvesting impact on fish communities. We have included two alternative designs, the first design looks at the effect of harvesting 10% of the bed compared to control areas. The second options studies the effects of harvesting 10% and harvesting 50% of a bed, in addition to control plots. The advantages and disadvantages of these methods are discussed below. A summary of each design is included in Table 1.

The method used to record fish composition and abundance is the visual transect count. Details on this method, including advantages, disadvantages, and ideal protocols are presented in Table 2. In this study particular attention should be paid to recording the abundance of juvenile fish in addition to adult fish. This is especially true for rock fish which are among the most abundant species in kelp beds (Leaman 1980, Foster and Schiel 1985). Kelps may be a key habitat for juvenile fish, and therefore a reduction in kelp is likely to affect the abundance and distribution of juvenile fish.

Year 1: Distribution and composition of fish in kelp beds

This year will provide an ideal opportunity to study the distribution and abundance of fish within kelp beds, and to examine the edge and interior effects. The null hypothesis being tested is: *That the abundance and composition of fish is the same across two sites and at the edge of the kelp bed and 100m from the edge of the bed.*

To test this hypothesis, a series of randomly placed transects should be set up at the edge of the bed and 100m from the edge. Transect lengths should be 100m each. This is based on previous data on the kelp fish distribution, and on power analysis (Long et al 1996). Studies should be carried out at two sites; Orford Reef and Rocky Point (see map), as these are the areas that are likely to be harvested. At each site, three representative kelp beds should be chosen for the study. A team of divers carries out 5 randomly chosen 100m transects approximately 5 m from the edge of the kelp bed (see below for methods). This will ensure that divers can count fish on either side of the transect tape. Divers then carry out three additional transects 100 m from the edge of the kelp bed. This design will result in a total of 60 transects (30 edge transects, and 30 interior transects). Assuming that divers can carry out one transect per dive, the number of dives for this study will be 60 dives.

Analysis of Results:

Data should be analyzed for normality and homogeneity of variances. Because fish are patchily distributed, data are unlikely to be normally distributed. Log transformations or arcsin may be appropriate transformations. Data are subsequently analyzed using ANOVA

ANOVA TABLE

Main effects
Site (S)
Bed (B)
Tmt (T)
Interaction Terms
S*B
S*T
B*T
S*T*B
Error

Main effects will determine the effect of site, and the individual kelp bed on the distribution of fish. Treatment will determine if there is a significant difference between the density and composition of fish between the edge and interior of the bed. ANOVA can be carried out for total number of fish, for each individual species (if densities are sufficiently high), and for juvenile versus adult fish. Interaction terms will determine the degree to which other variables such as site, and kelp bed contribute to any observed treatment differences. For instance a significant site*treatment interaction will indicated that fish use habitat differently at each site.

The results of this study will be to:

- provide standardized baseline data on fish distributions and abundance in kelp beds
- provide background information that can be used in assessing post-harvesting effects.
- aid in the design of subsequent sampling procedures. For instance, if weather and personnel are a constraint in subsequent years, the results from this study can be examined to see which factors are most important in determining fish distribution. If, for example, site has no significant effect on the results, then future research may be concentrated on more replicates in fewer sites.

Year 2 and subsequent years

Experimental Design to Test the Effect of Harvesting on Fish Composition and Abundance

Given the association of fish with kelp habitat we expect that harvesting will have some impact on fish communities. However, we are interested in knowing the extent of the impact so that sound management decisions can be made. The designs discussed below are to study the strength of the effect of harvesting on fish populations:

This design uses control and harvesting regimes set at 10% for Option ,1 and 10% and 50% for Option 2. The original design called for plots 300x100m in area. However, this design makes it difficult to test the effect of harvesting on fish populations. This is because the size of kelp beds varies greatly, and this variation is likely to confound the results. For instance, a 300x100m plot harvested in a small bed will result in significant habitat loss, and will change the physical conditions in the bed. However, the same size plot removed from a 10ha bed is unlikely to have much effect on the biological or physical characteristics of the bed. One method of dealing with the size variable is to include kelp bed size as a co-variate in the analysis. However, this would loose statistical power and require a greater number of replicates to detect a difference. Recall too, that the patchy distribution of fish already requires greater replication. We concluded that it would be impossible to carry out the required sampling regime to detect a significant effect using standard plots sizes in variable sized beds. Therefore we chose a design that standardizes the amount of habitat that is removed from each bed. This allows us to evaluate the effects of different amounts of habitat loss on fish composition. This can provide managers with a predictive tool for decision making. As noted above, we needed to balance the statistical

needs with what is possible logistically. Therefore our design includes two options that can be carried out depending on the weather and number of personnel available.

Option A. The effect of harvesting 10% of the kelp bed on fish composition and abundance

We recommend carrying out this study at two sites, Orford Reef and Rocky Point. At each site, eight beds are randomly chosen, and the position recorded using GPS. Plots should be marked either with buoys and/or other markers in the substrate so that plots can be repeatedly sampled. The beds should be approximately similar in size. Within these eight beds four control and four experimental beds are randomly designated. Prior to harvesting, researchers conduct 100m edge and 100m interior transects (100m from the edge of the bed) in each of the eight beds. (This provides a total of eight edge counts, and eight interior counts for each site.)

