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The harvesting of macroalgae in New Zealand

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Abstract

Several species of algae have been commercially harvested in New Zealand, mainly for extraction of agar and alginates. In the past, the harvest was comprised mostly of shore-cast plants. There has been more recent interest, however, in harvesting attached plants of *Pterocladia* spp., *Porphyra* spp., *Gracilaria sordida*, *Durvillaea* spp., *Macrocystis pyrifera*, and *Ecklonia radiata*. The ecological effects of harvesting attached algae depend largely on the sizes of plants, the season of removal, the patch size of clearances, and the proximity and identity of mature plants. These have not been well-studied for seaweeds in New Zealand, but population and life history studies indicate that harvesting methods affect the continuity of algal resources, at least on a local scale, and are crucial factors in their management.

Introduction

Seaweeds have been harvested commercially in New Zealand since the 1940s, but there is a much longer history of traditional use by the indigenous Maori people (Colenso, 1880; Moore, 1944). At no time, however, have large quantities of any species been harvested. The gathering of macroalgae has had few restrictions until recently, and consequently there are few data with which to gauge the quantities taken of each species. Because of increasing interest in seaweed harvesting over the past few years, the focus for management has shifted to consideration of the sustainability of the resource and the potential population and ecological effects that harvesting may have.

Most of the seaweeds of commercial importance have been rhodophytes of the genus *Pterocladia*, which form the basis of the agar industry. *Porphyra* and phaeophytes of the genera *Durvillaea*, *Macrocystis* and *Ecklonia* have been harvested on a lesser scale. Recent interest in these seaweeds has been generated for a variety of reasons including the extraction of alginates, an expanding local market for health food, and to meet the feeding requirements of an incipient industry of paua (abalone) farming. Commercial activities in the past were largely sustained by gathering beach-cast algae. As large harvests of attached plants are sought (> 2000 t wet weight annually of *Durvillaea* for example) there is an increasing importance in weighing the ecological consequences of plant removal.

There is only a relatively small literature on the removal of macroalgae from natural stands, and most of this assesses only population effects (Schiel & Foster, 1986 for review). The impact of species removals on the broader community has been harder to assess (c.f., Van Blaricom & Estes, 1987). The situation in New Zealand, and

Australasia generally, is no exception to this trend; there are few studies that experimentally assess the consequences of the removal of macroalgae.

This paper discusses the current state of knowledge on the effects of perturbation on populations of macroalgae, with an emphasis on the ecological impact of harvesting.

Materials and methods

Of the six genera discussed here, four are reviewed as work done by others, while the other two represent mostly original work. All of the genera are widely distributed along the coastline of New Zealand and the offshore islands (Fig. 1). Most of the species occur in the intertidal or shallow subtidal zones but the laminarians extend to deeper water (Fig. 2).

Population studies of *Porphyra* have recently been completed (Nelson *et al.*, 1989; Nelson & Conroy, 1989). Growth rate, biomass, and the effects of different timing and methods of harvesting were assessed in fixed quadrats at sites in Kaikoura and Wellington. The effects of removing canopies of the stipitate laminarian *Ecklonia radiata* (C.Ag.) J.Ag. were assessed at Leigh (by D.R.S.). Canopies were cleared in 5 replicate 1 m^2 areas by cutting plants above the holdfast.

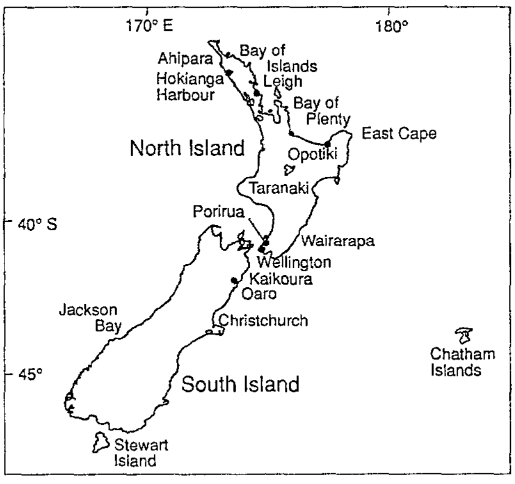

Fig. 1. Site localities in New Zealand.

