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Ecological effects of seaweed harvesting in the Gulf of California and Pacific Ocean off Baja California and California

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Abstract

The ecological effects of harvesting were investigated for two species, the giant kelp *Macrocystis pyrifera* and *Eucheuma uncinatum*, by using harvest records and aerial surveys that show yield changes and by using studies of recruitment, survivorship and community interactions. There were no ecological effects found for *M. pyrifera* harvested with contemporary methods, and there are no recommendations for changing current management practices for this species. It is recommended that *E. uncinatum*, which on occasion produces commercially significant standing crops, not be harvested unless special precautions are taken to leave some plants for regeneration of the harvested populations.

Introduction

In the Gulf of California and Pacific Ocean off Baja California, Mexico, and California, USA, the commercial harvesting of seaweeds from natural populations has been practiced for one species of Phaeophyta *Macrocystis pyrifera* (L.) C. Agardh, and three species of Rhodophyta, *Eucheuma uncinatum* (Setchell et Gardner) Dawson, *Gelidium robustum* Hollenberg et Abbott, and *Gigartina canaliculata* Harvey. From a review of journal articles, unpublished reports and results of our studies, we feel there is enough information to discuss the ecological effects of harvesting *M. pyrifera* and *E. uncinatum*, but not enough to consider *G. robustum* and *G. canaliculata*.

In assessing the ecological effects of seaweed harvesting in natural populations, we make the basic assumption that the management goal is the maintenance of maximal harvests and stable populations of all species in the communities where the harvesting takes place. Two approaches will be used to assess the ecological effects of harvesting. For *Macrocystis pyrifera*, where there are records of harvest yields and area harvested, changes in yields or the area harvested will be used as a rough measure of population stability. Where ecological studies of recruitment, survivorship and community interactions have produced results relevant to the effects of harvesting, they will be used to discuss how harvesting could affect population dynamics of the species.

Macrocystis pyrifera

Macrocystis pyrifera is harvested in Pacific Ocean waters off Baja California and California with similar methods in both regions. These methods

(Scofield, 1959; Guzmán del Proo, 1986; North, 1987) are highly mechanized and utilize large vessels capable of hauling 300 to 550 metric tons wet wt in a single load. Harvesting removes, at a depth of about 1.2 m, the parts of fronds in the surface canopy. This method does not cut the sporophylls that provide spores for the next generation, or the meristems that produce fronds. Fronds have a lifespan of about 6 months (Gerard, 1976; North, 1987). Estimates of biomass removed by harvesting range from 33% to 50% of the total biomass of a plant (Coon, 1981; North, 1987).

Population Stability

In a review of the available information on harvesting *Macrocystis pyrifera*, North (1968) concluded that '... kelp harvesting as currently practiced caused very little damage to the kelp beds and under some circumstances may be beneficial. It was noted that damage was done by propellers of small vessels near the Paradise Cove Pier, Carlifornia and by harvesting practices that are no longer used (Brandt, 1923). Brandt presented data indicating that yields in kelp beds harvested continuously for five or more months decreased each year whereas yields increased in beds where two or three months elapsed between harvests.

The findings of North (1968) have largely been substantiated by more recent work. Canopy areas and yields in Santa Barbara County, California kelp beds remained relatively constant during the five-year period when there were records of both (Coon, 1981). The stability of the maximally harvested kelp bed off Point Loma has not been noticeably affected by harvesting (Dayton *et al.*, 1984). Aerial photographs of the Carmel Bay, California kelp bed for the years 1971 through 1977 (Barilotti *et al.*, 1985) and 1973 through 1979 (Kimura, 1980) did not indicate any long-term stability changes in the harvested areas of the bed. Aerial surveys of kelp beds in California have regularly been conducted since the early 1970's to help plan harvesting. These surveys have not revealed any instances where stability changes in the kelp could be associated with harvesting (R. McPeak & D. Glantz, pers. com.).

In contrast to the studies that showed no long-term effects of contemporary kelp harvesting, experimental studies in central California that simulated the effects of maximal harvesting indicated that yields can be affected by overharvesting (Miller & Geibel, 1973). In this study, plants were cut at or below the 1.2 m permitted by California law and the frequency of cutting was 5 times in a 405-day period. Commercial harvesting in central California has never exceeded two cuttings per year since 1970 when harvesting there first began (Kelco, unpublished kelp harvesting records).

