

The effects of harvesting of the South African kelp (*Ecklonia maxima*) on kelp population structure, growth rate and recruitment

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Abstract

Ecklonia maxima is an economically important kelp in South Africa. The harvested kelp is used mainly as feed for cultured *Haliotis midae* (abalone) on farms all along the South African South and West Coast. The effects that different harvesting methods have on the growth of sub-canopy kelps, kelp population structure and kelp recruitment were tested in a kelp bed at Bordjies Rif near Cape Town. Two 30 × 10 m sites were set up, about 100 m apart, in near monoculture stands of *E. maxima*. Each 30 × 10 m area was subdivided into three treatments. In treatment 1 (T1) the whole ‘head’ of each kelp sporophyte that reached the surface was cut off between the bulb and the primary blade (‘lethal’ method). In treatment 2 (T2) (‘non-lethal’ method), the secondary fronds of all sporophytes that reached the surface were cut 20–30 cm from their junction with the primary blade, and removed. In the control plot, the kelp plants were not treated. Harvesting treatments were done approximately every four months, at low spring tide, from 3 March 2003 to 3 November 2003 (three treatments). The effects of harvesting on the kelps depend largely on the size of plant and the time the fronds were removed; however, no seasonal pattern could be observed. The different treatments had no effect on the growth rate, population structure or recruitment of the kelp. This means that factors other than light play an important role in the growth, structure and recruitment of the kelp beds in False Bay. Results are discussed in relation to current commercial harvesting practices.

Introduction

The commercial use of seaweeds in South Africa began during the Second World War when agar from Japan became unavailable in Britain (Anderson et al., 1989). This may have been the impetus needed to start the South African seaweed industry in the early 1950’s (Isaac & Molteno, 1953). Seaweed was mainly collected as beach-cast material, dried and then exported (Anderson et al., 1989). A number of seaweed species are harvested commercially in South Africa but the kelp *Ecklonia maxima* is harvested in the largest quantities (Anderson et al., 2003). The amount of fresh kelp fronds harvested for abalone feed in South Africa increased exponentially from less than one ton (wet) in 1992 to more than 6000 tons (wet) in 2003 mainly due

to the increase in the number of abalone farms along the South African West Coast. Abalone require about 7% of their body mass of kelp per day: to produce 100 t of abalone, to a size between 50–70 mm in diameter, requires 5 t of freshly harvested kelp daily (Levitt et al., 2002). It is likely that the harvesting pressure on kelp beds will increase as more abalone farms are constructed along the South African west coast and existing farms expand.

The South African coastline is divided into 23 concession areas in which successful applicants have the right to harvest one specified seaweed resource. Fourteen of these concession areas have kelp in them, the main species in the south being *Ecklonia maxima*. Levitt et al. (2002) studied the regrowth of *Ecklonia maxima* and the understorey biota after harvesting, but

knowledge of the effects of harvesting is still very limited. In South Africa kelp is harvested by various methods. When stipe and fronds are required divers cut the stipe at the bottom just above the holdfast, thus killing the plant. This method is not used for abalone feed and is not considered further here. Only fronds (blades) are used for abalone feed, and there are two methods of frond-harvesting. In the first method the whole 'head' of the kelp sporophyte is cut off between the bulb at the top of the stipe and the primary blade (Figure 2). This is an easy way of harvesting, but it kills the plant. In the second method, the secondary fronds are cut 20–30 cm from the junction with the primary blade (Figure 2). Levitt et al. (2002) showed that the latter type of harvesting does not kill the plant, because the meristematic zone at the base of the secondary fronds is unharmed. The fronds continue to grow, and Levitt et al. (2002) calculated that this non-lethal harvesting method ultimately gives yields that are 4–5 times higher than the 'lethal' method. Both of these frond-harvesting methods alter the state of the canopy in a kelp bed.