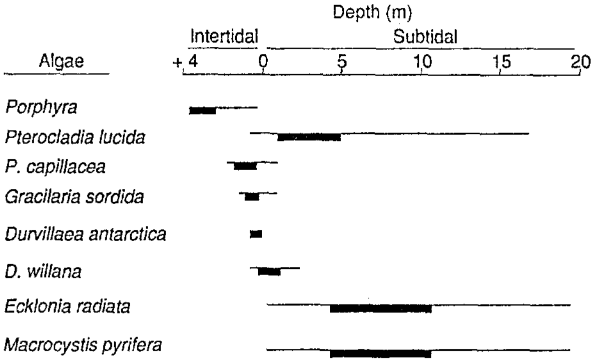

Fig. 2. Schematic representation of the distribution with respect to tidal height (M.L.W.) of the species discussed in text. Thin lines show distributional boundaries and thicker lines indicate positions of greatest abundance.

Removals were done during October, when *Ecklonia* was fertile, and again during January, when reproduction was largely finished (Schiel, 1988). The two treatments were canopy removal and canopies left intact as controls. Subsequent recruitment (i.e. visible recruitment at a size of ~3 mm) was recorded for *Ecklonia* and fucalean species.

Results

Pterocladia

Perennial *Pterocladia* species have been harvested commercially in New Zealand since the early 1940s when the cessation of agar supplies from Japan led to research on local agarophytes (Moore, 1944, 1946). The annual harvest has fluctuated from 50 t (dry weight) in 1944 to a current level of 250 t. From this harvest, 15–40 t of high-quality bacteriological grade agar is produced (Luxton, 1977; Luxton & Courtney, 1987).

Two species of *Pterocladia* co-occur on sheltered to very exposed shores, mostly in the North Island, reaching their distributional limits in the northern South Island. *Pterocladia lucida* (Turner) J. Ag. is widely distributed in New Zealand, the Chatham Islands, mainland Australia, Tasmania, Lord Howe Island and Norfolk Island (Moore, 1944). Its fronds reach

>50 cm in length. This species is particularly abundant to 4 m depth but is found as isolated plants to 20 m depth (McCormick, in press). In deeper water it commonly occurs beneath a canopy of fucalean algae. *Pterocladia capillacea* (Gmelin) Bornet et Thuret is also widely distributed in Australasia (Moore, 1944). Its fronds reach 18 cm and are much more delicate than those of *P. lucida*. As *P. lucida* comprises >95% of the *Pterocladia* harvest, it alone will be discussed here.

The harvest of *Pterocladia lucida* is done mostly by part-time collectors in rural coastal communities of the Wairarapa, the Bay of Plenty, the Bay of Islands and Ahipara. The amount and method of regional harvests are dependent on many factors, particularly the extent of the seaweed beds and the exposure of the coastline. About 77% of the harvest is beach-cast plants but this varies among regions. In the sheltered and warm waters of the Bay of Islands, 96% of the harvest is from attached plants, while in the exposed and colder waters of the Wairarapa 95% of the harvest is from shore-cast plants.

Pterocladia is harvested year-round, although the major period is during the warmer months of November – April. The yield of agar is highest during these spring and summer months. This seasonality of harvesting may not affect the natural re-seeding of beds as Luxton (1977) found that spores are released throughout the year. However, it has never been demonstrated that successful settlement and recruitment also occur year-round.

The ecological effects of harvesting large amounts of beach-cast plants are not known. Studies in Australia showed that drift plant material can be an important component of inshore productivity (Robertson & Lenanton, 1984). The effects of removing unattached *Pterocladia* are probably insignificant, however, as many other species occur in the drift and are not harvested.

Attached plants are harvested by pulling on them, and consequently entire plants may be removed or basal portions left attached. Where it is feasible logistically, the preferred picking strategy is to remove the fronds and leave the basal portions of the plants intact. Regrowth occurs at a rate of 10 cm year^{-1} (Moore, 1944; Luxton, 1977) although this depends on locality and may well be affected by the season of harvest and the age of plants as has been found for other species of red algae (Barilotti & Silverthorne, 1972). The harvest by hand-picking of attached *Pterocladia* is currently controlled by permit and is restricted to snorkel diving.