The beds are harvested according to the method outlined by the Division of State Lands i.e. by hand or small-scale mechanical cutter; both blades and stipe of the kelp will be cut and removed, however harvest will be no greater than two feet below the water surface. For these studies harvesting should take place around the edges of the bed.

After the beds have been harvested, researchers return to the sites and repeat the transects in the control and harvested plots. If time permits, a second sampling of the beds is recommended. Ideally both interior and center should be resampled, however if time is limiting, the edges of the beds can be resampled. A more informed decision on where to carry out limited additional sampling can be made after the results from year 1 have been analyzed. These results will provide a clearer picture of the distribution and composition of fish in the interior versus edge.

Pre-harvest and post-harvest data collection will yield a total of 64 transects, 32 pre-harvest and 32 post harvest transects. If each transect takes one dive then this study will require 64 dives.

Analysis

Data should be analyzed for normality and homogeneity of variance, and transformed if necessary. If the beds are sampled before and after harvesting only then analysis will be by ANOVA

Main Effects
Site
Block
Treatment 1 (harvest v control)
Treatment 2 (edge v interior)
Interaction Terms of interest
Tmt1 * Tmt 2

Site* Tmt 1
Site * Tmt 2
Site *Tmt1 * Tmt 2

Main effects will provide information on the significance of each variable and treatment independently. For instance independent effects of treatment 2 indicated that each habitat (edge v interior) is affected equally by harvesting. An interaction term of note is a treatment 1* treatment 2 interaction (harvesting *edge/interior interaction). If this term is significant it indicates that harvesting has affected one habitat (edge or interior) more than the other. For example we might expect to record fewer species in the edges of harvested beds, and/or more individuals in the center as species move inwards in response to harvesting. Alternatively, changes in light regimes and visibility in the harvested beds might attract more fish species to feed in the edge area. ANOVA may be carried out on total density of fish, juvenile density, adult density, individual species, or fish may be categorized into trophic or taxonomic groups depending on sample sizes.

If repeat surveys are carried out on the plots then a repeated measures ANOVA (RMANOVA) is the appropriate analysis.

OPTION B. The effect of harvesting 10% and 50% of the kelp bed on fish composition and abundance

This option is designed to give more information on the effect of habitat reduction on fish composition. This design is similar to Option A except that there is an additional harvesting regime set at 50% of the bed. The advantage of this design is that it provides more comprehensive information for managers, and can be of more help in decision making. For instance, a 10% harvest may result in minimal impact to fish, but impacts at 50% may shown highly significant impacts on the fish community. Under this scenario, managers may conclude that a 50% harvest rate is unacceptable but perhaps an ideal harvest regime lies in the region of 10% of the bed. The disadvantage of this method is that it requires additional time to complete the pre and post-harvesting sampling. Given personnel constraints and unpredictable weather conditions this may prove difficult.

This study is designed to be carried out at two sites Orford Reef and Rocky Point. At each site twelve kelp beds are randomly chosen. Each bed is randomly assigned one of three treatments, control, 10% harvest, or 50% harvest. Sampling and analysis is similar to that described for Option A above.

Fish Studies	Location	Design	Sample Size	Analyses
Year 1				
Test abundance and distribution of fish (edge v. interior)	Orford Reef Rocky Point	3 kelp beds/site 5 edge and 5 interior 100m transects/bed/ site.	60 x 100m transects over 2 sites	ANOVA
Year 2 and Subsequently				
Effect of harvesting on fish distribution and abundance	Orford Reef Rocky Point			
OPTION A				
2 treatments: control and harvest (10% of bed).		4 experimental beds harvested at 10% of bed, and 4 control beds at each site. One transect at edge and one transect at interior of each bed. Pre- and post- harvest transacts at edge and interior of the bed.	Preharvest 32 x 100m transects Post-harvest 32 x 100m transect Total = 64 transects	ANOVA
OPTION B				
3 treatments: control; 10% of bed harvested, 50% of bed harvested.		4 blocks of 3 tmts. at each site. Pre-harvest transects at edge and interior. Post- harvest transects edge and interior.	Pre-harvest 48 x 100m transacts Post-harvest 48 x 100m transects. (May be repeated) Total = 96 transects	ANOVA or RMANOVA if repeat sampling

Table 1 Summary of experimental design for testing the effects of kelp harvesting on fish composition and abundance

Table 2 Visual transect method for assessing abundance and composition of fish

Advantages

- Visual census of fish is one of the most common quantitative and qualitative sampling methods used in temperate and tropical fish surveys and studies.
- It is rapid, nondestructive, and inexpensive.
- It utilizes a minimum of humanpower and specialized equipment.
- It can be used to resurvey the same areas through time.
- It has the potential to produce large databases rapidly for management and assessment purpose.

Disadvantages

- Observers must be well trained and experienced.
- There may be repulsion and /or attraction of fishes to divers.
- Observer error and biases occur in estimating the numbers and sizes.
- There is low statistical power to detect changes in rare species.
- The use of abundance categories reduces the power to detect small changes.
- The techniques are restricted to shallow depths due to decompression constraints.

Logistics

- Fish survey team consists of 2 to 3 divers. One diver is designated as the observer to reduce bias.