Reports from other countries indicate that dense kelp canopy can decrease the amount of light that penetrates to the bottom by more than 90% (Norton et al., 1982; Kimura & Foster, 1984; Schiel & Nelson, 1990). Removing kelp canopies can increase the abundance of understory plants (Kimura & Foster, 1984; Sharp & Pringle, 1990) because light is one of the factors affecting their growth (Schroeter et al., 1995). We therefore hypothesized that removal or thinning (by cutting the distal fronds) of the surface canopy of *E. maxima*, would, through its effect on light penetration, result in an increase in the relative growth rate of the subcanopy kelp plants. Furthermore, we expected an increase in kelp recruits (juvenile sporophytes) and ultimately in the number of subcanopy kelp plants, which would alter the population structure of harvested beds. This study investigated the effects of these two methods of frond-harvesting (of the canopy) on the growth (stipe elongation) rate, recruitment, and population structure of the sub-canopy of the kelp *E. maxima*.

Materials and methods

Study site

A site was selected on the Cape Peninsula, about 60 km south of Cape Town, at Bordjies Rif ($18^{\circ}27'48''\text{E}$, $34^{\circ}18'54''\text{S}$) (Figure 1), where no previous harvesting had taken place. The substratum is of medium relief

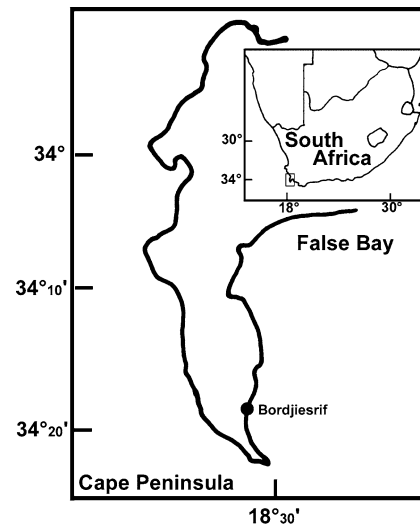


Figure 1. Location of Bordjies Rif in South Africa.

Table Mountain sandstone with 1–1.5 m gullies and mixed vertical/horizontal aspect. The homogeneous stand of kelp (*Ecklonia maxima*) is fairly dense (~ 8 plants m^{-2}) and the bed is between 70–100 m wide and 300–400 m long. The study site is in a partially sheltered bay that allows for favorable working conditions most of the time.

Experimental design

Two areas, each 30×10 m, were marked out parallel to the shore (Figure 2; ABCD) with weights and stainless steel eyebolts fixed to the rock with epoxy putty. The corners were marked with small sub-surface buoys. Each 30×10 m area was then subdivided

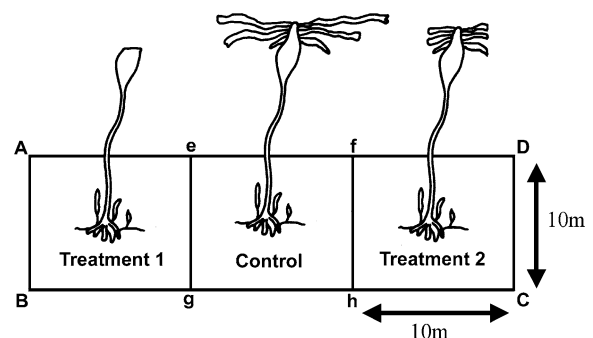


Figure 2. Treatment 1 (T1), where the whole head was harvested just above the bulb (lethal). Treatment 2 (T2), where only the fronds were harvested, 20–30 cm from the primary blade (non-lethal). The centre plot was the control (C, no treatment).

into three 10 × 10 m plots and marked with eyebolts (Figure 2; efg). The two replicate, 30 × 10 m areas were approximately 100 m apart, and both were between 2–5 m deep.

Each 30 × 10 m area was subdivided into three treatments. In treatment 1 (T1) the whole ‘head’ of each kelp sporophyte that reached the surface was cut off between the bulb and the primary blade, and the primary blade and the secondary fronds were removed (‘lethal’ method). In treatment 2 (T2) (‘non-lethal’ method), the secondary fronds of all sporophytes that reached the surface were cut 20–30 cm from their junction with the primary blade, and removed. In the control plot (C), the kelp plants were not treated. Harvesting treatments were done approximately every four months, at low spring tide, from 3 March 2003 to 3 November 2003 (three treatments). These treatments mimicked the two frond-harvesting methods used commercially. All subsequent sampling was done on sub-canopy kelps (see below).

