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Harvesting of the kelp *Ecklonia maxima* in South Africa affects its three obligate, red algal epiphytes

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Abstract

In South Africa, more than 7000 t (f wt) of kelp (*Ecklonia maxima*) fronds are harvested annually to feed cultured abalone. *Carpoblepharis flaccida*, *Gelidium vittatum* and *Polysiphonia virgata* are conspicuous red algal epiphytes on older kelps and provide habitat and food for numerous animals. Over 4.5 y, we examined the effects of one destructive harvest of *E. maxima* on these 3 epiphytes. Two 20 × 20 m plots of kelp with similar epiphyte loads were demarcated. In one, all *E. maxima* sporophytes with stipes longer than 50 cm were harvested. The other plot served as a control. After 2.5 y the biomass of *E. maxima* in the harvested plot had recovered to control levels, but the epiphyte load (g epiphytes. kg kelp^{-1}) was statistically lower in the harvested plot after 2.5 and 3.5 y, and only recovered after 4.5 y. While most commercial harvesters cut through the "heads" (primary blades) of the kelp, effectively killing them, a new, non-lethal method removes secondary blades 20–30 cm from their bases, leaving the meristems and primary blades intact. At 5 sites studied, *G. vittatum* and *P. virgata* were found almost entirely on stipes and primary blades, and harvesting only distal parts of secondary blades limited losses to about 50% of *C. flaccida* biomass. To protect epiphytes, non-lethal harvesting is recommended and permanent non-harvest zones have been established in addition to limiting kelp yields and disallowing harvesting in Marine Protected Areas.

Introduction

The kelp *Ecklonia maxima* (Osbeck) Papenfuss occurs along the cool-temperate west coast of South Africa, where it dominates the surface canopy of kelp beds between Cape Agulhas and at least Cape Columbine (Figure 1). It has been collected as beach-cast since the 1950's (Anderson et al., 1989) and harvested since the 1970's for the production of a plant-growth stimulant. Since the early 1990's, increasing amounts of *E. maxima* have been harvested as feed for abalone cultured in land-based farms (Anderson et al., 2003). In 2003 more than 7000 t of fresh fronds were harvested from *E. maxima* beds, and demand is increasing as abalone farms expand.

The effects of harvesting on the *Ecklonia* plants and understorey communities have been studied in the past (Levitt et al., 2002) and are being studied now (M. Rothman pers. comm.). However, these studies do not consider effects on the 3 macroalgae that are obligate epiphytes on the stipes and fronds of *Ecklonia*. These 3 rhodophytes, *Gelidium vittatum* (Linnaeus) Kuetzing, *Polysiphonia virgata* (C. Agardh) Sprengel and *Carpoblepharis flaccida*, (C. Agardh) Kuetzing attain significant biomasses (see later) and were shown by Allen and Griffiths (1981) to bear at least 27 species of invertebrates. Furthermore, *C. flaccida* forms a significant part of the diet of the commercially important linefish *Pachymetopon blochii* (Val.) (Pulfrich & Griffiths, 1988). *G. vittatum* was formerly called *Suhria vittata* (Linnaeus) Endlicher (see Tronchin et al., 2002) and has been considered as a potential commercial agarophyte, but because of its epiphytic nature, would be difficult to obtain in sufficient quantities unless it could be

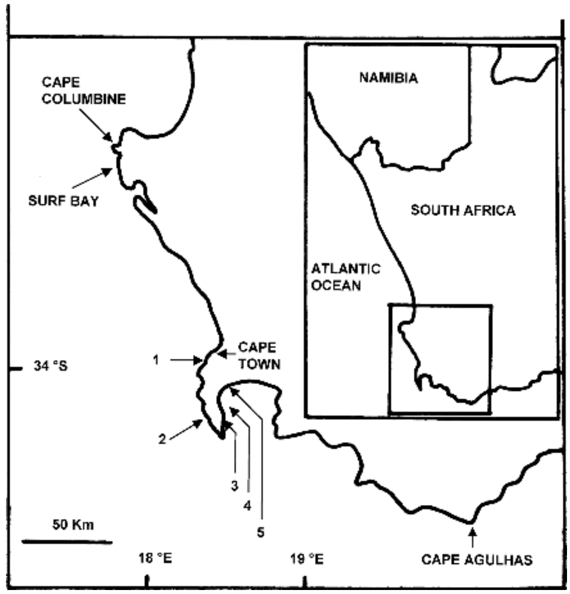

Figure 1. Map showing location of study sites on the South African west coast. Epiphyte survey sites on the Cape Peninsula, are: 1 Oudekraal, 2 Soetwater, 3 Buffelsbaai, 4 Glencairn, 5 Dalebrook.