Technique

- Lay the transect, and wait 5-15 minutes before counting to allow the fish to resume normal behavior (Carpenter et al 1981).
- Each transect is censused as a 100m x5 m transect. Transects should not be broken into smaller units as this will underestimate the abundance of more mobile species.
- The observer swims slowly along the transect, recording fish encountered within 2.5m on either side, and 5 meters above the transect. If visibility is poor then it may be necessary to reduce the belt width for instance to 2.5m wide and 2.5 meters high. A consistent width and height that is suitable for normal visibility conditions is recommended.
- It is important to verify the divers ability to estimate the distances. Bell et al (1985) found that the ability to estimate length frequency is reduced if divers do not practice it for 6 months.
- If visibility is poor, or if species tend to hide out in crevices, use a dive light to sample dark caves or crevices.

Data Recording

- A plastic write-on dive slate already tabulated for fish counts is best to use. Divers marks off the fish as they are counted.
- The observer should record data on species identity, and note whether each fish is a juvenile or adult. Data should be transferred to computer as soon as possible after the dives.

Modifications and Additions to the Fish Studies

The studies described below are additional studies or modifications of the existing design to give further information on the dynamics of kelp forests, particularly in relation to the impact of harvesting on kelps

1. The role of kelps as a habitat for juvenile fish (recruitment of juvenile fish into kelp beds)

The studies described above will provide information on the density and distribution of juvenile fish in the kelp bed. To get more information on the relationship between juveniles and kelp a separate study can be undertaken. This study should sample the edges and interior of the kelp beds as described above. However, additional plots 100-300 meters outside the kelp bed should also be sampled as a non-kelp habitat. The researcher records the abundance of juvenile fish in each habitat, and classifying fish into size classes to distinguish new recruits from older juveniles. The observer should pay particular attention to searching caves and crevices when recording data for this study. In addition this study should include more frequent sampling. It will be ideal to start the study as kelp beds are beginning to grow in April and May, and to record the changes in juvenile fish abundance in kelp and non-kelp areas as the season progresses. Sampling should be carried out every 2 week to monthly during the main growing season. However, sampling will likely be much more infrequent in winter months.

2. A comparison of fish composition and abundance between the outer kelp beds and more protected beds near Port Orford (Tichner Bay area).

Fox (1996, personal communication) noted that *Nereocystis* beds in the protected areas just west of Port Orford pier have smaller kelp beds, but appear richer in fish life. This observation can form the basis of a study to examine the extent of the difference in the fish community. For instance if fish were limited by kelp only, then we would predict that the larger kelp beds would have more fish. A comparison between sites may provide some information on whether other factors are limiting fish distributions in offshore beds. This study should be set up as described above (year 1 is most appropriate, unless inshore beds will be harvested in which case harvest and control methods plots should be used), and with the same number of fish transects in inshore and offshore beds. The observer should record both species identity, and juvenile or adult stage. In addition other physical factors should be recorded including depth, temperature current, water clarity, community profile (see additional studies under benthic studies). If any of these variables differ significantly they can be incorporated into an analysis of covarianace.

Plants, Invertebrates, and the Benthos

The substrate in a kelp bed is home to a diverse array of plants, sessile, and mobile invertebrates (see section1). May of these species play a major role in the establishment and persistence of kelp (e.g. sea urchins) (Duggins 1982, Foster and Schiel 1985, Graves and Richmond 1992, Estes and Duggins1995,), and others are food for a range of herbivores and predators (e.g. understory algae, invertebrates) (e.g., Leaman 1980, Foster and Schiel 1985, and references therein). Changes in kelp abundance may have an effect on the trophic dynamics among these species. In addition change in light and flow regimes as a result of harvesting may favor different species e.g., the growth of fleshy algae over corralines. Section 1 describes the trophic and non-trophic interactions in a kelp bed. This section is confined to studies designed to monitor the impacts of kelp harvesting on the benthic community.

The study is designed to address the following questions that were identified as needed information above:

- What are some of the main interactions between kelp and benthic species?
- What is the strength of the interaction between kelp and associated species?
- What is the spatial and temporal distribution of associated species?
- How does the harvesting of kelp affect associated species in the community?

This study will also provide some information on:

- What are the temporal and spatial fluctuations in the distribution of kelp bed communities?

Design and Methods

We recommend using the quadrat method to study changes in the benthic community. Permanent quadrats are ideal, if the area will be resurveyed on a regular basis, which is highly recommended as this will provide long-term data. However, if the area will only be surveyed for one year, then there is no need to set up permanent quadrats, and random or fixed position quadrats can be sampled. Table 3 provides an overview of the quadrat method, including advantages, disadvantages, and techniques. This assumes that photography or video is being used to collect data.

The benthic community should be sampled at the same time as fish abundance studies are underway. This allows the researcher to compare responses in the fish and benthic communities. It also saves time and effort as fish and benthic sampling can be carried out together.

General Method

After observers have collected fish abundance data, divers swim back along the transect line and collect data on benthic cover using 1m x1m quadrats. Data can be collected using photography or video (described in detail below). Ground truthing is often

required when video or photography are initially used. This can be time consuming, but as observers and recorders become more experienced, there is less need for ground truthing. We have organized the benthic methods to follow the sampling design described above for fish, i.e. year 1 sampling is designed to provide standardized background information on kelp forest dynamics, subsequent years studies are designed to test the effect of harvesting on the community. Table 4 provides an overview of the different sampling strategies.