The studies showing no effects of contemporary kelp harvesting on population stability do not rule out the possibility that harvesting affects some aspects of population dynamics. It is possible that harvesting reduces survivorship, as noted in the Miller & Geibel (1973) studies, but is counter-balanced by increased recruitment of juvenile plants. This possibility requires that the effects of harvesting on recruitment and survivorship be studied separately.

Recruitment Effects

Possible harvesting effects on the production of juvenile plants by spores that complete gemetogenesis, fertilization and growth through microscopic stages (i.e. juvenile recruitment) have not been studied. Recruitment has the potential to be affected by harvesting in two ways. If the plants are so shocked by harvesting that spore production is reduced, stability of beds where recruitment is limiting could be affected. Reed (1987) found that removal of 75% of the fronds on plants (to simulate storm damage) reduced sporophyll production. While sporophyll production in harvested beds has not been studied, observations since 1968 throughout the maximally harvested kelp bed off Point Loma indicate that juvenile recruitment has not been reduced in harvested areas of the bed (R. McPeak, pers. com.).

A possible second effect of harvesting is that it could increase recruitment by increasing light that reaches the bottom. Since gametogenesis and growth of the juvenile plants is generally thought to be light-limited except during 'recruitment windows' (Dean & Jacobsen, 1986; Deysher & Dean, 1986), recruitment would be expected to increase after harvesting. Evidence for this is provided by studies in the Carmel Bay kelp bed where recruitment of juvenile *Macrocystis pyrifera* and *Pterygophora californica* was increased in harvested areas relative to unharvested adjacent control areas (Kimura & Foster, 1984).

Carmel Bay Survivorship Studies

The studies of Miller & Geibel (1973) raised concerns that harvesting could adversely affect *Macrocystis pyrifera* in central California. As a result, a series of studies were initiated to determine the effects of harvesting on survivorship in this locale. McCleneghan & Houk (1985) reported, on the basis of one year of measurements, that hapteral branching was significantly lower in plants that were experimentally harvested relative to unharvested control plants. In contrast, during a three-year study of hapteral elongation and branching, no significant effect of commercial harvesting on hapteral elongation and branching was found (Barilotti *et al.*, 1985). Hapteral branching was found to be extremely variable, significantly lower in harvested areas relative to controls in one year, significantly higher in the harvested areas another year, and not significantly different the third year (Barilotti *et al.*, 1985). In part due to the inconclusiveness of the results of the above studies and problems relating them to actual survivorship in commercially harvested populations, it was decided to conduct controlled field studies where survivorship in harvested areas could be compared to natural survivorship in adjacent unharvested control areas.

These survivorship studies were initiated during 1978 in the Carmel Bay kelp bed near the areas studied by Barilotti *et al.* (1985). The survivorship of tagged plants, which were within 5 m of a 30 m long leaded nylon line that was secured to the bottom, was followed in harvested and adjacent unharvested control areas. Plants with 15 or more fronds were selected for study and were marked both with tags in the holdfast and on posts driven into the bottom adjacent to each plant. The position of each plant was noted on a map used by scuba divers when noting the presence or absence of the plants during the spring, summer and fall census periods. During 1978 and 1979, survivorship of 69 and 70 plants, respectively, was followed in control and harvested areas. During 1980 through 1982, additional harvested and control areas were added to the study to bring the total number of study sites to five harvested and five controls. Twenty-five plants were marked in each of the ten study areas during the summer census just prior to harvesting. Diving and boat surveys revealed that over 95% of the plants in the harvested areas had their surface canopies removed during harvesting. Survivorship studies were terminated in 1983 because extreme waves during the winter of 1982/83 destroyed all the plants being studied.

No short-term effects of harvesting, such as those reported for the Del Mar, California kelp bed where some dislodgement of plants was attributed to harvesting (Rosenthal *et al.*, 1974), were detected in the two to three-month period after harvesting if plant loss in control (Fig. 1) and harvested (Fig. 2) areas are compared. Also, there