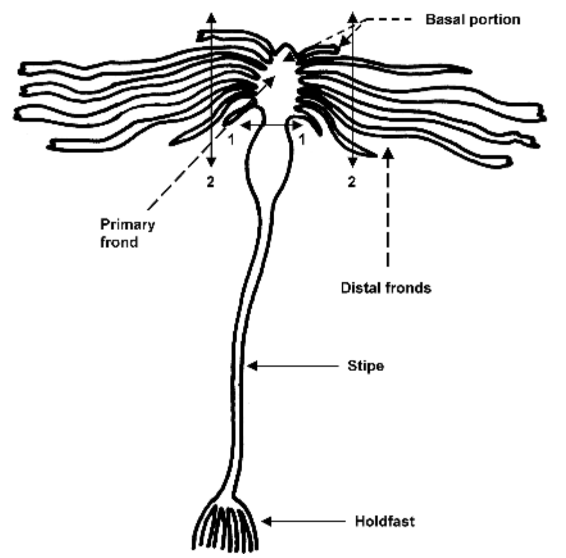

Figure 2. Diagram of *Ecklonia maxima* sporophyte to show parts referred to in text.

cultivated (Anderson & Bolton, 1985; Anderson et al., 1989; Anderson, 1994).

How harvesting affects epiphytes depends on the harvesting methods and the position of the epiphytes on the kelp. If whole kelps are removed, all attached organisms will be lost. In Norway, after harvesting of *Laminaria hyperborea* (Gunn.) Foslie by trawling, young kelps grew up rapidly to replace the mature sporophytes, but epiphytes and holdfast fauna populations took significantly longer to recover (Christie et al., 1998). Because epiphyte populations take time to become established, they are more abundant on older kelp plants (Whittick, 1983; Christie at al., 1998). Epiphytic macroalgae are often an important habitat for small invertebrates that may be ecologically important in the kelp–bed system (Christie et al., 1998; Allen & Griffiths, 1981). Furthermore, it is reasonable to assume that the abundance of such invertebrates will increase with the biomass of the epiphytes, as shown in Norway (Christie, 1995).

The 3 epiphytes in this study were known to have somewhat different distributions on the sporophytes, but these have never been quantitatively established. *Gelidium vittatum* is found on stipes or on the limpet *Cymbula compressa* that in turn grows only on these stipes. *Polysiphonia virgata* grows on the stipes. While *Carpoblepharis flaccida* was known to grow on fronds, it was not clear where on the primary or secondary fronds it is concentrated.

It is important to know where the epiphytes occur on the kelp sporophytes, because there are basically 3 harvesting methods used in South Africa. Kelp harvested for the extraction of a plant-growth stimulant is cut at the base of the stipe, and stipes and fronds used. The holdfast subsequently dies and rots off the substratum. Kelp for abalone feed is harvested in one of two ways. In the first method, the whole "head" (primary frond and attached secondary fronds – see Figure 2) is cut off, and either the stipe and holdfast die and rot off, or the stipes are cut off by divers a few days later and collected and sold for alginate extraction. In the second method, only the distal parts of the secondary fronds are cut off. This method does not kill the sporophyte: the remaining basal parts of the secondary fronds continue to grow, and all other parts are unharmed. The main advantage of this "non-lethal" method is that a substantially higher yield of kelp fronds can be obtained from a given area of kelp bed, because the replacement of biomass does not involve going through the whole life-history of the kelp: the secondary fronds continue to grow from their basal meristems (Levitt et al., 2002).

Most of the commercial harvesters supplying abalone feed prefer to cut the whole head off the *Ecklonia* sporophyte because it is easier and yields a high return per effort during each boat trip. However, on some areas of the coast, the demand for kelp fronds is now threatening to exceed the limits set by management, and on this basis alone, it may become necessary to ban lethal harvesting for abalone feed (generally only the fronds are used) in order to increase overall annual yields.

This study had two main aims. The first was to determine how long it takes for epiphyte populations to recover after *Ecklonia* sporophytes are harvested. The second was to determine the distribution of the 3 epiphytes on *Ecklonia* in order to assess the relative effects of lethal versus non-lethal (distal frond) harvesting methods.

