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Mass Mortality of a Dominant Kelp (Laminariales) at Goat Island, North-eastern New Zealand

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Abstract. In north-eastern New Zealand, monospecific stands of the laminarian *Ecklonia radiata* occupy rocky reefs at depths below 10 m on exposed shores. In the austral summer of 1992–93, mass mortalities of populations of *E. radiata* in the Cape Rodney to Okakari Point Marine Reserve near Leigh were recorded, in which 40–100% of the sporophytes at depths greater than 10 m died. Mortality was gradual, beginning with erosion of the laminae and ultimately progressing to the stipes, which eventually decayed. The mortality was first evident in the deepest plants and culminated in the elimination of large areas of kelp forest. The event was not associated with any previously reported mortality agents. Investigations of the effects of the mortality on other organisms are continuing.

Kelps may have major effects on the physical environment of temperate reefs and their faunas. Factors controlling the distribution and abundance of kelp sporophytes include storms (e.g. Seymour *et al.* 1989; Dayton *et al.* 1992), competitive interactions (e.g. Reed 1990*a*, 1990*b*), nutrient limitation (e.g. Dean and Jacobsen 1986), and grazers (reviews of Schiel and Foster 1986; Jones and Andrew 1990). Recent studies (e.g. Dayton *et al.* 1992) have emphasized the complexity of interactions within algal stands and the many environmental and biological agents that may act to control the distributions of kelps.

The dominant alga on wave-exposed rocky reefs in north-eastern New Zealand is *Ecklonia radiata*, which forms monospecific stands below depths of about 10 m (Choat and Schiel 1982; Schiel 1988). *E. radiata* occupied most of the reef between depths of 10 and 18 m in the intensively studied Cape Rodney to Okakari Point Marine Reserve (36°16′S,174°47′E) in the late 1970s (Ayling *et al.* 1981). This pattern persisted throughout the 1980s and into 1992 (A. MacDiarmid, personal communication; C. Battershill, personal communication; R. Cole, personal observation). The present note documents the mass mortality of most monospecific stands of *E. radiata* in the marine reserve.

In late 1992, mortality of kelp was observed in deeper areas (>15 m) of the marine reserve (A. Duckworth, personal communication). Symptoms were an initial paling of the laminae leading to a blotchy and perforate state (Fig. 1*A*), which was then followed by a reduction of the secondary laminae (Fig. 1*B*). Laminae of healthy plants have a distinctive golden brown colouration—lacking in affected plants—whereas the tissue in the affected regions became necrotic and dark brown in appearance, lacked turgor, and fell off the plants if they were disturbed. Erosion of the primary lamina, and then the stipe and holdfast, followed (Figs 1*C* and 1*D*). Forests of stipes persisted on the reef for some time, but since the meristem of *E. radiata* is at the base of the primary lamina, these gradually decayed to leave bare space (Fig. 2).

Because mortality was initially greatest in deeper areas, the focus of the present study was on the distribution of *E. radiata* along depth gradients. The unexpected nature of the mortality meant that no comprehensive pre-event survey existed, but the presence of sporophyte remnants was used as an indication of the former extent of the kelp forests. In January 1993, populations of *E. radiata* were surveyed at eight sites in the marine reserve to ascertain the extent of mortality. Sites were randomly chosen and extended through most of the central marine reserve (Fig. 3). *Ecklonia* at each site was quantified by use of underwater video, and quadrats were used at five sites (1-m^2 quadrats, $n = 5$ per 3-m depth stratum). Continuous video recordings were made of a transect down a depth profile at each site by using a Panasonic MC10 VHS-C camera in a waterproof housing with artificial lighting. A depth gauge and scale bar (20 cm) were always present in the field of view, supported by an aluminium rod mounted on the camera housing. The rod also acted as a range-finder so that the camera lens could be maintained 1 m from the substratum. The camera operator swam along a tape measure used to delineate the transect line, providing a constant record of distance travelled along the bottom.

Video recordings were analysed on a standard VCR with variable-shuttle playback control. Density and condition of *E. radiata* within a single field of view (0·17 m^2) were recorded every 5 m along the tape.