Year 1

In the first year quadrat sampling will provide baseline information on benthic composition in the edge and interior of the kelp bed. (Recall that the design is based on studies at 2 sites, with 3 beds per site, and 5 edge and 5 interior transects in each bed.) For benthic studies, three quadrats should be monitored per transect at the 10m, 50m, and 90m mark on the transect tape. This will result in a sample size15 quadrats per kelp bed, 90 quadrats/site and a total sample size of 180 quadrats (Table 4).

Data Analysis

Data can be broken down by category: corraline algae, algal turf, fleshy algae, bare rock, invertebrates. If any species is a key species in the community or tends to dominate a category then this species can be analyzed separately. For instance, sea urchins are key species in the establishment of Nereocystis beds and researchers may wish to analyze changes in this species separately. Analysis will be by ANOVA (see section on fish abundance year 1 above). Data should be tested for normality, and homogeneity of variances, and transformed if necessary.

Subsequent years studies to test the effects of harvesting on benthic species composition and abundance.

We have presented two design options for testing the effects of harvesting on kelp forests (above section). Option A requires 4 control beds and 4 experimental beds harvested at 10%, at each of two sites. Pre and post-harvest data are collected along an edge and interior transect at each bed. Quadrat sampling should be carried out along three transects. At each transect divers should record (using video or photography) the benthic community composition at 3 x $1m^2$ quadrats at the 10m, 50m, and 90m marks on the transect tape. Option B requires three treatments, control, 10% harvest, and 90% harvest. To monitor changes in benthic community composition and abundance, researchers should also carry out 3 x $1m^2$ quadrats at the 10m, 50m, and 90m marks on the transect tape, during both pre and post harvesting. Data should be recorded after fish abundance data have been collected (to minimize the impact of divers on fish behavior before fish data are collected), and if possible during the same dive.

Data Collection

Before entering the water record the location and any ambient parameters on a data sheet. Once in the water other physical parameters should be recorded immediately

on reaching the bottom (e.g. temperature depth etc.). While the transect is being laid out, an observer should record any additional information on the site etc.

1. Video recording. Video is less used for permanent quadrat recording than photography, nevertheless it can offer a rapid and accurate way to assess the benthic community. Video also provides a permanent record of the quadrat. To record the benthic composition, the observer places a 1m quadrat on the substrate at the desired mark on the transect tape. In a position directly over the quadrat, the observer records the community inside the quadrat square, using the quadrat as a guide for frame size. The observer then zooms in on the top right corner of the plot and gradually (moving left to right) records the species within the quadrat. This close up video can help the data recorders to identify certain species that may be difficult or cryptic in the video frame. Before the video shot is taken, the accompanying diver should place a slate in front of the lens which indicates the site, date, transect number, and plot number so that the shot can be assigned to the correct transect and site.

It is also often necessary to ground truth the video results. Here a diver must take visual data on species composition and abundance. This provides the data recorder with a comparison of methods (for instance, video may be difficult to use in heterogeneous substrates where part of the cover is hidden). It also allows the observer to identify certain species that may be difficult to distinguish in video frame.

The data are analyzed by digitizing the image (many commercial programs are set up to grab individual video frames, including Framegrabber, and Adobe premier). An image analysis program (e.g. NIH image) is then used to estimate the relative abundance of each species in each plot.

2. Photographic recording: Many subtidal communities have been examined using photo-quadrat methods (see Hanisak et al 1989 for examples). The use of photographs to monitor changes in benthic communities was begun by Connell (1973, 1976) and has been used in many other studies (e.g. Endean and Stablum, 1973, Pearson 1981, Hughes 1989). Photographs allow speedy collection of data in the field, and also provide a permanent record of the quadrat which is useful for long-term monitoring (Gittings et al 1990).

Photography recording can be cumbersome underwater. Usually two divers are required to move and position a tetrapod frame. Photo-monitoring works best on relatively flat surfaces. Visibility off the Oregon coast is often limiting, therefore it is important that the frame be close to the substrate. In poor visibility a framebase of 0.5 x 0.5 and frame height should be 0.4m. provides better resolution. This design is for a 15 mm lens with one or preferably two strobes. If the divers are using only one strobe, then they should adjust the strobe position depending on the substrate profile, so that areas of the photo are not in shadow. The set of vertical plane photographs which make up the photocomposite of the quadrat must be taken in a set sequence so that the photographs can be assigned to the correct section of the quadrat. Initial ground truthing is also usually required for photo-quadrat monitoring.

Photographs can be taken as print film or using Kodachrome 64 or Ektachrome 100 or 200ASA. Prints or slides can be scanned into a computer and analyzed using an image analysis program as described above.

Alternative Technique for Collecting Data on Benthic Composition and Abundance: Line Intercept Transect

The techniques described above require that personnel are trained and experienced in species identification. There is an alternative technique, the line intercept transect, for collecting information on lifeforms or categories of species (e.g. corraline algae, algal turf etc.). It has the advantage that personnel with limited experience can be trained to recognize simple categories of species. This may be particularly useful for volunteers, including urchin divers who may be able to collect transect information. This technique also involves collecting data in situ.