Growth rates

Divers using SCUBA made measurements once every two months. In each 10 × 10 m plot (in each treatment, in three different size classes, 10 in each) 30 plants were marked, each with a unique number. The first group of plants, with stipe lengths ranging from 0–10 cm (small plants), were numbered 1–10. The second group, with stipe lengths ranging from 11–50 cm (medium plants), were numbered 11–20. The third group, with stipe lengths of 51–100 cm (long plants), were numbered 21–30. In total, 180 plants (in six plots at two sites) were marked.

Divers measured the stipe length of each marked plant and recorded it on an underwater slate. Two months later divers again measured all marked plants. The tags were then removed and new sets of plants in each size class were marked and measured to keep the samples independent. It is important to note that growth rate was measured as stipe elongation. The relative growth rates (RGR, % day⁻¹) were determined using the formula

$$\text{RGR} = \frac{\ln(W_2/W_1)}{n} \times 100$$

where W_2 and W_1 are the final and initial mass, respectively, and n is the number of days. An ANOVA and a Tukey post-hoc comparison were done to determine the effect that the different treatments had on growth.

By using a 3-way analysis of variance, the growth rates were compared over time, treatment and between the different size classes.

Plant density, recruitment and population structure

Divers haphazardly placed ten 1 m² quadrats within each of the six blocks. The number of plants within six size classes (0–1 cm, 2–10 cm, 11–25 cm, 25–50 cm, 50–100 cm and >100 cm) was recorded in each 1 m² quadrat. For this study kelp plants with a length of ≤10 cm were regarded as recruits. The effects of treatments (T1, T2 and C) on population structure and recruitment were tested statistically using a 2-way ANOVA and Tukey’s *post-hoc* test.

Water temperature

Water temperature was measured using a Starmon-mini temperature recorder with a Hart 1504 thermometer at 8 m depth placed on a concrete block approximately 300 m from the site at Bordjies Rif. Temperatures were recorded every 10 min and daily means calculated.

Light

Light was measured using a LI-COR LI-1000 Data Logger and SA: LI-193SA Underwater Type Spherical Quantum Sensor. Eight to twelve readings were made at each of the following depths: above the surface, 10 cm under the surface, 1 m, 2 m, 3 m, and at the bottom and between 10h00 and 12h00, with good visibility (about 15 m) on a cloudless day in November. Mean values were calculated for each depth and expressed relative to the surface value (1). The light was measured before and after experimental harvesting in a treatment 1 plot, a treatment 2 plot, and once in a control.

Results

Growth rate

Treatment had no significant effect on growth rate in all three size classes of sub-canopy kelp (Figure 3). Long plants (50–100 cm) grew faster than short plants (0–10 cm) in all treatments (Figures 3 and 4). Growth rates of medium plants (11–50 cm) were intermediate between those of long and short plants (Figures 3 and 4) and often overlapped with one or both (Figure 3). A

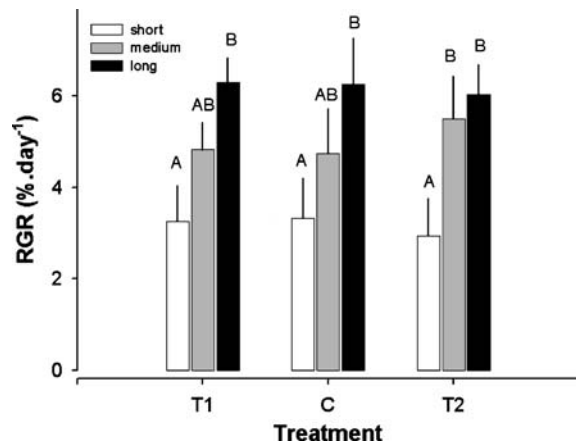


Figure 3. Relative Growth Rate (stipe elongation) of the different size classes of *Ecklonia maxima* under different harvesting conditions. Bars denote 95% confidence intervals. Letters denote statistical grouping (ANOVA and Tukey *post-hoc* test).