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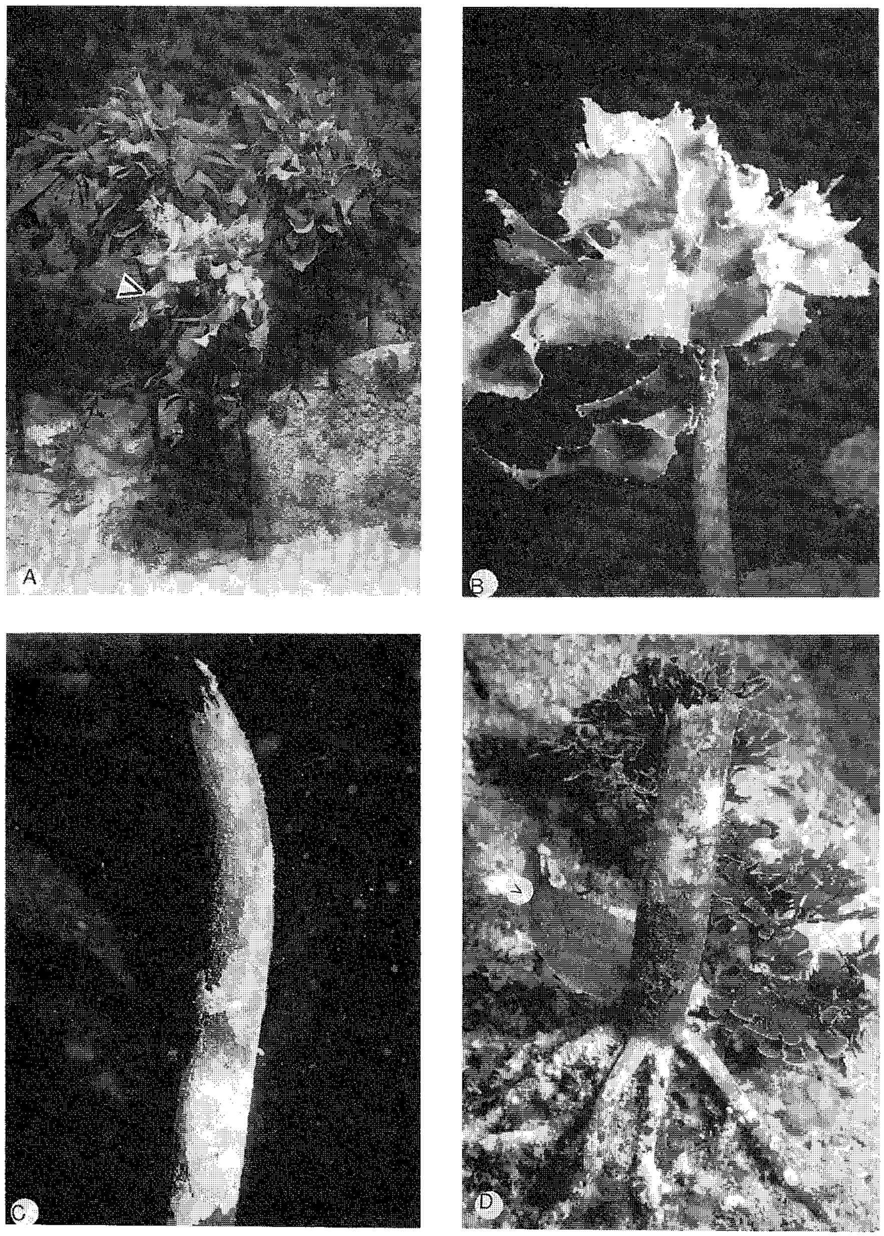

Fig. 1. *Ecklonia radiata. (A)* Healthy and moribund thalli in various stages of dieback. The most seriously affected plant is indicated by the arrowhead in the centre foreground, its pale appearance indicative of the earlier stages of the condition. Healthier plants with darker laminae are visible in the background. *(B)* Sporophyte exhibiting reduced primary and secondary laminae. *(C)* Sporophyte consisting of stipe and holdfast only. *(D)* Holdfast with remnant of stipe, the terminal stage of dieback. The small arrowhead at centre left indicates a recently recruited *E. radiata* plant growing from between the haptera.