The continued harvesting of *Pterocladia* at low intensity over 40 years in some areas appears to confirm the renewal of beds and the sustainability of harvest at relatively low levels. However, the effects of denuding large areas within beds have never been demonstrated. This has not been a problem to date as most collectors remove plants haphazardly, particularly when snorkeling in surgy conditions. If *Pterocladia* were removed from large areas, invasion by other species could occur, particularly by fucalean species that are usually abundant nearby (c.f. Schiel, 1988).

Applications to permit the use of SCUBA gear are being opposed by managers until more is known about the effects of removing plants intensively. It is considered that the use of SCUBA will alter harvesting strategies from haphazard collection to more intensive and systematic efforts, with potential population and community consequences.

Porphyra

This annual genus is widely distributed on rocky, moderately to very exposed coasts around the North Island, South Island, Chatham Islands, and Stewart Island, and includes a number of undescribed species. Plants are harvested by hand and are the most accessible of the commercial seaweeds, growing in mid- to upper intertidal regions. Known as 'Karengo' in Maori, *Porphyra* is a traditional food that is eaten fresh or dried. During the last century it was traded by coastal communities for goods from the forested interior (Colenso, 1880). Over the past 10 years there has been increasing commercial interest in harvesting karengo as well as a high level of concern in the Maori community about the vulnerability of this seasonal resource to harvesting pressures. The commercial *Porphyra* harvest in New Zealand is 1–2 t (dry weight) annually, taken from the Kaikoura region (Fig. 1).

Plants harvested at Kaikoura belong mostly to two undescribed species (Nelson & Conroy, 1989). They first appear in April and reach their greatest densities in June/July and their maximum size in August/September (Nelson *et al.*, 1989).

The method and timing of harvest have a strong influence on the yields obtained. At all the study sites harvesting by cutting (using scissors and leaving holdfasts intact) gave very good regeneration with plots recovering their pre-harvest biomass within 60 days (Fig. 3). Clearing quadrats by removing whole plants, however, resulted in very poor regrowth. For example, mean yields of 0.8 g 100 cm^{-2} after 60 days (September) from quadrats that had been cleared compared with 6.8 g 100 cm^{-2} from quadrats that had been cut.

At Kaikoura, the yields from harvests in September were significantly greater than from harvests in July. There was no significant difference between the aggregate yield from two harvests and that from a single late harvest. At the Wellington site where *Porphyra columbina* Mont. was the sole species, the yields were greater from two harvests (July/September) than either a single early or a single late harvest (Fig. 3; Nelson & Conroy, 1989).

Because of its position on the shore, few other algae co-occur with *Porphyra*, and it is unlikely that there are measurable community effects of removing these species. There is substantial natural annual variation in the size of *Porphyra* populations. In areas where modest harvesting has occurred there seemed to be similar colonization in subsequent years.

Gracilaria

Gracilaria sordida W. A. Nelson is found growing on rocks, pebbles and shells in the mid-to low-intertidal and upper subtidal regions in harbors, estuaries and sheltered coastal sites throughout New Zealand. Dense aggregations of this alga