Methods and materials

Harvesting experiment

The harvesting experiment was done at Surf Bay (32°58′70″S, 17°53′00″E), about 120 Km north of Cape Town, between May 1995 and November 1999. This area was chosen because it had never been harvested. A large and apparently uniform kelp bed was selected by visual inspection from the shore at LWS and by SCUBA inspection, and two 400 m^2 (20 × 20 m) areas (one harvest area, one control) marked out with subsurface buoys. In order to measure epiphyte abundance but limit destruction in the control at the start of the experiment, we did not collect all kelps from quadrats (see later) but randomly collected 20 sporophytes with stipes longer than 2 m, by cutting the base of the stipe. SCUBA was used for all sampling. Holdfasts were not removed from the rock, and plant and animal epiphytes on holdfasts were ignored. The sporophytes and their epiphytes (if present) were weighed individually. We then statistically compared epiphyte loads (as g epiphytes per g kelp) in the two areas using a *t*-test for independent sample means, after establishing homogeneity of variances using Levene's test (all statistics were done on Statistica 6, Statsoft). The harvest area was then cleared of all kelps with stipes longer than 50 cm (a normal commercial method).

The site was inspected periodically, and 2.5 y later, in November 1997, the kelp in the harvest plot was judged to have recovered to a visually similar biomass to the control. We then placed fifteen 1 m^{-2} quadrats haphazardly in each plot, and collected from them all kelp sporophytes with stipes longer than 25 cm. The sporophytes were taken ashore, weighed (fresh weight) and the fresh weight of all epiphytes on the stipes and fronds of each kelp recorded. All comparisons (data shown in Figures 3–4) were done using *t*-tests, after testing for homogeneity of variances (Levene's Test). We compared the harvest and control plots with respect to mean kelp biomass, mean kelp density, mean biomass of epiphytes and mean weight of epiphytes per kelp plant. This sampling method was repeated in November 1998 (3.5 y) and November 1999 (4.5 y).

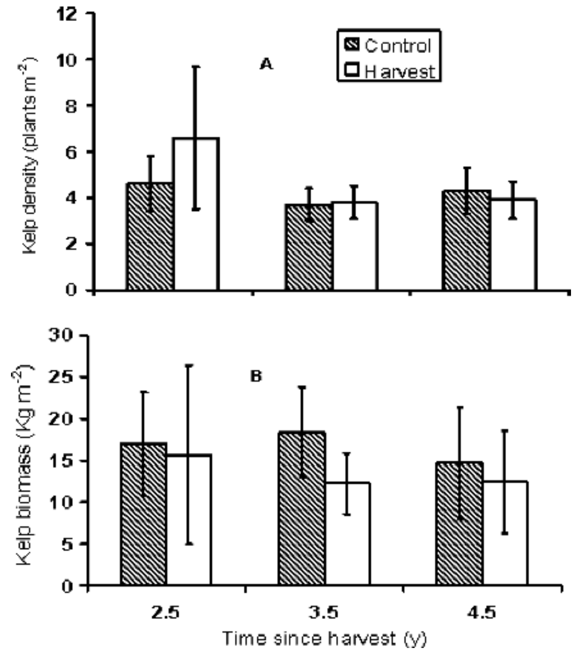

Figure 3. Mean density (A) and mean fresh biomass (B) of *Ecklonia* sporophytes at Surf Bay, in harvested and control areas, at various intervals after harvesting, with 95% confidence limits of means.

Epiphyte survey

Five sites were sampled, at spring low tides, on the Cape Peninsula (Figure 1), between April and September in 2001. At each site ten 1 m^2 quadrats were placed at approximately equal intervals along a line from 1 m depth to the edge of the kelp that reached the surface. All *Ecklonia* sporophytes with stipes longer than 50 cm were cut above the holdfast and taken ashore. Each plant was cut into 3 parts (see Figure 2): stipe, primary blade with the first 30 cm of the secondary blades attached (referred to as "basal fronds") and the remaining portion of the secondary blades ("distal fronds"). All epiphytic macroalgae were removed from each of the above portions of the sporophytes, identified and weighed wet. Each portion of sporophyte was weighed wet.