The line intercept transect technique (LIT) was developed in terrestrial plant ecology and subsequently was adopted by coral reef ecologists (Loya 1978; Marsh et al 1984). The procedure fuses a classification system based on structural attributes of life forms rather than species level data (English et al 1994). The LIT is used to estimate the cover of categories within a specified area by calculating the fraction of the length of the line that is intercepted by each category. This measure of cover, usually expressed as a percentage, is considered to be an unbiased estimate of the proportion of the total area covered by that category if the following assumptions apply: the size of the object is small relative to the length of the line and that the length of the line is small relative to the area of interest. The technique has been widely used (English et al 1994). Most studies using this method have used similar techniques: a plastic fibre tape placed on the substrate. General methods, and advantages of the LIT are discussed in Table 5

For this study, the transects sampled can be the same transects that are used for fish abundance. We have no information available on the ideal length for the transects that will give most power. For coral reef studies English et al recommend a 5 transects of 20m length. This study will provide 5 transects per bed in year 1. Subsequent years will provide 4 edge and 4 center transects each for control and experimental beds at each of two sites. Therefore this should be sufficient to meet the criteria of English et al (1995), and to allow for detection of differences among sites. Transects can be carried out after fish counts have been recorded. Divers should use from 0-20m mark on the transect tape.

Data Collection

Divers record physical parameters and location before entering the water, and any additional information on reaching the bottom. When the fish counts have been finished, divers swim back along the transect line, and begin a LIT at 0m mark and continue recording to 20m mark. At each point where the benthic lifeform changes, the observer

records the transition point in centimeters and the name or category of the lifeform. Hence, along the length of a transect (XY) a number of transition points are recorded for each lifeform. The intercept of each lifeform encountered under the transect (I) is the difference between the transition points recorded for each lifeform.

Categories: For benthic forms off the Oregon coast suggested categories are corraline algae; algal turf; kelps; other fleshy algae; sea urchins; sessile invertebrates; mobile invertebrates.

Analysis

Summary data showing percent cover and number of occurrences of each lifeform may be calculated using the line intercept data. After calculating the intercept (length) from the transition points recorded along the transect, the percent cover of a life form category is calculated:

$$\text{Percent Cover of Lifeform} = \frac{\text{Total length of lifeform}}{\text{Length of transect}} \times 100$$

These analysis will provide quantitative information on benthic community structure, and comparisons may be made between sites, and over time. ANOVA analysis can be carried out on the data to test for significant differences among sites and treatments.

Sea bird surveys

Studying the effect of kelp harvesting is made difficult by the range of factors that affect seabird distribution. Biological factors, including reproductive status, age, migrations, food availability, and the presence of humans can play a large role in habitat selection. In addition birds appear to respond to oceanographic factors, for instance, Briggs (1987) found that some birds are found at upwelling zones at certain times of year. Scale is a major consideration in the design of sea bird studies (Haney 1985, Hanowski et al 1990). Studies carried out at small spatial scales can be too small to detect differences in densities among habitats, and work is ongoing on designing appropriate sampling strategies for seabirds (George Hunt, UCLA *personal communication*). Given these complexities, it would be premature to design a long term seabird sampling strategy for kelp forests off the Oregon coast. We need more information on what species of birds are using kelp areas, at what times of year, and how they use the habitat. For instance, some birds may use kelp regularly but it may not be critical to their survival. However other species may use kelp for a brief critical period e.g., juvenile marbled murrelets are associated with kelp in Alaska (Kathy Kuletz USFWS *personal communication*). At this stage, we feel that it will be best to carry out exploratory studies that are appropriate for the temporal and spatial scale of the work. The results from these preliminary studies can then be used to design a more appropriate and efficient study program for seabirds. There are many species that may occur in kelp bed at some time during the year, some of those are sensitive or threatened species. These include common murres, marbled murrelet,

tufted puffins. If these species are present in high enough densities then we recommend that special attention be given to the distribution and abundance of these species in kelps, and the impacts of kelp on behaviors and abundance. Not however, that sampling is confined to a short period during the year, primarily summer, and so the study will not be able to determine the role of kelps in seabird ecology in winter months.

Methods

There are three basic methods to study the abundance and behavior of seabirds; line transects; extended point counts; and focal bird studies. We recommend that the focal bird study be used as the primary method, with limited extended point counts if time permits (see below).

Line Transects

Line transects are widely used in bird suveys. However they are most appropriate for large scale studies because of high variance over small areas. This technique was carried out by ODFW in previous years studies in Port Orford Reefs but with limited success. We do not recommend that this technique be a major part of the study at this time.

Extended point counts

This study involves sitting at a single point, adjacent to a particular habitat for an extended period. The observer records the abundance and behavior of birds present. Because birds are patchily distributed, an observer may have many zero counts from different habitats, and this type of study will result in high variance. However, it will provide some background information on which species are present. We recommend that ODFW carry out limited extended point counts in harvested, non-harvested, and undisturbed beds.

Focal-bird study

In this design an observer follows an individual bird for a fixed period of time, recording the birds activities during that period. For species in high abundance the time spend observing an individual will be less than for species in low densities. (This design is optimal for minimizing variance). An observer uses a tape recorder to record behavior in real time for a fixed period (e.g. 5 minutes (=300 seconds)). Data is analyzed by estimating the proportion of time spent in different activities or habitats. For instance if an observer records a marbled murrelet foraging twice during the fixed period, the first of 30 seconds duration and the second of 60 seconds duration. Proportion of time spent foraging is calculated by the equation (90/300) =0.3 In other words the bird spent 30% of its time foraging.

