

# Changes in the fish fauna associated with a sub-Antarctic *Macrocystis pyrifera* kelp forest in response to canopy removal

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**Abstract** The fish fauna associated with a *Macrocystis pyrifera* forest and the effects of the canopy removal on this fauna were studied in the Beagle Channel, Tierra del Fuego. Seasonal changes and differences in the fish communities that inhabit the canopy and the holdfast were also studied. Two patches of kelp forest separated by 200 m were selected. In one, the canopy was removed periodically while the other was used as a control. Samples were collected seasonally, from autumn 1999 to 2001. Fish fauna in the water column was sampled using trammel nets and holdfast fish fauna was sampled by removing the complete holdfast. Different assemblages of fish species were captured in the water column (surface and bottom) and in the holdfast. In the former there were mainly pelagic and benthopelagic species and the latter predominantly demersal species. The principal effect of the canopy removal was a drop in the abundance (and total weight) of *Paranotothenia magellanica* (doradito), the species with the strongest relationship with the canopy, principally at the surface of the treated patch probably

due to a reduction in the availability of refuges. A high degree of seasonality was observed for fish species' total weight, abundance and diversity, with higher values in summer and autumn. Taking into account our data and available data on kelp growth in the same locality, we suggest of cutting the kelp forest (preferably those farther away from the coast) once a year in winter or early spring, in order to minimize impact on the fish community.

**Keywords** Kelp forest · *Macrocystis pyrifera* · Canopy removal · Sub-Antarctic fish · Notothenioids

## Introduction

Kelp forest ecosystems consist of the structure-producing kelp and its associated biota including other algae, marine mammals, fishes and different invertebrate groups (crabs, sea urchins, mollusks, etc.). These forests are, therefore, one of the most structurally complex and highly productive components of cold-water marine rocky coastlines. Kelp forests occur in a mid-latitude belt (roughly 40° to 60°) in both hemispheres (Steneck et al. 2002).

Kelp forests of *Macrocystis pyrifera* (L.) are very abundant in the shallow waters of the Beagle Channel, at the southernmost tip of South America (54°S). They offer food and refuge for many species of invertebrates and fishes, generating a space for trophic interactions between these as well as with seabirds and marine mammals (Schiavini et al. 1997; Raya Rey and Schiavini 2000; Raya Rey and Schiavini 2001). Different stages of fish (larvae, juvenile, adults) have been associated with different parts of the macroalgae (glades,

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elbows and stipes; Nelson 2001). Holdfasts of brown kelp have been proposed as a site for recruitment, spawning and shelter against predators for many species of macroinvertebrates (Vásquez and Alonso Vega 2004) or fishes (Nelson 2001). Drift kelp is used as food by sea urchins in southern Chile (Steneck et al. 2002) and could be linking fauna of isolated kelp forest patches, increasing their complexity (Hobday 2000).

Changes in fish assemblages due to seasonality have been reported in different ecosystems, for example, a sector of a continental shelf (Beentjes et al. 2002), an estuary (Jaureguizar et al. 2004), a tidal flat (Vendel et al. 2003) or fish aggregation devices such as buoys (Dempster 2005) and also in *Macrocystis* forests (Moreno and Jara 1984). The variability in the abundance and diversity observed in these studies had been explained by physical and/or biological factors. Temperature and reproductive migrations are the principal aspects affecting fish assemblages. In the case of kelp, another common source of variation is the manipulation of the forest for commercial purposes (Carr 1989). The commercial utilization of *M. pyrifera* forests as a source of alginic acid has been considered an important potential resource for exploitation in Tierra del Fuego (Mendoza and Nizovoy 2000). Due to the ecological importance of the kelp forest, baseline information about its community dynamics and seasonality is necessary if an extractive activity is planned.

This study was carried out to test the effect of canopy removal (mimicking extraction for commercial purposes) on the fish fauna associated with *M. pyrifera* forests. Seasonal variations in the structure of the fish community and differences between the canopy and the holdfast communities were also studied.