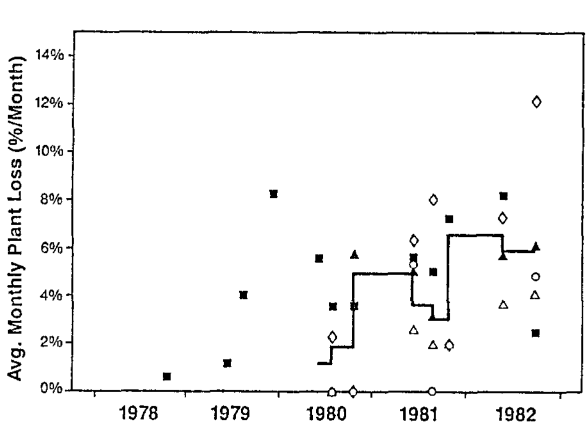

Fig. 1. Average monthly percent plant loss for the control study sites in Carmel Bay. The symbols represent the average monthly plant loss, expressed as a percentage loss per month, for each of the five control sites studied. The solid line is the average percent plant loss from May 1980 to September 1982 when the five control sites were studied.

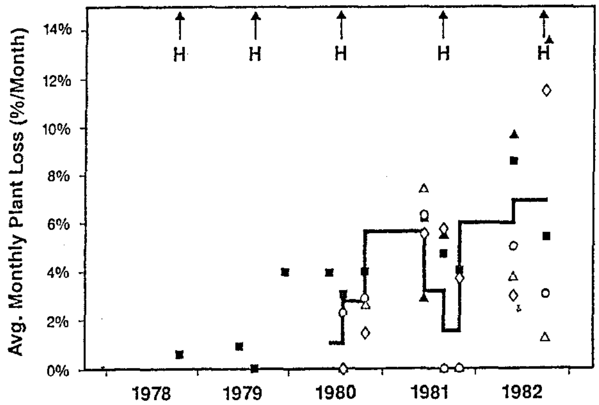

Fig. 2. Average monthly percent plant loss for the Carmel Bay sites that were harvested. The results are presented in the same format as those for the control areas in Fig. 1. The H's with arrows indicate when the 5 sites were harvested.

were no long-term effects of harvesting on survivorship during the period lasting ten months after harvesting and spanning the winter months when plant loss is maximal in other central California kelp beds (Gerard, 1976).

To determine if there was a difference between harvested and control plants that was not noticeable by a visual inspection of the results, a Model I, two-way ANOVA was performed on the percentage plant loss per month data. We assumed losses were independent from month to month in the same area. The data were arcsin transformed to produce homogeneity of variances (Bartlett's test; Sokal & Rohlf, 1969). There was no significant statistical difference in survivorship between harvested and control areas and the interaction term, but there was a highly significant seasonal difference ($p < 0.001$).

The average annual plant loss for all study sites in the two-year period from May 1980 to May 1982 was 46.3% the first year and 48.8% the second year. These losses are less than the maximum loss of 82% reported by Gerard (1976) for the Cabrillo Point kelp bed in Monterey Bay, California, measured over the winter of 1974. They are similar to the 47% plant loss reported for middle part of the Point Loma, California, kelp bed that received the least amount of damage during the extreme wave events in the winter of 1982–83 (Dayton & Tegner, 1984).

Community Interactions

There are no reports of any long-term effects of harvesting on community interactions that would affect the stability of *Macrocystis pyrifera* or associated plants and animals. It has been reported that harvesting removes all the attached invertebrates on the harvested fronds (Clendenning, 1968) and less than 1/4 of the small fish and motile invertebrates that inhabit the kelp canopy (Quast, 1968), but there is no evidence that this removal affects the stability of their populations or community interactions. Miller & Geibel (1973) reported that a dense growth of red algae inhibited recruitment of *Macrocystis* in the area where kelp was lost due to overharvesting, but neither the persistence nor long-term ecological effects of the dense red algae were followed. Studies in the Carmel Bay kelp bed in commercially harvested areas revealed no increase in the abundance of red algae as a result of harvesting (Kimura & Foster, 1984).

Eucheuma uncinatum

Eucheuma uncinatum is endemic to the Gulf of California (Norris, 1975; Zertuche-González, 1988) and has been commercially harvested on occasion (Guzmán del Proo, 1986). Standing crops fluctuate widely, and it has been reported that the species dies off in the summer due to high water temperatures (Norris, 1975; Dawes *et al.*, 1977; Polne *et al.*, 1980).