The video survey showed that high proportions of *E. radiata* in the marine reserve were affected. This was supported by the quadrat survey, which also showed increasing percentages of affected plants with increasing depth at all sites (Fig. 4). At all sites except Marimo, the proportion of affected plants was greater than 50% beyond 10 m (Fig. 4). At Alphabet Bay, The Point and Lookout Point, the deepest stratum had no intact kelp plants. Subsequent observations at several sites found that the mortality progressed up the reef until there was no kelp forest remaining below the urchin-dominated coralline flats (lower limit ~10 m—Choat and Schiel 1982).

Fig. 2. A stand of *Ecklonia radiata* affected by dieback in about 6 m depth. The once-dense forest has been reduced to a collection of stipes. Plants in the background were at a shallower depth (~3 m) and a smaller proportion of the population was affected.

Ayling (1978) estimated that kelp forest occupied an area of 42 ha in the marine reserve and that the average density of sporophytes was about 8 m^{-2}. If 40% of the kelp forest habitat area was affected (a conservative estimate, we believe), this amounts to a loss of 1·3 million adult sporophytes from the reef.

There was *(1)* broad-scale mortality of many plants in the marine reserve and *(2)* greatest mortality deeper on the reef. Whereas mass mortalities of dominant herbivores of rocky reefs are relatively well documented (e.g. Scheibling and Stephenson 1984; Andrew 1991), we know of few accounts of mass mortalities of kelps that have not been associated with storms. Scotten (1971) suggested that nutrient limitation was responsible for 'black rot' of *Macrocystis*, and Zimmerman and Robertson (1985) have also implicated nutrients in *Macrocystis* mortalities. Tegner and Dayton (1987) suggested that an outbreak of grazing by an amphipod reduced kelp canopy. All of these studies linked the mortalities to abnormal oceanographic conditions. Nutrient limitation is unlikely to be important in the present case, as nutrients were in excess year-round at Goat Island in the 1960s (Taylor 1981) and almost certainly continue to be so. We have no information regarding the impact of local epifauna, but most are filter-feeders (Taylor and Cole 1994); we believe that they are unlikely causative agents. Dense phytoplankton blooms and aberrantly cold conditions occurred during 1992 (Rhodes *et al.* 1993). Temperature might have affected plants directly, and phytoplankton could have limited light. Our working hypothesis and the basis of ongoing experimental investigations is that the physiological stress imposed by low light may have been sufficient to place the plants into photosynthetic debt, from which they were unable to recover. This condition may have increased the susceptibility of the plants to viral pathogens (Easton 1995).

Because the focus of the investigation was the mortality of the plants, all remnants of plants, including recent holdfasts, were recorded. Recording all plants showing