Categories of behaviors will need to be clearly determined prior to recording. Categories recommended include: diving, feeding on the surface, looking underwater, active swimming on the surface, social interactions (fighting, calling, courtship), preening, sleeping, resting, flying. In addition habitat categories should be recorded simultaneously at 30second intervals. These include location in or outside of kelp, distance from edge of the kelp bed, and distance to other conspecifics, and other species.

Study Areas

This study should be carried out in the harvested and control sites described above for fish and benthic studies. In addition, completely undisturbed beds should also be sampled. This will test for the effects of human disturbance (harvesting and data collection) on bird distributions and behaviors. This design cannot be completely orthogonal.

Harvested Plots	bed interior	harvested area outside the kelp bed
Unharvested Plots	bed interior	outside the kelp bed
Unharvested Plots (no other data collected)	bed interior	outside the kelp bed

Data Analysis

The effects of harvesting will be tested by comparing harvested and unharvested plots. Human disturbance will be tested by comparing unharvested plots (no other data collected) with unharvested study plots. Depending on the hypothesis to be tested, data can be analyzed by one-way ANOVA or a t-test.

Fish Studies	Location	Design	Sample Size	Analyses
Year 1				
Benthic community composition and distribution	Orford Reef Rocky Point	3 kelp beds/site 5 edge and 5 interior 100m transects/bed/ site. Video/photo quadrat monitoring of 3 1x1m quadrat per transect at 10m, 50m, and 90m marks	30 quadrats /kelp bed (=15 edge &15 interior) 90 quadrats /site. Total 180 quadrats	ANOVA
Year 2 and Subsequently				
Effect of harvesting on benthic distribution and abundance	Orford Reef Rocky Point			
OPTION A				
2 treatments: control and harvest (10% of bed).		4 experimental beds, and 4 control beds at each site. One edge and one interior transect/bed at pre- and post- harvest. 3 quadrats along each transect at 10m, 50m and 90m	Preharvest 48/site for a total of 96 quadrats preharvest. Post-harvest 96 quadrats Total = 192 quadrats	ANOVA
OPTION B				
3 treatments: control; 10% of bed harvested, 50% of bed harvested.		4 blocks of 3 tmts. at each site. 3 quadrats along each transect at 10m, 50m and 90m	Pre-harvest 6 quadrats/tmt. 72 quadrats per site Post-harvest 72 quadrats/site.) Total = 144 transects	ANOVA or RMANOVA if repeat sampling

Table 3. Summary of experimental design for testing the effects of kelp harvesting on benthic species composition and abundance

Table 4 Permanent Quadrats

Advantages

- Sampling is non-destructive
- Detailed and careful observation, photography, and mapping of such a fixed area provides a good record of what takes place in the area
- Provides a permanent record of the site

Disadvantages

- The method is slow
- Equipment is somewhat cumbersome, especially in strong currents
- Photography requires a relatively flat area
- The method only examines a small area

Logistics

A team of 3 personnel, 2 divers and a boat person.

Equipment for Permanent Quadrats

- Quadrat markers, e.g. stainless steel rods, or angle iron
- 1x1m quadrat This can be marked into 4 equal sectors
- For photography: a stable tetrapod stand which will hold the camera a fixed distance from the substratum for vertical -plane photographs. Underwater camera e.g. Nikonos camera with 15mm lens/strobes, Frame base 0.5 x0.5m, and the camera plate mounted at a height of 0.4m (recommended for poor visibility areas (English et al 1994)
- For video: Underwater housing and video, laser lights for measuring distance
- Slates, data sheets, and pencils

General Procedure

- Mark the position of the quadrat at each corner, using steel rods, angle iron, or other suitable material. Markers must be hammered into the substrate. Mark one corner (e.g. top right) with a tag or some form of distinguishing mark to identify quadrat number and position at a later date.
- Place the quadrat on the corners of the markers when collecting data (photography or video)

Photography and video

- Photograph and video record at right angles to the substratum.

Table 5. Line Intercept Transect

Advantages

- Allows the collection of useful information by persons with limited experience in the identification of benthic communities
- It is a reliable and efficient sampling method for obtaining quantitative percent cove data
- Requires little equipment and is relatively simple

Disadvantages

- Objectives are limited to questions concerning percent cover data or relative abundance
- It is inappropriate for assessing demographic questions concerning growth, recruitment or mortality.
- While the method provides detailed information on spatial patterns, it is not as reliable for providing information temporal change because the same areas are not precisely re-sampled. This can be overcome by also using permanent quadrats.

Logistics

- Requires 3 people, 2 divers and a boatperson
- Life forms should be standardized and all observers should be familiar with the lifeforms. Often training is necessary and this should be carried out in the field.
- Standardization between observers and continuity of observers throughout the project is important as observer variability may obscure or complicate real spatial patterns.

Additional Studies on Community Responses to kelp dynamics and kelp harvesting

1. Key species of species of concern

The benthic design outlined above is designed to a community-wide response rather than focusing on a particular species. However some species are important members in the community, and their presence or absence can influence the persistence of the kelp bed and other species. Sea urchins *Strongylocentrotus franciscanus* can regulate the abundance of kelp (see references in section 1). This species is currently being harvested off the Oregon coast. We recommend that research on sea urchins be integrated with the kelp study. For example, a researcher, or volunteer divers (including urchin divers e.g. surveys carried out in 1990-1 (Graves and Richmond 1992)), can carry out urchin density counts along the same transects that are used for fish and community data collection. The effect of harvesting on urchins can be studied by estimating changes in the urchin population in control and harvested plots. Further the effect of urchins on recruitment of kelp can be studied by either correlation analysis or if densities are sufficiently high, urchin density can be a co-variate in an analysis of covariance. In addition data on recruitment, growth, and reproduction of urchins will provide valuable information for managers of kelp and urchin resources. Long term data is especially useful as it can address spatial and temporal change in the community.