## Materials and methods

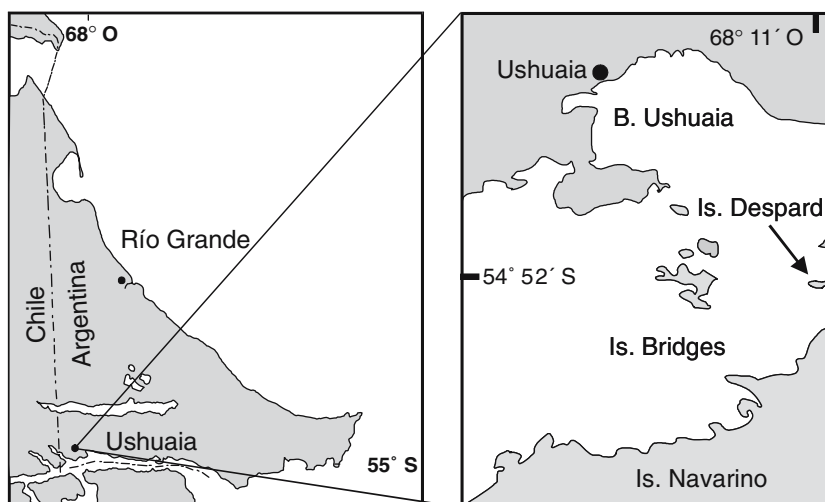
### Sampling and laboratory work

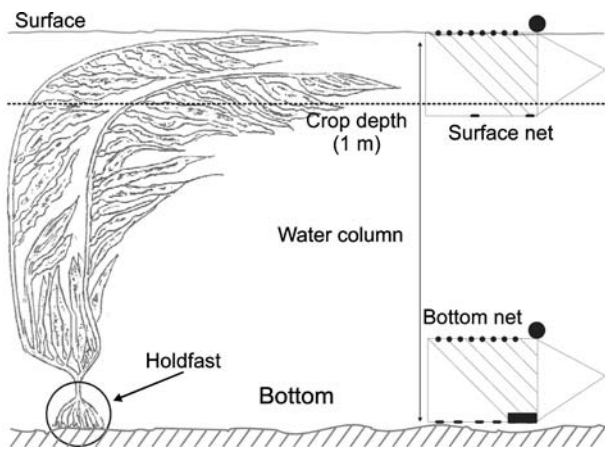
In the summer of 1999/2000, two patches of kelp forest were selected in the Beagle Channel area to carry out this experiment. The two selected patches were located 200 m apart and 150 m to the north of Isla Despard ( $68^{\circ}11'W$ ,  $54^{\circ}52'S$ ; Fig. 1). Each patch had a surface area of around  $4,300\text{ m}^2$  and an average depth of 6 m. Average tidal variation is 1.2 m approximately. Their exposition to wind and sun was similar, and there was no direct influence of freshwater inflows. At the beginning of the experiment, the canopy of one of the patches (thereafter, the treated patch) was removed by scuba divers, to a depth of 1 m below the water surface. A schematic draw with a vertical view of the forest showing the sampling methods is shown in Fig. 2.

The other patch was considered a control. The recovery of the treated patch was checked periodically, and the harvest operation was repeated throughout the extension of the experiment when kelp stipes reached the water surface covering approximately 25% of the patch (4 times per year).

Between March 1999 and April 2001, the fish fauna of the water column was sampled during each season (a total of eight samplings) using trammel nets in both patches. Four nets were placed inside the limits of each patch. Two were ballasted to remain at the sea floor and the other two had additional buoys which allowed them to float at the surface. Each trammel net (20 m long, 1.2 m height, 160 mm stretched mesh in the two outer panels and a 30 mm stretched mesh inner panel) was placed in the sampling area during morning hours and was removed 24 h later. Five holdfasts were also taken

**Fig. 1** Location of the sampling area near Isla Despard, 6 km away from Bahía Ushuaia, in the Beagle Channel





**Fig. 2** Schematic draw of a vertical view of the *M. pyrifera* forest and the relative position of the holdfast and the nets used to sample the water column. Modified from Mendoza and Nizovoy (2000)

randomly from each kelp forest patch by scuba diving during each sampling. Before its extraction each holdfast was covered by a fine net (1 mm stretched mesh) to avoid the escapement of mobile organisms. In the laboratory, the holdfasts were dismembered and all fish fauna collected. The fish fauna was identified using identification keys (Lloris and Rucabado 1991; Pequeño 1989; Fisher and Hureau 1988). After identification, total length, standard length and total weight were measured for each fish specimen. Fish captured in the water column and in the holdfast were not returned to the experimental sites.

The Shannon–Wiener diversity index was calculated for each seasonal sample in both kelp forest patches.

Separate calculations were made for fish fauna captured with surface and bottom trammel nets and found inside the holdfasts.