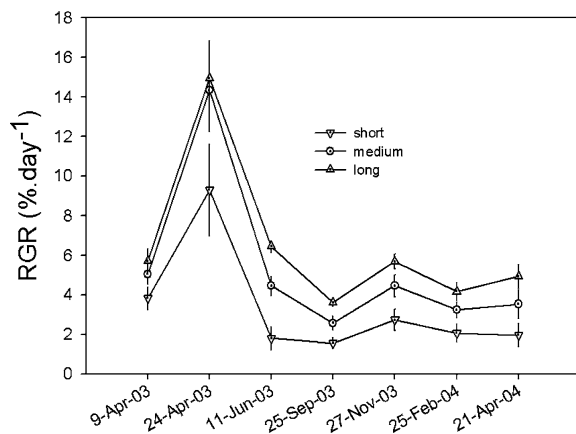


Figure 4. Relative Growth Rate (stipe elongation) of the different size classes of *Ecklonia maxima* over time. Bars denote 95% confidence intervals.

peak in growth rate of all three size classes of sporophytes was observed in April 2003 (Figure 4).

Plant density and recruitment

Treatment had no effect on density of recruits ($n = 960$, $p = 0.8796$) although the density of the recruits varied significantly between sampling periods ($n = 960$, $p < 0.0001$; Figure 5). The density of sporophytes with stipe length between 11 and >100 cm (Figure 6) different between treatments and size classes ($n = 5280$, $p < 0.0001$) but densities at each sampling were variable and showed no consistent pattern. Note that densities of recruits

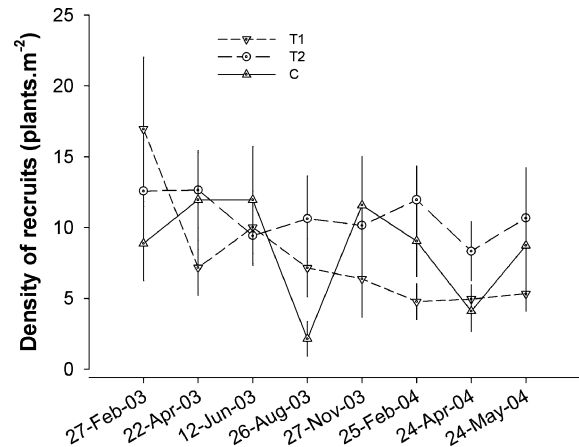


Figure 5. Mean densities of recruits (sporophytes with stipe length under 10 cm) over time under different harvesting conditions. Bars denote 95% confidence intervals.

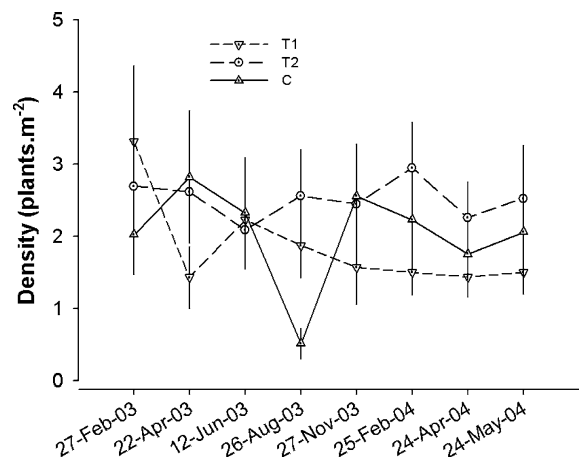


Figure 6. Mean densities of sporophytes (sporophytes with stipe length >10 cm) over time under different harvesting conditions. Bars denote 95% confidence intervals.

(plants with stipe <10 cm: Figure 5) were consistently higher than those of the longer sporophytes (Figure 6), but showed similar patterns of temporal fluctuation.

Population structure

Recruits (plants with stipe length <10 cm) constituted the largest proportion of the kelp bed population (Figure 7). Once sporophytes reached the 10–25 cm size class, decline in density (mortality) was relatively gradual (Figure 7).

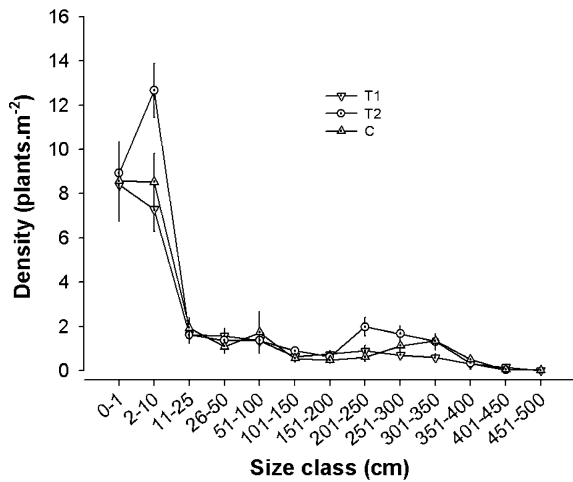


Figure 7. Mean densities of sporophytes of different size classes under different harvesting conditions. Bars denote 95% confidence intervals.