The community of small animals associated with kelp beds (both on the kelp itself and on hard substrate) can be sampled quantitatively using a simple suction device. See Kennelly and Underwood 1985 for details on methodology and sampling sizes.

The effect of grey whales on the ecology of kelp beds. Grey whales were often associated with kelp beds, but hunting greatly reduced the inshore populations. Since the hunting ban, the density of inshore grey whales has increased in recent years off the Oregon coast, and many individuals are found in kelp beds (author, *personal observation*, S. Gobat, M. Noack, T. Grubba, S. Courtney, B. Abbott *personal communication*). The feeding ecology of grey whales were studied feeding in Nereocystis beds along the West coast of Vancouver island (Murison et al 1984). The authors found that whales were feeding primarily on mysids associated with the kelp beds. It is interesting to speculate how grey whales may have affected the ecology of kelp beds directly through food consumption, and indirectly through disturbing the habitat and other species in the kelp bed. A fruitful study will be the ecology of kelp beds in areas without grey whales, and studies in areas with whales, or follow-up studies in beds when grey whales start foraging in the areas.

The effect of harvesting on other plant species. Foster and Schiel 1985 (and references therein) suggest that the presence of kelps affects the abundance of other algal species through direct competition for sunlight, or indirectly be providing a habitat for herbivores. The effect of kelp harvesting on other plant species can be monitored inside the permanent quadrats. Researchers can compare recruitment and abundance of other plants between control and harvested plots, using the methods described above. For a

more in depth study a researcher can additionally compare the growth rates and reproductive output of understory plants in the control and harvested areas. However to distinguish whether kelp have an indirect or direct effect on other plants, the density and abundance of herbivores will also need to be monitored. The epiphytic community on *Nereocystis* plants is also deserving of study. For instance, Woessner (1981) concluded that *Porphyra nereocystis*, which is epiphytic on *Nereocystis luetkeana* can potentially be commercially harvested in certain areas.

2. *The role of kelp beds in the dynamics of rocky shore communities (including bird communities).*

The presence of kelp beds can affect the abundance of plankton, and the dynamics of marine communities on adjacent shorelines. Kelp forests harbor predators that feed on the larvae of rocky shore invertebrates. Gaines and Roughgarden (1987) found that predation by juvenile rockfish in kelp beds reduced the density of barnacle larvae by 1/50 of the level in the absence of fish.. This in turn can affect barnacle recruitment onto nearby shores. As barnacles are often necessary for the establishment of the middle and upper intertidal community (Farrell 1991. Grubba and Brosnan in press), kelps may indirectly affect the composition of the marine shore community. In addition many shorebirds are dependent on drift kelp. For example, shorebirds associated with algal windthrows increased dramatically after kelp recovery off the southern California coast (Bradley and Bradley). Associated studies can be carried out that examine patterns of recruitment, community dynamics, and shorebird abundance in response to the abundance of offshore kelp.

Kelp Population Dynamics

The previous section presented designs and methods for studying the kelp community. It is also vital to understand the dynamics of Nereocystis luetkeana so that sound management decisions can be made. There are a number of studies that can be carried out on kelp plants. These can be independent projects (e.g. graduate theses), and can also be integrated into the ongoing research at State agencies.

In the introductory paragraphs above, we identified four main questions concerning kelp population dynamics:

- How does the recruitment and growth pattern of kelp vary spatially and temporally?
- What is the dispersal pattern of kelp spores?
- How does harvesting affect recruitment growth and reproduction of kelp?
- What is the current size of the kelp population and how does the size vary?

The study of spatial and temporal variation in kelp beds (which addresses questions one and two, and last questions above) is probably best carried out using either aerial photography or satellite imagery. The spatial scale required for this study is large. ODFW carried out previous aerial kelp surveys. Other methods and results are discussed in Sharp and Carter (1986). The results of a satellite imagery study is reported by Belsher and Mouchot (1992). Remote sensing techniques for monitoring kelp populations are evaluated in an article by Deysher (1993).

Algal dispersal has been studied in a number of kelp species (see Santelices 1990 and references therein). Most studies involve placing settlement plates(often glass slides or plates) in the water column at a range of distances from adult plants, and at a range of depths. Settlement plates are collected regularly and germination induced in the lab (See Santelices and references therein for details on the methods). This type of study should also be correlated with studies on oceanographic factors such as upwelling, current speeds and direction etc. (See for example, Tegner 1986)

On study that can easily be integrated into the current ODFW program is an investigation on the effects of harvesting on growth and reproduction of kelps. This study should investigate the reproductive pattern in a sample of kelp plants from different beds (including control and harvest beds). Researchers can investigate the reproductive patterns within kelp beds (i.e. number of sori, time of appearance of sori) in the interior and edges of the kelp bed. In addition, the effect of harvesting on overall reproductive output can be studied by comparing growth and reproductive rates of plants that have been harvested, with unharvested plants. Survivorship among harvested and non-harvested plants should also be studied. Sections of this study can be carried out by volunteers, including kelp harvesters. For example, kelp harvesters can count the number of sori and lamina on a representative sample of harvested plants, and non-harvested plants.