Temperature (*T*) was measured at each sampling, from the surface to the bottom of the water column with 1 m intervals.

Statistics

Surface, bottom and total weight of fish fauna were compared between the control and treated kelp forest patches. The total weight of the fish fauna found inside the holdfast was also compared between the two patches. All these comparisons were made using the *t* tests. Normality was tested using the Kolmogorov–Smirnov test and homoscedasticity was tested with the Levene test. Data were transformed by square root when necessary. The Shannon–Wiener diversity indexes were also compared using *t* test.

Results

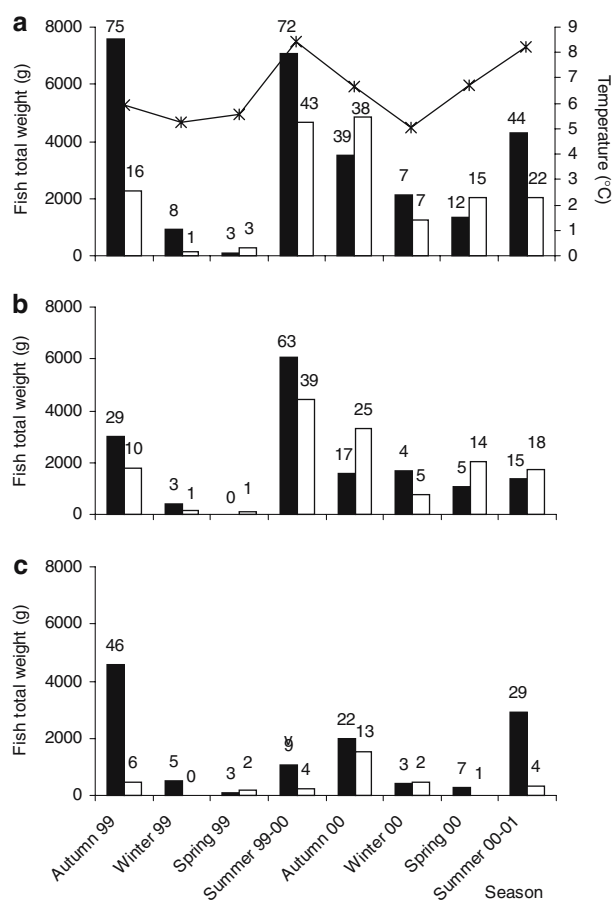
The fish species captured in the water column and the holdfast were different, regardless of the treatment (Table 1). Samples from the holdfast were dominated by the nototheniid *Patagonotothen cornucola* (Richardson 1844) (65.2% of the total weight), followed by the zoarciid *Crossostomus sobrali* (Lloris and Rucabado 1989) (22.4%). Other species captured were the

**Table 1** List of species, abundance and total weight of fish captured in the water column (bottom + surface) and the holdfast for both treated and control patches of *M. pyrifera* forest

Species	Habitat	Total length		No. captures		Percent captures		Species total weight (g)		Percent species total weight	
		Average (cm)	Range (cm)	Control	Treated	Control	Treated	Control	Treated	Control	Treated
<b>Holdfast</b>											
<i>Patagonotothen cornucola</i>	Demersal	6.15	3.6–10.9	43	45	51.2	68.2	105.3	119.8	63.1	67.1
<i>Crossostomus sobrali</i>	Demersal	6.12	3.1–22.7	26v	16	31.0	24.2	20.8	56.4	12.5	31.6
<i>Careproctus pallidus</i>	Demersal	3.2	2.3–5.8	7	2	8.3	3.0	5.0	0.5	3.0	0.3
<i>Austrolycus depressiceps</i>	Demersal	9.1	4.3–9.5	6	2	7.1	3.0	27.5	1.5	16.5	0.8
<i>Patagonotothen sima</i>	Demersal/ pelagic	7.6	7.2–8	2	–	2.4	–	8.3	–	4.9	–
<i>Pogonolycus marinae</i>	Demersal	4.0	4	–	1	–	1.5	–	0.3	–	0.2
Subtotal	–	–	–	84	66	100	100	166.9	178.5	100	100
<b>Water column</b>											
<i>Paranotothenia magellanica</i>	Demersal/ pelagic	18.5	7.7–36.5	221	103	85.4	72.0	2,2382.4	1,2328.6	82.5	70.5
<i>Patagonototen tessellata</i>	Demersal	19.9	11.1–23.0	35	34	13.1	22.7	3,167.8	2,827.7	11.7	16.2
<i>Cottoperca gobio</i>	Demersal	32.1	11.6–55.5	3	6	1.1	4.0	1,468.1	2,012.3	5.4	11.5
<i>Champscephalus esox</i>	Pelagic	30.0	26.3–28.2	–	2	–	1.3	–	307.7	–	1.8
<i>Patagonotothen longipes</i>	Demersal/ pelagic	20.6	20.6	1	–	0.4	–	99.7	–	0.4	–
Subtotal	–	–	–	260	145	100	100	2,7118.0	1,7476.4	100	100