All tests were done with Stastistica 6, and a critical significance of $p = 0.05$ was assumed. Chi-square

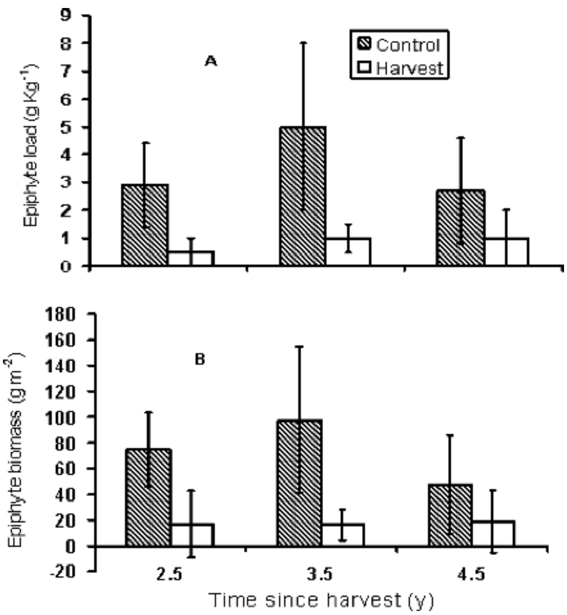

Figure 4. Mean load of total epiphytes (A) and mean total epiphyte biomass (B) for all 3 species (*C. flaccida*, *G. vittatum*, and *P. virgata*) at Surf Bay, in harvested and control areas, at various intervals after harvesting. A: units are g fresh mass of epiphytes per kg fresh mass of kelp. B: units are g m^{-2} of substratum. Vertical lines show 95% confidence limits of means.

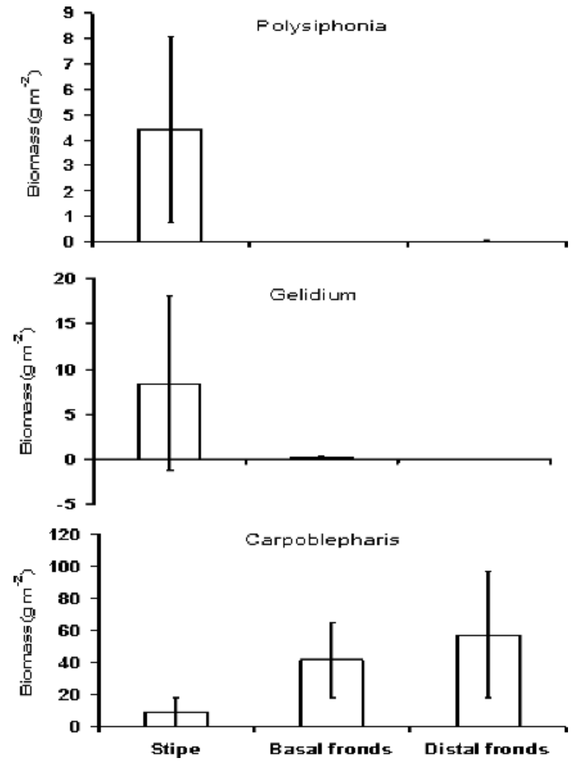

Figure 5. Mean fresh biomass of *Polysiphonia virgata, Gelidium vittatum* and *Carpoblepharis flaccida* on different parts of *Ecklonia*, for all 5 survey sites. Vertical lines show 95% confidence limits of means.

tests were used to compare the presence/absence of epiphytes on the different parts of the kelp and mean biomass values are shown in Figure 5. A *t*-test was used to compare the biomass of *Carpoblepharis* on the distal fronds with the biomass remaining on the basal fronds, using log-transformed data to satisfy conditions for normal distribution.

Results

Harvesting experiment

At the start of the experiment, the 20 *Ecklonia* sporophytes from the harvest plot had a mean epiphyte load of 11.64 (±7.26: 95% confidence limits of mean) g epiphyte per kg kelp, while mean load for the 20 sporophytes from the control was 10.29 ± 7.13 g kg^{-1}. These were statistically similar (*t*-test; $p = 0.942$). There was no significant difference between the densities of the kelp sporophytes in the harvest and control plots (Figure 3A) after 2.5 y ($p = 0.207$), 3.5 y ($p = 0.895$) and 4.5 y ($p = 0.761$). Similarly, there were no significant differences in mean kelp biomass (Figure 3B) after 2.5 y ($p = 0.827$), 3.5 y ($p = 0.385$) and 4.5 *y* ($p = 0.579$).

The mean epiphyte: kelp biomass ratios in the treatment and control areas (Figure 4A) were different after 2.5 y ($p = 0.040$) and 3.5 y ($p = 0.018$), but similar after 4.5 y ($p = 0.104$). The mean biomass of epiphytes (per m^2 of substratum; Figure 4B) was very variable but followed a similar pattern to the epiphyte/kelp ratio, with statistically different means after 2.5 y ($p = 0.039$) and 3.5 y ($p = 0.012$) but similar means after 4.5 y ($p = 0.169$).