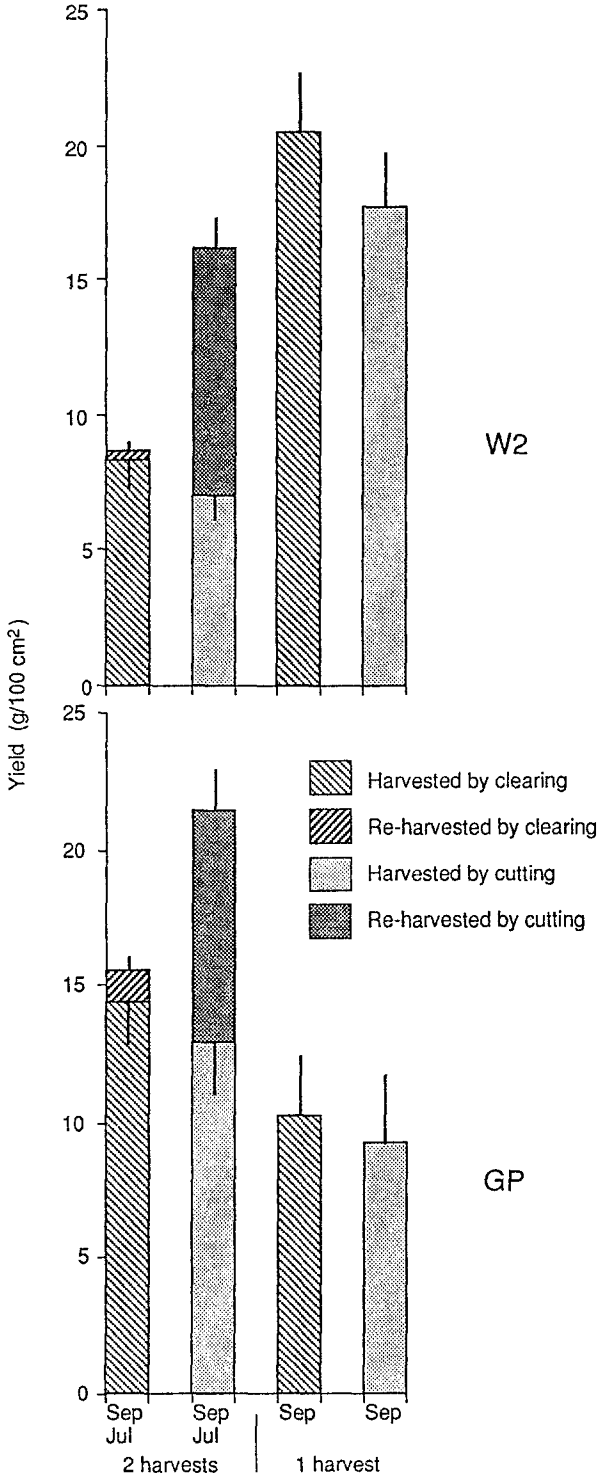

Fig. 3. Mean yields (g 100 cm^{-2}) ± standard error of *Porphyra* from quadrats (n = 10) harvested at two sites using two methods, harvested either twice (July, September) or once (September) (W2 = Waipapa, Kaikoura; GP = Greta Point, Wellington).

may occur in areas affected by human activity, particularly sewage (Henriques, 1977). The plant is perennial, but there is a peak in biomass and abundance of fertile plants during the summer (Nelson, 1989).

This species has been examined as a source of agar and as a food for cultured paua (Pickering, 1989; Miller & Furneaux, 1987 – as *Gracilaria secundata* Harvey f. *pseudoflagellifera* May), but so far only experimental harvesting has been done.

Resource managers at present are limiting the harvest of *Gracilaria* by restricting the numbers of permits issued as well as the quantity and harvesting method. There is concern that the process of harvesting *Gracilaria*, particularly mechanically, will disturb the sediments and have a deleterious impact on the associated infauna and shellfish beds.

Experimental enhancement trials employing methods similar to those used by Pizarro and Barrales (1986) have been tried by Pickering (1989). At present, field enhancement of *Gracilaria* beds requires a special permit under the Marine Farming Act, and this has not yet been pursued. The demand for *Gracilaria* is growing and is not currently satisfied by the developing on-shore cultivation or by harvesting of shore-cast plants.

Durvillaea

Durvillaea antarctica (Cham.) Hariot is a prominent species on exposed shores of the west coast of the North Island, the entire South Island, all of the offshore islands of southern New Zealand, and in other areas of the southern hemisphere (Hay, 1979a, 1979b, 1988). In very exposed areas of the South Island it reaches standing crops of 24 kg m^{-2} (wet wt). It occurs in the lower intertidal zone and is only rarely found in subtidal areas. Individual plants can be massive, with the buoyant fronds reaching 10 m in length. Another species, *D. willana* Lindauer, is found in southern New Zealand, commonly occurring below *D. antarctica* at depths of 1–3 m. Its fronds are shorter and are not buoyant although its stipes can be up to 2 m in length.