zoarcid *Austrolycus depressiceps* (Regan 1913) (8.4%) and *Pogonolycus marinae* (Lloris 1988) (0.1%), the nototheniid *Patagonotothen sima* (Richardson 1845) (2.4%) and the liparidid *Careproctus pallidus* (Vaillant 1888) (1.6%). The samples from the water column were dominated by the nototheniid *Paranotothenia magellanica* (Forster 1801) (77.9% of the total weight) followed by another nototheniid, *Patagonotothen tessellata* (Richardson 1845) (13.5%). Other species captured were the bovicthead *Cottoperca gobio* (Günther 1861) (7.8%), the channichthyid *Champsocephalus esox* (Günther 1861) (0.7%) and the *Patagonotothen longipes* (Complex) (Steindachner 1876) (0.2%).

Neither fish total weight in both trammel nets nor the fish total weight in the bottom trammel nets were significantly different when treated and control patches were compared ( $\alpha$ : 0.05;  $P = 0.25$  and  $0.55$ , respectively) (Fig. 3a, b). Although the fish total weight in the surface

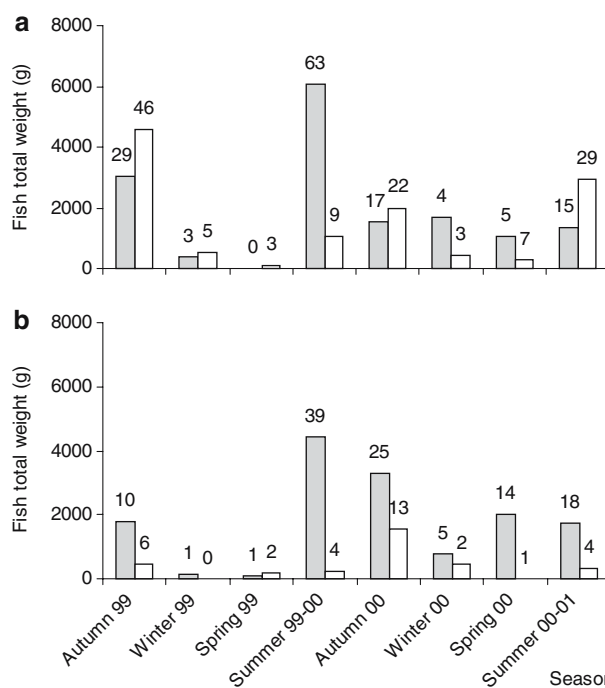


**Fig. 3** Fish total weight captured by trammel nets in control (filled rectangle) and treated (open rectangle) kelp forest patches during the experiment. Water temperature (asterisks) measured between the autumn of 1999 and summer of 2000/2001. Abundance (number of fish) shown above the bars. **a** Total fish weight (bottom + surface trammel nets) and temperature (each point is an average of temperatures taken along the water column). **b** Bottom fish total weight. **c** Surface fish total weight

trammel net was not significantly higher in the control than in the treated patch ( $P = 0.058$ ) there was an evident difference (Fig. 3c). The fish total weight in the surface nets did not differ significantly from the fish total weight in the bottom nets in the control patch, ( $P = 0.63$ ; Fig. 4a). Nonetheless, the fish total weight in the bottom nets was significantly higher than the fish total weight in the surface in the treated patch ( $P = 0.024$ ; Fig. 4b).

In the control patch, the abundance of *P. magellanica*, the principal species in the water column, was higher in surface nets than at the bottom in all samples except in the summer of 1999/2000. In the treated patch, in contrast, the abundance of *P. magellanica* was higher in the bottom samples for most of the seasons (Table 2). The frequency distribution of the total length showed strong seasonality throughout the experiment in both the treated and control patches (Fig. 5). Fish total weight inside the holdfast was not significantly different in the control and the treated patches ( $P = 0.89$ ; Fig. 6). Nevertheless, there was a peak in the total weight of the treated patch in the summer of 1999/2000, due to the exceptionally high weight of the fish captured in that sampling point.