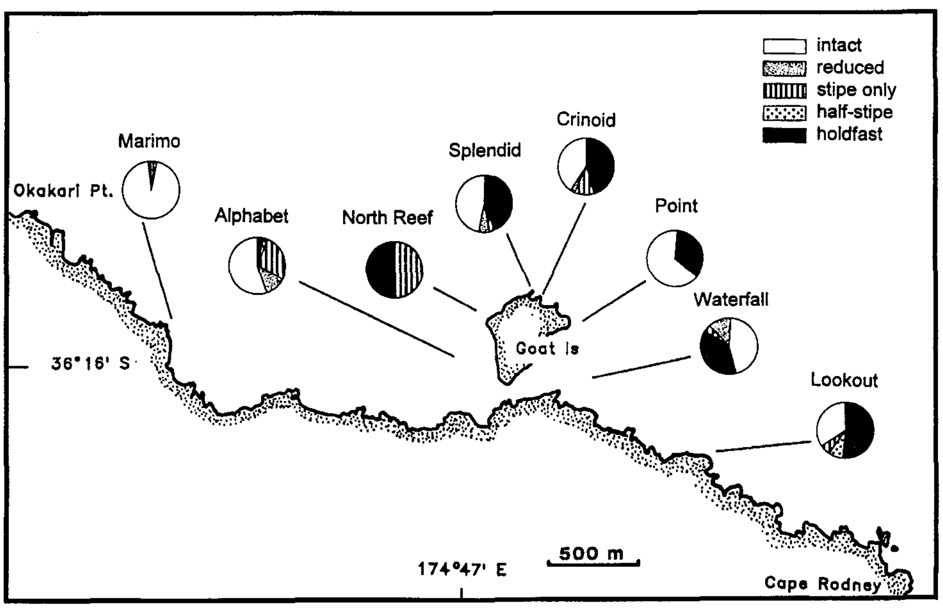

Fig. 3. Proportions of *Ecklonia* affected by dieback at eight sites in the Cape Rodney to Okakari Point Marine Reserve. Data are from video transects, pooled across entire reef profiles.

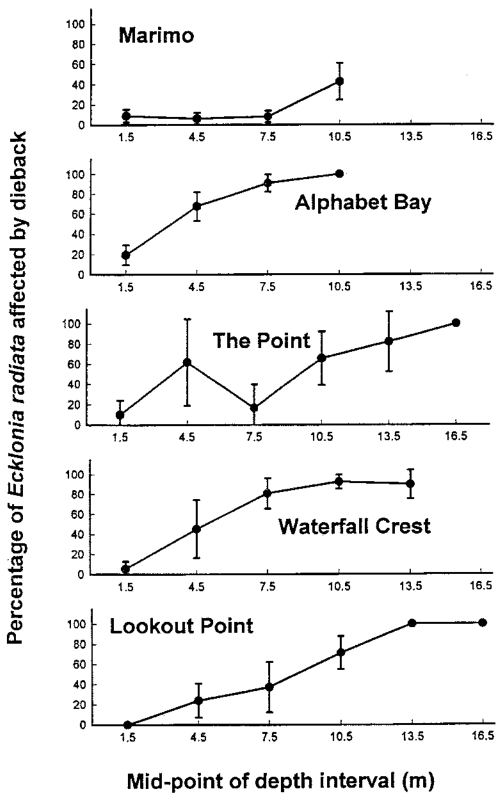

Fig. 4. Percentage (mean ± 1 s.d.) of *Ecklonia* affected by dieback (1-m^2 quadrats, n = 5) in 3-m depth intervals at five sites in the Cape Rodney to Okakari Point Marine Reserve in January 1993. At The Point, *E. radiata* did not occur in all quadrats; hence, n = 4 for the 16·5-m depth stratum and n = 2 for the 1·5-m and 7·5-m depth strata.

damage will lead to overestimates of the effects of the mass mortality agent if other mortality agents produce similar symptoms. In shallow water, grazing by sea urchins or wave action could have been responsible for removing sporophytes and leaving holdfasts. However, the pattern of mortality along depth gradients does not conform to the action of these agents, as both are more prevalent in shallow water.

The ecological consequences of the mortality event are being investigated. A vast amount of kelp-derived dissolved and particulate organic matter, as well as kelp detritus, would have become available on the reef. Observations elsewhere suggest that such material affects many trophic groups on reefs (Duggins *et al.* 1989). Some kelp detritus would have entered adjacent urchin-grazed areas; this would likely lead to reduced grazing by urchins (Harrold and Reed 1985). Loss of habitat for epifaunal organisms (Taylor and Cole 1994) and recruitment habitat for fishes (Choat and Ayling 1987) following the event are likely to have had further assemblage-level effects.

We are presently monitoring the recovery of kelp populations from this event; widespread recruitment of *E. radiata* below 10 m has occurred. This is the largest-scale perturbation to kelp forests at Leigh that we are aware of, but our initial impression is that the event may have little lasting impact on assemblages of algae. This suggests that *E. radiata* forests are resilient to perturbations (Dayton *et al.* 1984; Johnson and Mann 1988). Long-term alterations to assemblage composition might occur if such mortalities occurred frequently.

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