Water temperature

There was a seasonal pattern in the mean daily seawater temperatures, with consistently cooler winter months (mid-May to end August), while the summer water temperatures (September to May) were 2–5 °C higher but a lot more variable (Figure 8). In February 2003 to March 2003 and November 2003 to March 2003 water temperatures were above 17 °C for long periods but also occasionally fell to below 14 °C but only for short periods (Figure 8). In April 2003 temperatures fluctuated

regularly (every 5–7 days) between about 14 and 16 °C, but were on average about 2 °C lower than during the previous 2 months.

Light

In the control and before harvesting in both treatments, 60–80 % of light incident on the surface was lost in the first 10 cm (in the kelp canopy) (Figure 9). At 1 m depth, over 90% of the light was lost and light remained low down to the bottom at 3–3.4 m (between 27.5 and 54 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$). Harvesting treatment 1 (removal of entire kelp heads), increased light penetration at all depths: the mean amount of irradiance at the bottom increased 12 times from 27.5 to 330.8 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$ (Figure 9).

Discussion

Growth rates

Contrary to our hypothesis, removal of either the whole surface canopy (T1) or only distal portions of the secondary fronds (T2) had no effect on rate of growth (stipe elongation) of sub-canopy kelps despite a 12-times increase in bottom irradiance after harvesting in T1. We considered this to show that growth is limited by a factor other than light in this kelp bed. Treatment 2 left a considerable biomass of fronds intact and shading at depths below 1 m remained similar to the control.

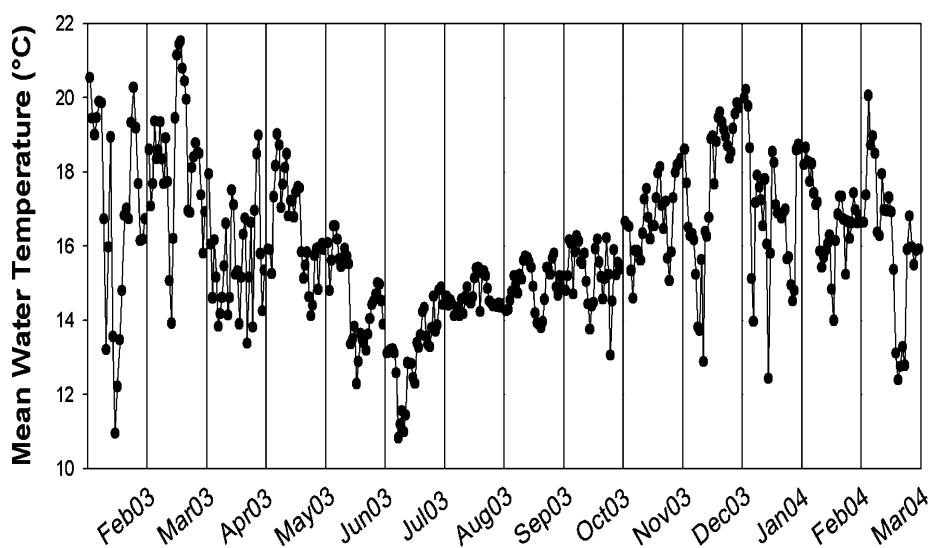


Figure 8. Mean daily water temperatures (°C) at Bordjies Rif, 8 m depth.

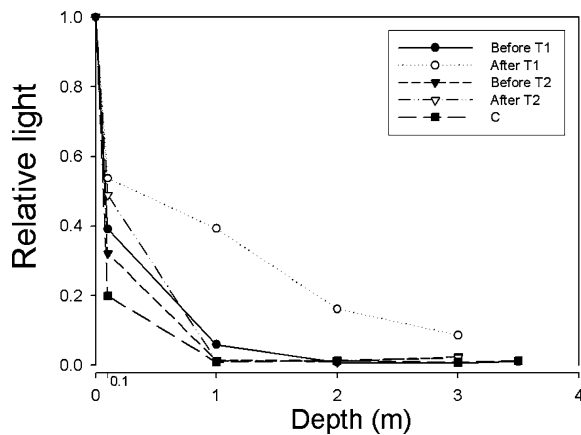


Figure 9. Relative light, before and after harvesting, with increase in depth in the kelp bed at Bordjies Rif. Mean values were calculated for each depth and expressed relative to the surface value (1).