Recent studies (Zertuche-González, 1988) of two *Eucheuma uncinatum* stands in Bahía de Los Angeles (a bay approximately half-way down the east coast of the Baja California Peninsula) have shown that *E. uncinatum* undergoes a major reduction in standing crops in the fall rather than the summer, and that some living and growing tissue could be found at all times of the year. Experimental studies showed that high temperatures were not directly related to the massive fall reduction in standing crops. During these studies *E. uncinatum* was never found to be a competitive dominant or to provide a food resource or unique habitat for fish or invertebrates. Thus, since we have no results indicating harvesting this species significantly affects community interactions, we will not discuss possible community effects of harvesting.

Population Effects

Eucheuma uncinatum attached to rocks in Bahía de Los Angeles exhibit characteristics of annual plants: i.e. after they become reproductive in the fall they die and no plants can be found attached to the rocks for several months until sporelings appear in the winter. Sporelings are first found in the late fall or winter, as are the sporelings of *Gigartina pectinata* Dawson. The rapid growth of *G. pectinata* in winter and spring months when water temperatures are coldest results in the *E. uncinatum* being totally covered by layers of *G. pectinata*. When warm water sets in during the summer, *G. pectinata* dies off and *E. uncinatum* dramatically increases in relative abundance (Fig. 3). It is likely that the growth of *E. uncinatum* is competitively inhibited by *G. pectinata*, a factor that needs to be considered if *E. uncinatum* is harvested.

In habitats with a gently sloping bottom, broken fragments of *Eucheuma uncinatum* continually add to the standing crops during the summer months. Some fragments persist throughout the winter months when the abundance of attached plants is reduced after reproduction. The unattached fragments are a major part of the standing crops in gently sloping habitats and at times are the only evidence of *E. uncinatum*. It has not been established that unattached plant fragments contribute spores for recruitment.

In habitats where the slope of the bottom is steep and deep water is close to shore, as is the case for many of the island populations of *Eucheuma uncinatum*, standing crops appear to be produced mostly from sporelings and vegetative reproduction is minimal. Any thallus fragments that are broken off in these habitats are generally carried into deep water and are lost. Therefore, in these populations harvesting should leave mature plants for propagation because it would be very difficult to schedule harvests in a way that would

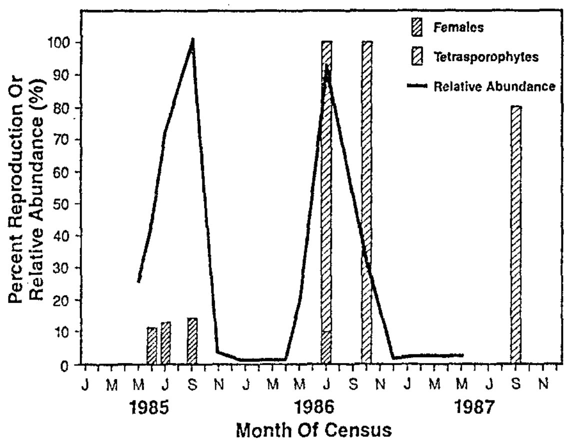

Fig. 3. Reproductive status and relative abundance in a population of *Eucheuma uncinatum* in the northwest corner of Bahía de Los Angeles about 5 km from Punta La Gringa. Reproductive status is based on percentage of reproductive plants among 30 or more randomly selected plants along a transect line extending through the 5 m bathymetric range of the population. Relative abundance was calculated as the total of the percent cover estimates in 32 permanent 1 m^2 quadrats, divided by the maximum total percentage measured in September 1985 and expressed as a percentage of the September 1985 total. Sampling for relative abundance and reproductive status was done during each bi-monthly field trip.

allow the plants to reproduce before they die out (Fig. 3). The amount of attached material that should be left for reproductive purposes would need to be determined empirically.

Conclusions

The possible effects of harvesting these two species range from slight for *Macrocystis pyrifera* to major for *Eucheuma uncinatum*. These effects are related to the methods of harvesting and life history of the species. For *M. pyrifera*, where only the surface canopy is removed (i.e. Type 3 harvests; Foster & Barilotti, this vol.), no changes in harvesting practices are recommended for Baja California or California because there is no evidence that the stability of kelp bed populations has been effected by contemporary harvesting methods. In contrast, harvests of *E. uncinatum* would have significant effects on the stability of the populations and should not be attempted unless the effects of removing a source of spores for the next generation is provided for. In the harvests of Type 1 species (Foster & Barilotti, this vol.)

such as *E. uncinatum*, providing a spore source for propagation of future generations should be a regular feature of resource management.

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