The effects of harvesting on the persistence of kelp beds should also be studied. harvesting can change the hydrodynamic forces acting on a kelp bed (Mark Denny,

Stanford University *personal communication*). This is turn could lead to increased drag, and loss of kelp canopy in winter storms. Initially, to test for the effects of harvesting on kelp bed persistence, ODFW should record whether the study beds (i.e.control and harvest beds described above) persist throughout the winter, and what proportions of the beds are lost during storms. Long term, if harvesting increases, this study might be best carried out by aerial or remote sensing.

Oceanographic Factors

It is outside the scope of this report to produce a design for an oceanographic study of factors affecting kelp beds. However, a complete kelp program should include an oceanographic component. The key questions that should be addressed include:

- Is there a relationship between ocean circulation patterns and spore and larval dispersal, settlement, and survival?
- Can ocean patterns be used to predict distribution and settlement patterns?
- What is the relationship between productivity and kelp abundance, and how does that influence the abundance of associated species?
- Can distribution and settlement patterns be detected and predicted by physical parameters (e.g. using satellite imagery , sea surface temperatures etc.)?
- Is there a relationship between large scale oceanographic events (e.g. El Nino events, the Aleutian Low) and settlement and recruitment patterns?

Some of these questions can be addressed in related studies. For instance, a study that looks at settlement and dispersal should also investigate the circulation patterns during the study period. Some of this information is available from other studies and agencies (e.g. NOAA). See the study by Farrell et al (1991) which looked at recruitment patterns in relation to oceanographic circulation and El Nino.

Productivity will vary with nutrient availability. These in turn are affected by oceanographic factors including circulation patterns (e.g., El Nino), upwelling strength etc. Productivity can affect growth and reproduction of kelp species (see Foster and Schiel 1985). In addition productivity can also affect trophic dynamics in a community, by determining the number of trophic levels, and species composition and biomass at each level. (See The Trophic Cascade Model papers by Carpenter et al 1991 et sub.). The relationship among productivity, oceanographic factors, and kelp beds is in itself a major program. However it is a program that should be carried out and that can potentially provide valuable information on the dynamics of kelp beds and the ocean community.

ODFW carried out simple oceanographic measurements that included detecting upwelling events. These measurements should be continued and integrated into the results from biological studies (see below).

Physical Characteristics

Biological and physical factors interact to determine the abundance and composition kelp forest communities. It is vital that ODFW continue to monitor physical factors in the environment. These include: salinity, surface and subsurface temperature, surface and subsurface light, turbidity using the methods described in Long et al 1996.

Integrated sampling

In Table 6, we outline a sampling protocol that can be used by ODFW in each days sampling plan. This protocol is assumes that the following studies will be carried out
Year 1: The distribution and composition of fish in kelp beds: benthic composition in kelp beds; focal individual studies on seabirds (and if time permits, limited extended point counts); physical oceanographic sampling.
Year 2. The effects of harvesting on fish, and benthic species composition and abundance; focal studies on sea birds (limited extended point counts); physical oceanographic sampling.

If time permits, we recommend that additional studies should focus on the dynamics of the kelp population. Growth, reproduction, and recruitment in harvested and non-harvested beds should be studied. This study will not require additional dive time, and can be conducted from the boat. Some of the material (from harvested plots) can be collected at the sites and analyzed in the lab, thus reducing time requirements at sea.

Table 6 Daily Field Research Protocol

As the boat arrives at the study site, the bird observer notes the presence of birds at the site, and records any observations including birds leaving the area as the boat approaches etc.

When the boat is anchored or stopped

Physical Oceanographic Data
Researchers collect physical oceanographic data using CTD, Secchi disk, light meters etc.

Divers enter water and collect oceanographic data at the bottom (temperature, depth, and any other information). Equipment including video cameras, transect frames etc. can be taken down to the bottom and anchored while fish transects are onging. This means that divers do not have to resurface to collect cameras or other equipment after fish counts are completed.

Community Sampling
Divers lay out 100m transects, and after waiting 5-15 minutes carry out fish transects. Divers return to permanent quadrat markers and either video, photograph or ground truth the plots.

Seabird and Other Studies.
While the divers are in the water, the bird observer continues with focal individual counts or with limited extended period counts.

If studies on kelp dynamics are ongoing e.g. reproductive status, data can also be collected while divers are in the water.

After Completion of community sampling (at the end of the first dive)

After the dive, researchers can either continue with bird surveys or move immediately to the next transects and plots to continue the fish and benthic surveys (and kelp population studies if they are underway).

When the day's diving has been completed, the additional bird focal studies can be carried out by visiting by visiting the undisturbed plots. (Note if time and boats permit, bird sampling can be carried out independently of dive studies).

BIBLIOGRAPHIES

This section of the report contains references and abstracts of kelp papers

1. List of reference from combined life sciences search using Nereocystis as the search word.

2. List of references from combined life sciences search using Macrocystis as the search word.

3. List of references and abstracts from combined life sciences search using kelp as the search work. This is included as a disketted in word for windows 2.0 format.

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