In treatment 1 (after harvesting) the bulbs protruded above the surface of the water and light penetration on the bottom increased visibly.

In the South African west coast upwelling system, water temperature is inversely related to nutrient levels, with temperatures below 14 °C generally associated with nutrient-rich conditions (Andrews, 1974). Bolton and Anderson (1987) showed that, under nutrient-sufficient culture conditions, small sporophytes grew well over a range of temperatures between 8 and 18 °C, with the best growth achieved at 12 °C. It is thus likely that kelp growth may be faster when there is frequent import of cold, nutrient-rich water interspersed with short periods of warmer water, such as occurred in April 2003 when very high growth was recorded. Long periods (up to 2 weeks) of high temperatures (>17 °C) may have indicated poor nutrient conditions: this corroborated our observation of pale, unhealthy looking fronds in February 2003. However, there must be a balance between available light and nutrients: although the water was cold and nutrient-rich in June, this was midwinter, when cloud cover was high and irradiance levels low.

The relatively slow growth rate of short (0–10 cm) compared to long (51–100 cm) sporophytes may be a result of the former expending more growth effort in frond production rather than stipe elongation, although we did not measure frond growth. This is consistent with what Sjøtun et al. (1998) found in *Laminaria hyperborea* beds. The maximum rate of stipe elongation of subcanopy *E. maxima* appears to be greater (57 mm/week) than the maximum rate of stipe elon-

gation in *Laminaria hyperborea* (13 mm/week: Kain, 1979). This is perhaps not surprising for a sporophyte with a gas-filled bulb that suspends its fronds at the surface, such as *E. maxima*.

Density and recruitment

The absence of a treatment effect on the density of *E. maxima* recruits, despite a large increase in light penetration after treatment 1 has been harvested, suggests that at least in this kelp bed, which is only 3–5 m deep at low tide, density is controlled by a factor other than irradiance. Additionally, the absence of a clear seasonal pattern in recruit density suggests that recruitment here may be stochastic, as has been shown in the study of *E. maxima* (Levitt et al., 2002) and in California *Macrocystis* beds (Deyscher & Dean, 1986). In the latter study, recruitment was shown to be episodic rather than seasonal, and resulted from a combination of several factors creating an 'environmental window' (Deyscher & Dean, 1986). Factors which may control the density of recruits in South African kelp beds include grazers (Fricke, 1978), and the availability of substratum (Anderson et al., 1997). The fecundity of the kelp population also plays a role as well as suitable environmental conditions and the time it takes for the propagules to settle and to become established (Reed et al., 2004). It appears likely, therefore, that the availability of primary space may be the most important factor for recruitment in *E. maxima* beds where light is not limiting.

Population structure

The population structure of *E. maxima* sporophytes at all sites (Figure 7) is typical of many plant populations where most of the mortality is among the juveniles (Everard et al., 1995). Juvenile sporophytes are easily accessible to a suite of benthic grazers in the kelp beds of False Bay, including abalone, sea urchins and two turbinid snails: *Turbo sarmaticus* and *T. cidaris* (Anderson et al., 1997). We frequently observed grazing damage to the stipes of juvenile *E. maxima*. Our results show that, in this kelp bed, once sporophytes attain a stipe length of between 11 and 25 cm, they have approximately a 70% chance of growing to reach the canopy. This appears to be the size where *E. maxima* becomes less vulnerable to grazing, as suggested by Fricke (1978).

Conclusions

Current frond-harvesting methods (lethal and non-lethal) do not affect the growth (stipe elongation) rate of sub-canopy *E. maxima* plants, their density or recruitment of juveniles in a shallow-water, dense kelp bed in False Bay. Management should thus continue to allow both methods of harvesting to be used when ease of harvesting is more important than obtaining maximum yields. Future research should investigate the effects of canopy clearing on deeper and/or denser kelp beds, as well as trying to determine what factors may affect kelp recruitment.

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