A strong seasonal variation in fish total weight was observed in the water column (Fig. 3a), but not in holdfasts (Fig. 6) in both patches. Temperature ( $T$ ) variations were markedly seasonal in both patches. The



**Fig. 4** Fish total weight captured by trammel nets in the control and treated kelp forest patches. Bottom (filled rectangle), surface (open rectangle). Abundance (number of fish) shown above the bars. **a** Control kelp forest patch. **b** Treated kelp forest patch

**Table 2** Abundance of *P. magellanica* and *P. tessellata* (number of fish captured) in the water column samples of both control and treated kelp forest patches for each season

	<i>P. magellanica</i>				<i>P. tessellata</i>			
	No. captures				No. captures			
	Control		Treated		Control		Treated	
	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface
Autumn 1999	29	43	6	6	0	3	3	0
Winter 1999	3	5	1	0	0	0	0	0
Spring 1999	0	3	0	1	0	0	1	1
Summer 1999–2000	63	9	36	4	0	0	3	0
Autumn 2000	11	22	16	9	5	0	8	3
Winter 2000	1	3	4	1	0	0	1	1
Spring 2000	2	4	3	1	3	3	7	0
Summer 2000–2001	6	17	11	4	9	12	6	0

maximum temperature (8.4°C) registered was in the summer of 1999/2000. Minimum temperature (4.7°C) was in winter 2000. No significant differences in temperature were observed between patches or along the water column.

The diversity of species (Shannon–Wiener index) did not differ significantly between treated and control patches in the samples from trammel nets ( $P = 0.15$ ) or from the holdfast ( $P = 0.38$ ; Fig. 7).

## Discussion

### Fish assemblages

The kelp holdfast fish assemblage was different from that of the water column (Table 1). The species that inhabit the holdfast, except for *P. sima*, are all demersal fishes (Johnston et al. 2003). The only species captured in the water column that is undoubtedly demersal is *C. gobio*. The other species are pelagic or benthopelagic. It could be argued that no species of the holdfast assemblage was observed in the water column due to a limitation of our fishing gear. However, the smallest fish captured in the trammel nets was 7.7 cm TL, and 15% of the fish captured in the holdfast were larger than 8 cm. Small or juvenile individuals of the species captured in the water column with trammel nets were never found inside the holdfast. Moreover, we did not see specimens escaping during underwater sampling of the holdfasts.

### Abundance and diversity

*Paranotothenia magellanica* and *P. tessellata* were the most abundant species in the water column. *P. magellanica* is principally at the surface (associated with kelp fronds and stipes) and *P. tessellata* is distributed rather evenly between the surface and the bottom. A