Beach-cast *Durvillaea* has been harvested occasionally since the 1960s. Uses have been for sodium alginate, as fodder for cattle, and as fertilizer (Francki, 1960a, 1960b). There has been recent interest in harvesting *Durvillaea*, particularly *D. antarctica*, by removing attached plants as well as using drift and beach-cast algae.

Of the seaweeds of potential commercial importance, *Durvillaea* has been relatively well-studied. Gametes are released during the colder months of May-November, with a peak during August (Hay & South, 1979). After adult plants had been experimentally removed from the shore during April, May and June, a dense settlement of 1300–7000 plants m^{-2} followed. Only a sparse recruitment of $< 10\ m^{-2}$ occurred after adult plants had been cleared during the months from September through February (Hay & South, 1979). At these latter times, gametes were not available in large quantities, and other species of algae colonized the open space. Hay & South (1981) also found that the method of removal affected recolonization and growth. Because holdfasts of *D. antarctica* are large and those of several plants may merge when plants are at high densities, their removal may significantly increase the area available for recolonization. Where plants were cut above the holdfast, the reharvest after 15 months was 32% of the first harvest, whereas in areas where holdfasts were removed at the first harvest, the reharvest was 1.5 × the original weight removed. It should be noted, however, that *Durvillaea* holdfasts are extremely difficult to remove from rocks, and it is unlikely that total removal would be used as a commercial harvesting technique.

Durvillaea interacts with other organisms in potentially important ways, which has a bearing on harvesting regimes. *Durvillaea* fronds have a whiplash effect on the surrounding substratum, keeping it mostly bare. The removal of adult plants allows other species to colonize. If harvesting is done during the warmer months when *Durvillaea* gametes are not produced, the invasion of other species can effectively prevent recolonization by *Durvillaea* (Hay, in press). Because the floating fronds of *Durvillaea* often form a dense cover over the sea surface, they dominate inshore habitats. Shading by fronds may affect the species of algae, fish and invertebrates present, although this has not been demonstrated. Fish, however, can affect *Durvillaea*. The herbivorous *Odax pullus* grazes fronds and changes their morphology (South & Hay, 1979).

Durvillaea fronds may also have a dampening effect on water turbulence inshore. This, in fact, formed the basis of the major objection to large-scale harvesting in the 1970s. The New Zealand Railways Corporation was concerned that the removal of *D. antarctica* would increase the effects of wave action, thereby causing erosion and damage to their coastal rail lines.

Although the standing crop of *Durvillaea* in New Zealand is large, it is clear that strict management is required. It is especially important that harvesting of attached plants is not done year-round but is restricted to the colder months when gametes are produced and re-settlement is likely.

Macrocystis

Macrocystis pyrifera (L.) C. Ag. occurs from the Wairarapa region southwards along the east coast of the South Island, at the Chatham Islands, Stewart Island and all the subantarctic islands excluding the Snares. It has been considered for commercial harvesting since the 1940s when it was examined as a source of potash (Rapson *et al.*, 1942). Compared to *Macrocystis* forests in other temperate areas, however, those in New Zealand are usually not large and the extensive floating canopies seen elsewhere are generally absent. Consequently, large-scale harvesting such as that done in California is considered to be uneconomical. The current harvest in New Zealand is 15 t (dry wt), used for the manufacture of kelp powder and kelp salt for the health food market. There is increasing interest in harvesting this species for algin and alginic acid and as a base for fertilizer as well as for paua feed.

The numerous studies done elsewhere on the biology and ecology of *Macrocystis pyrifera* have not been matched in New Zealand, mostly due to its abundance in remote southern areas. Because the beds in New Zealand are generally shallower and less dense than those in California (Rapson *et al.*, 1942; Lummarck, 1981; Foster & Schiel, 1985), it is unlikely that the ecological effects of *Macrocystis* populations are similar. For example, one of the most important effects of the dense canopies is reduced light levels to sub-canopy areas (Lüning, 1981; Reed & Foster, 1984). These effects would be much less pronounced in New Zealand *Macrocystis* beds. Community effects such as changes in the distribution and behavior of echinoids in response to the availability of drift *Macrocystis* (Ebeling *et al.*, 1985; Harold & Reed, 1985) are also not seen in New Zealand due to the relatively small sizes of beds and comparatively small number of drift plants.