Epiphyte survey

Seventeen species of seaweeds, besides the 3 epiphytes under study, were found on the stipes and 13 on the basal fronds of *Ecklonia*, but the distal fronds bore only *Carpoblepharis flaccida*. Because all species except these 3 epiphytes were never abundant on *Ecklonia* but are common in the understorey of these kelp beds, we do not consider them to be threatened by kelp-harvesting, and they were omitted from further analyses.

Table 1. Two-way summary of the occurrence (presence/absence) of each epiphyte species on the different parts of *Ecklonia,* based on combined samples for all 5 sites. For each species df = 2, *p* indicates observed vs expected probabilities according to the null hypothesis that epiphytes are equally distributed on all parts of kelps

Epiphyte	Part of kelp	Present	Absent	Total	Pearson Chi-square	Probability
Polysiphonia virgata	Stipe	28	193	221	47.57	$p = 0.00001$
	Basal	2	219	221		
	Distal	1	220	221		
	Total	31	632	663		
Gelidium vittatum	Stipe	35	186	221	61.49	$p = 0.00001$
	Basal	3	218	221		
	Distal	0	221	221		
	Total	38	625	663		
Carpoblepharis flaccida	Stipe	16	205	221	111.69	$p = 0.00001$
	Basal	92	129	221		
	Distal	117	104	221		
	Total	225	438	663		

Most of the biomass of *P. virgata* and *G. vittatum* occurs on the stipes of *Ecklonia* (Table 1, Figure 5A and B). However, almost all *C. flaccida* is found on the distal and basal fronds of *Ecklonia*, with very little on the stipes (Table 1 and Figure 5C).

If only distal fronds are harvested, almost all of the *P. virgata* and *G. vittatum* will be left behind. However, the biomass of *C. flaccida* on the distal fronds (mean and 95% confidence limits = 58 ± 31 g m^{-2}) was similar to the total remaining on the basal fronds and stipes (55 ± 24 g m^{-2})($t = 0.0898$; $n = 50$; $p = 0.929$).

Discussion

This study shows that while *Ecklonia* has recovered from harvesting after 2.5 y, the 3 obligate epiphytes take more than 3.5 y (up to 4.5 y) to recover, both in terms of total biomass (g m^{-2} of substratum) and biomass per kelp biomass. These results are consistent with the findings of Christie et al. (1998) on *Laminaria* in Norway. There the kelps recovered biomass and many of their stipes some epiphyte cover, within 2–3 y after a trawl harvest, but the relative abundance of epiphytes had not recovered before the next trawl 5 y later.

From the available evidence it appears that the cover of algal (and faunal) epiphytes on kelps is mainly related to the age of the host plants, as reported by Whittick (1983) in a study of *Laminaria hyperborea* in Scotland. Jennings and Steinberg (1997), in Australia, found that when *Ecklonia radiata* (C. Agardh) J. Agardh tissue was suspended in the water, epiphyte abundance correlated positively with time of exposure. They also found that most of the variation in epiphyte distribution on *E. radiata* was explained by the increase in epiphyte loading on older tissue. They ascribed this to either simple accumulation, or the fact that older tissue is higher in the water column. However, in *E. maxima*, the biomass of *C. flaccida* was similar on distal and basal portions of fronds. Basal and distal fronds *E. maxima* are at a similar level, because the fronds are long and stream out in the water. Thus epiphyte load is unlikely to depend on a higher position (and more light) in this case. Also, it does not appear to depend on the relative age of the frond portion, because although the distal fronds are older, the basal portion as defined here consists young parts of secondary fronds (the bases) and the primary frond (which is older).

In *E. maxima*, the meristem of each secondary frond lies near its base and junction with the primary frond, and is very high in polyphenols (Tugwell & Branch, 1989). Although Russell (1983) considered phenols in the meristem of *Laminaria* to prevent the settlement of *Ectocarpus*, Jennings and Steinberg (1997) discount these substances as deterrents of algal epiphytes, because of their solubility in water. Our results suggest that *Carpoblepharis* is not inhibited by phenols in the younger parts of *Ecklonia* fronds. While it is not possible to age individual *Ecklonia maxima* sporophytes, we have repeatedly observed that the highest epiphyte loads are borne on apparently old plants: those with stiff, dark stipes and broad, often tattered fronds. Our results agree with those of Whittick (1983), indicating that age is probably the main determinant of epiphyte load on these kelps.