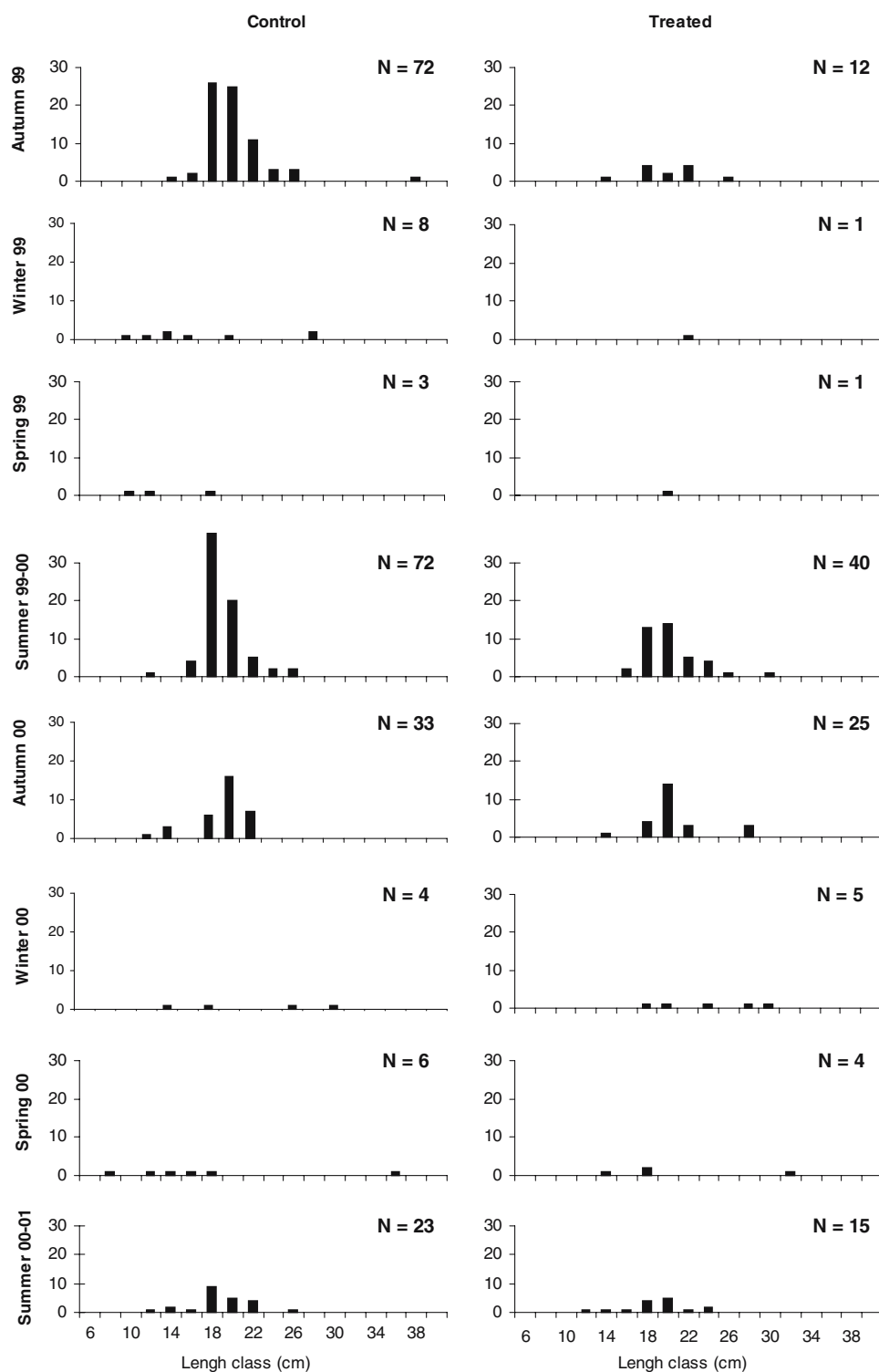
similar distribution inside the kelp forest by *P. magellanica* was described by Moreno and Jara (1984) in the eastern Beagle Channel. They also described *P. sima* inhabiting mid-water among kelp fronds and a reproductive migration to the holdfast in winter. The only two specimens of this species captured in our study were 7.2 and 8.0 cm TL, in holdfasts. The trammel nets captured fishes of this size but no specimens of *P. sima*.

*Harpagifer bispinis* (Forster 1801) was another species reported by Moreno and Jara (1984) in the kelp forest but not found by us. *H. bispinis* is abundant in the intertidal shores of the Beagle Channel, as a resident species, hiding beneath rocks (personal observation). This species, with a maximum TL of about 9.5 cm, is mostly outside the range of selectivity of the sampling gear used in this study. Nevertheless, a more plausible explanation for its absence would be the fact that the forests we studied were approximately 150 m from the coast, while the ones studied by Moreno and Jara (1984) were 1–2 m from the coast, and therefore migrations between the kelp forest and the shore were probably more common.

*Austrolycus depressiceps*, a species regularly found in the intertidal zone of the Beagle Channel at low tides (personal observation), was found inside the holdfast but was not captured with trammel nets in this study, although we have captured this species with the same sampling gear in kelp forests close to the shore, similarly to the forests studied by Moreno and Jara (1984). The other two zoarcids we found inside the holdfast do not occur in the intertidal zone (personal observation).