There may be detrimental effects due to grazing by fishes, similar to those found by Harris *et al.* (1984) at Naples Reef in California. In New Zealand, the herbivorous *Odax pullus* grazes small sporophytes and can cause extensive damage to sporophylls and laminae (Schiel, pers. obs.). Interactions with other species have not been investigated.

A permit is required to harvest *Macrocystis* as beach-cast or attached plants. Cutting of attached fronds 1 m below the sea surface is recommended, similar to the method in California.

Ecklonia

Ecklonia radiata is the ubiquitous kelp of New Zealand, occurring on virtually all rocky shores from the northern tip of the North Island to the Snares Islands (south of Stewart Island). It can occur from the low intertidal zone to >25 m (Choat & Schiel, 1982; Schiel, 1990). Commercial interest has been expressed in both beach-cast and attached plants for alginate extraction although there has been only minimal harvesting to date.

Ecklonia radiata reaches peak densities of up to 75 m^{-2} (mature plants) and a biomass of 1 kg

m^{-2} (dry wt) at depths of 4–15 m, often forming exclusive patches in areas also occupied by several fucalean species (Choat & Schiel, 1982). An echinoid-dominated zone usually occurs at an intermediate depth of 8 m in northeastern New Zealand, but this is rare south of East Cape. *Ecklonia* is clearly important to inshore communities. Jones (1984a, 1984b) showed that reef fishes such as wrasses and monocanthids recruit, some exclusively, among the fronds of *Ecklonia* and feed extensively on small invertebrates there. Choat & Ayling (1987) showed that the presence of *Ecklonia* beds affects the character of the fish fauna throughout northern New Zealand. Andrew & Choat (1985) demonstrated that sea urchins do not recruit or survive well as juveniles in *Ecklonia* beds even though their grazing effects as adults can be extensive.

Ecklonia radiata populations are reproductively fertile from May to November (Novaczek, 1984; Schiel, 1988). The experimental removal of canopies within and outside the reproductive season clearly showed there was a suppressive effect on the recruitment of *Ecklonia* and fucalean species (Table 1). Of importance for harvesting considerations is that *Ecklonia* has virtually no recruitment during the warmer months (December to April) while some fucalean species are still able to colonize space. The longer term result of these clearances was that those done during the reproductive season (October) were successfully recolonized by *Ecklonia*, which quickly formed a dominant canopy due to its much faster growth than fucoid species. The January clearances eventually produced mixed stands of sparse *Ecklonia* and fucoids.

Table 1. Summary of experiment in which canopies of *Ecklonia radiata* were removed from 1 m^2 plots (n = 5) during the season of reproduction (October) and non-reproduction (January). Fucoids were *Sargassum sinclairii* Hookey f. & Harvey, *Landsburgia quercifolia* (Hooker f. et. Harvey) Harvey, and *Carpophyllum angustifolium* J. Ag. Numbers shown are mean number of recruits per plot over a 4-month period. All treatment effects (clearance times, canopies, species) were significant (cf. Schiel, 1988).

	October clearance		January clearance	
	Canopy removal	Canopy intact	Canopy removal	Canopy intact
Ecklonia	80	19	3	0
Fucoids	55	6	63	4

Because of logistic difficulties in collecting attached stipitate laminarians, it seems unlikely that large-scale harvesting will be done. However, if SCUBA gear or dredges are used for harvesting, only relatively small patches of *Ecklonia* should be removed. The average dispersal distance of propagules is probably only a few meters, and removal of large patches will probably affect recolonization. Clearly, harvesting should only be done during the winter – spring months.

Conclusion

For its land mass, New Zealand has a particularly large coastline. There is increasing pressure to exploit marine resources but, unfortunately, there is often little information with which to judge a suitable harvesting strategy. The expanding corpus of studies on the life histories and ecology of seaweeds elsewhere, and select efforts in New Zealand, provide the most useful background to management. Fortunately, fishing permits are required for the commercial harvesting of algae, and this has allowed careful consideration of methods and quantities. So far, this has proved to be an adequate approach to seaweed harvesting in New Zealand.

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