We also provide quantitative proof that the 3 obligate epiphytes are distributed differently on the kelp sporophytes, with *Polysiphonia virgata* and *Gelidium vittatum* essentially limited to stipes, and *Carpoblepharis flaccida* distributed equally on "basal" and "distal" fronds, but with very little on stipes. The reasons for these distribution patterns are unknown, but may be related to how suitable the different substrata are for attachment of epiphytes. The stipes are relatively rigid, and subject to far less mutual abrasion than the fronds. We found a total of 21 macroalgal species (including these 3 obligate epiphytes) to be epiphytic on *Ecklonia* stipes in this study, and Stegenga et al. (1997) recorded 50 species on stipes of *E. maxima*, attesting to their suitability as a substratum. Christie et al. (2003) reported a higher diversity and abundance of fauna on the stipes than on the fronds of *Laminaria hyperborea*. Why is only *Carpoblepharis flaccida* found on distal fronds? In a physiological study, Stacey (1985) showed that the closely related *Carpoblepharis minima* is partly parasitic on its host, *Laminaria pallida,* in that photosynthetic assimilates are transferred from the host to *C. minima*. However, there is no transfer from *E. maxima* to *G. vittatum* (as *S. vittata*), which is thus fully autotrophic (Stacey, 1985). Although the *C. flaccida*/ *E. maxima* relationship has not been studied, it is possible that it is similar, implying a partly parasitic and perhaps closer link (in evolutionary terms) between *C. flaccida* and *E. maxima*.

The results of this study are important for management of the harvesting of *Ecklonia*. The non-lethal harvesting method has the least ecological effect on epiphytes because only distal fronds are cut and only about 50% of the biomass of *C. flaccida* is removed, while the other two species, and any of the other numerous macroalgae growing epiphytically on the stipes in particular, are essentially unaffected. Clearly this method will have the least effect on fauna that inhabit the epiphytes (Allen & Griffiths, 1981) and on *Pachymetopon* (Pulfrich & Griffiths, 1988) and other fish that feed on and among the epiphytes. Furthermore, this method is also predicted to yield up to 5 times more frond biomass per area of substratum over time (Levitt et al., 2002) and so when only frond material is required, it is clearly preferable on ecological grounds. However, many commercial operators are reluctant to harvest this way, claiming that it is difficult and expensive. Harvesters operate at low tides, and must lean out of a boat and gather the distal fronds of each plant, then cut them about 30 cm from the base and pull the slippery mass of loose fronds aboard. It is easier to take hold of secondary fronds, lift the "head" or primary blade out of the water, and cut it off, with all the secondary fronds attached. Also, each cut then yields more material, because no basal frond portions are left behind.

South African kelp harvesting is managed on an area basis, with a single company having the right to harvest in each Concession Area (Anderson et al., 2003), with a maximum annual yield permitted. This maximum is based on the biomass in the Concession Area. Up to now the kelp-frond harvesters in 13 of the 14 kelp areas have been free to choose their harvesting method. In the remaining area, where demand is most intensive, the o perator has only been allowed to harvest distal fronds, but was granted twice the relative yield because kelp recovery was presumed to be much faster (Levitt et al., 2002). After 3–4 years the success of this operation will be evaluated. Meanwhile, Marine and Coastal Management (the controlling authority) has set aside about 10% of each Concession Area as a "kelp reserve zone", where no harvesting may be done. This is intended mainly to protect some populations of "old" kelps and their epiphytes. However, parts of all of the harvested zones are in fact not accessible, because of shallow reefs or pinnacles, and many sub-surface kelps bear epiphytes but cannot be reached from a boat. General diving observations suggest that there are still healthy epiphyte populations even in harvested kelp beds, but a quantitative survey would be difficult because of the scale of the harvesting operations and the spatial and geographical variations in epiphyte biomass.

In areas where there are many abalone farms, *Ecklonia* beds are harvested whenever the surface canopy appears to have recovered: in areas where kelp heads are cut off, this means effectively about every 2 y. Because this interval is too short to allow full recovery of epiphyte populations, it is likely that they are being reduced, with ecological consequences that are difficult to predict. However, the results of this study clearly support the introduction of a "non-lethal", fronds-only method of harvesting *Ecklonia* in South Africa.

Acknowledgments

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