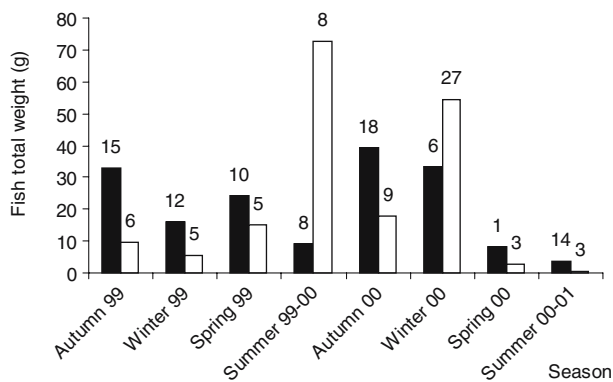
In terms of diversity it could be said that there are differences in the diversity of the fish fauna of kelp forests located close to the shore (Moreno and Jara 1984) and farther away from the shore (our data). The former fish community is more diverse (18 species vs. 11 species) with more representation of species that are also

**Fig. 5** Absolute frequency of length classes of *P. magellanicus* during the experiment in control and treated forest patches

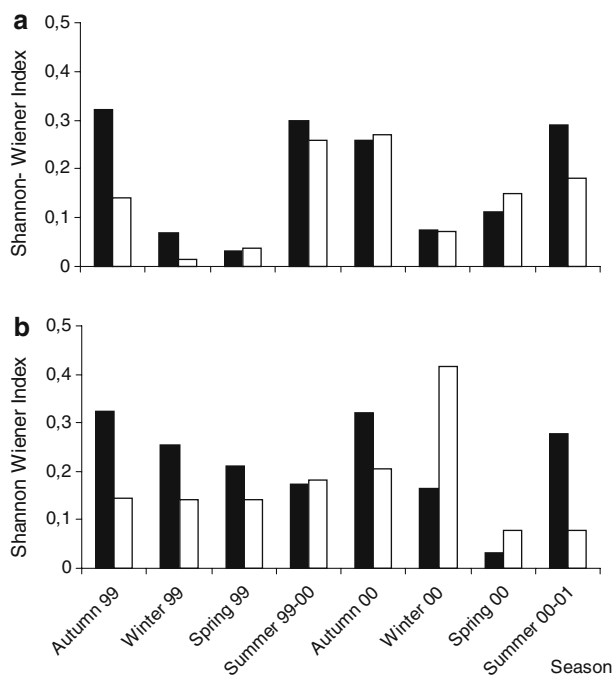


found in the intertidal zone. This difference could also be explained by the fact that Moreno and Jara (1984) combined, in their study, fish collected by gill nets, fish collected by hand and quantitative observations, while we used only trammel nets in the present study.

From the 11 species captured during this experiment, 7 belonged to the Suborder Notothenioidei (63%). This dominance indicates the importance of the kelp forest ecosystem for this suborder since the Notothenioidei represents only 31% of the total number of



**Fig. 6** Fish total weight captured inside the holdfast in the control and treated kelp forest patches. Control (filled rectangle), treated (open rectangle). Abundance (number of fish) shown above the bars



**Fig. 7** Shannon–Wiener index, calculated for fish fauna captured in both kelp forest patches. Control (filled rectangle), treated (open rectangle). **a** Fish fauna from the water column. **b** Fish fauna from the holdfast

species of the total fish fauna of the Beagle Channel (López et al. 1996).

Treatment effect

The principal effect of the canopy removal was a decrease in the fish total weight in the surface of the treated forest, mainly of the most abundant species, *P. magellanica*. All samples of the treated kelp forest showed higher or similar abundance of *P. magellanica*

in the bottom (Table 2). It is clear from our data, from many years of underwater observations and previous captures in and outside the kelp forest (Rae 1991), that *P. magellanica* is the species with the strongest relationship with the canopy of the kelp forest. Therefore, it is to be expected that *P. magellanica* is more sensitive than the other species to the clearance of the canopy.

The abundance of *P. tessellata* in the surface of the kelp forest decreased in the treated patch with an increase in the bottom, although the total abundance remained unchanged. The differential response to the treatment of these species could be explained by their different habits. The demersal-pelagic *P. magellanica* uses the canopy of the kelp more frequently than does the demersal *P. tessellata*. The clearance of the canopy decreases the availability of refuges close to the surface, affecting the former species more directly. Kennelly (1987) showed that a lack of the canopy causes a raise in the presence of filamentous algae and micro-invertebrates as a result of an increase in sunlight penetration at the bottom level of sublittoral cleared kelp patches of *Ecklonia radiata* (C. Agardh J. Agardh). If the same kind of process occurs in *M. pyrifera* kelp forests, a greater offer of food could attract fish species usually living in relation with the superficial canopy of macroalgae, explaining the movement toward the bottom of *P. magellanica*. However, the macroalgae community of the *M. pyrifera* forest during this experiment showed no changes in the specific composition (Mendoza, personal communication).

The abundance of *P. magellanica* increased in the summer of 1999/2000 in the bottom nets (Table 2) in both kelp forest patches. A reason for this anomalous values could be a strong storm that took place a few days before the sampling date with wind speed of 42.55 km/h, twice the average speed (21.81 km/h) for the season (Meteorological Station, Ushuaia Airport, personal communication). This could have triggered the movement of the demersal-pelagic *P. magellanica* from the surface to the bottom.

We consider that the fact that the experiment was carried out without reposition of the fish captured did not affect the results since the difference between control and treated patch remained similar along the experiment.

Seasonality

A high degree of seasonal variation was observed in the total weight of fish in the water column, with higher values in summer–autumn and lower ones in winter–spring in both control and treated patches (Fig. 3a).

The observed variations could be explained, to a great extent, by the change in the abundance of *P. magellanica*. In previous studies, seasonal changes in fish community structure have been attributed to migrations caused by environmental (salinity and temperature) or behavioral changes (reproductive movements, recruitment, nursery ground) (Jaureguizar et al. 2004). The reproductive biology of *P. magellanica*, the principal species of the water column, was studied by Rae (1991). He described *P. magellanica* using the *M. pyrifera* forest as a growing zone and leaving it after reaching sexual maturity, between May and June. Moreno and Jara (1984) also noticed a migration of relatively large individuals in early winter (June–July). We did observe strong seasonal differences in the total length distributions in winter–spring (low numbers and no recognizable distribution pattern) and summer–autumn (normal distributions) with a tenfold difference in the abundance for these periods of 21 and 207 individuals, respectively. To satisfy the hypothesis of reproductive migration, half of the fish present in summer–autumn would have had to have grown about 10 cm TL in less than 3 months until reaching 30 cm TL (probable length of first maturation; Rae 1991). This would be a very speculative explanation since no data on growth exists for this species, but it seems that such a high growth rate is unlikely.

*Patagonotothen tessellata* reproduces twice a year, in summer (January–March) and winter, (June–July) in the intertidal zone (Rae and Calvo 1996) and since the summer reproductive event is coincident with the maximum abundance of *P. tessellata* in the forest the reproductive migration hypothesis could not explain the seasonal variation of abundance of this species. An alternative explanation for the seasonal variation in the total weight of both species could be a change in the activity pattern of the ichthyofauna. Seasonal temperature variation (Fig. 3a) is coincident with the variation found in the total weight of the fish captured throughout the experiment. The relationship of temperature with activity pattern is well established in the literature (Clarke and Johnston 1999) and also reported specifically for sub-Antarctic fauna (Vanella and Calvo 2005; Fernández et al. 2002). Therefore, a rise in the activity of the mobile fauna in moments of higher temperature (summer–autumn) could have influenced the captures during the experiments, especially taking into account that the samples were taken using passive nets.

The diversity of the fish fauna in the water column and the holdfast did not vary significantly in the treated and the control patches. Maximum values of diversity were measured in the water column of both kelp

patches during the months with higher sea water temperature (Fig. 7a), while the holdfast fish fauna did not show a clear seasonal pattern (Fig. 7b).

## Conclusion and recommendation

In summary, the principal effect of the canopy removal was a decrease in the total weight of the species most strongly related to the canopy, *P. magellanica*, probably due to a decrease in the availability of refuges. Nevertheless, the diversity in the treated and control patches was not different. A great degree of seasonality in the abundance of *P. magellanica* and *P. tessellata* was observed, probably due to the variation in temperature and, therefore, in the activity of these species. Diversity also varied seasonally, being higher in the months with higher temperatures.

The harvest of the *M. pyrifera* kelp forest had no measurable impact on the benthic community, but a strong influence in the one species most associated to the canopy (*P. magellanica*). In order to quantify the impact of the harvest on the *P. magellanica* population, the putative migration of the individuals to the surrounding kelp forests should be monitored.

Mendoza and Nizovoy (2003) recommended only one intervention per year since the plants are too fragile for a higher number of interventions increasing the risk of detachment, despite the good recovery the forest showed after winter, spring and summer interventions. Our data show a higher activity of the fish fauna, and probably a higher impact on it, in summer and autumn, and also that the kelp forests located farther away from the shore have lower diversity than those closer to the shore. Our recommendation would be to cut patches of the forest farther away from the coast once a year in winter or early spring to allow for a good recovery of the forest and to minimize the impact on the fish fauna.

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