

# Testing sustainable management in Northern Chile: harvesting *Macrocystis pyrifera* (Phaeophyceae, Laminariales). A case study

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**Abstract** Kelp harvesting in northern Chile is managed by local fishermen and is part of an organized industry. However, the lack of standardized harvesting protocols has made regulation difficult. This, in combination with the impacts of oceanographic disturbances has resulted in some kelp populations being considerably reduced during the last decade. Consequently, harvest methods that maintain kelp resources are sorely needed if harvesting is to remain a viable industry in Chile. Here, experiments were done to identify sustainable methods for harvesting *Macrocystis pyrifera* along the coast of northern Chile. Three methods were compared with regard to their impacts on kelp populations; one that involves extracting half of the fronds from each individual in a population, one that involves extracting all the fronds from half of the individuals in a population, and a third that involves extracting all the fronds from all of the individuals in a population (i.e., the method currently used). Following this, populations were evaluated over a 2-month period to monitor re-growth of the remaining individuals and recruitment of new individuals, as well as changes in understory algal diversity and herbivore abundance. Our results indicate that removing half of the fronds from each individual in a population was the best method for maintaining the resource for future harvest because, it (1) maintains rapid

growth of new fronds on the harvested individuals, (2) promotes recruitment of new individuals, and (3) reduces herbivore densities through physical abrasion. Consequently, this method is recommended for future harvesting of *M. pyrifera* in Northern Chile.

**Keywords** Ecology · Kelp harvesting · *Macrocystis* · Phaeophyta · Sustainability

## Introduction

During the last three centuries, many communities around the world have become economically reliant on kelp harvesting for the extraction of alginates (McCleneghan and Houk 1985; Foster and Barilotti 1990; Schiel and Nelson 1990; Vásquez 1995; Kirkman and Kendrick 1997; Rothman et al. 2006; Vásquez 2008). The word “alginate” comes from the salts and derivatives of alginic acid, a polysaccharide found in the cell walls of some brown algae (Phaeophyceae) that upon extraction are used for their stabilizing, thickening, film-forming, and antiviral properties (Kelco 1976; Skjåk-bræk and Martinsen 1991a, b; Reyes-Tisnado et al. 2005; Yabur et al. 2007). In addition to their economic importance, kelps are ecologically important to coastal ecosystems, playing a major role in the sustainability of numerous species by creating forests that supply biogenic habitat and food (North 1971; Dayton 1985a; Duggins et al. 1989; Santelices 1989; Graham et al. 2007). Consequently, maintaining the integrity of these forests is crucial to proper ecosystem function in coastal environments. Ecological studies on the impacts of kelp harvesting have shown some temporal decreases in associated fish assemblages (Bodkin 1988) and subsequent temporary reductions to the canopy habitat (McCleneghan and Houk 1985), though no persistent effects on benthic communities

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have been shown (Barilotti and McPeak 1985; Barilotti and Zertuche-González 1990; Foster and Barilotti 1990). However, many of these studies have been conducted in areas where kelp harvesting is strongly regulated (e.g., California, USA), while little information on the impacts of harvesting is available for areas where the industry is poorly regulated (e.g. northern Chile). Consequently, as kelp harvesting continues to grow as a global industry, more information is needed to better manage this resource, especially in areas where kelp populations are in decline or already in low abundance.

Chile is considered to have one of the most productive coastlines for kelp forests worldwide, accounting for ~10 % of the global supply of alginates (Vásquez 2008). More than 90 % of the kelp extracted in Chile comes from two species, *Lessonia trabeculata* and *Lessonia nigrescens*. In northern Chile, these species are typically gather by collecting individuals that have been deposited on the beach following storms a method that has been described in other countries (Kirkman and Kendrick 1997; Casas-Valdez et al. 2003). However, the accelerated growth of abalone aquaculture since 2000 has created an additional demand for ~4,800 t of fresh kelp per year for abalone food that cannot be met using this technique alone (Anuario Estadístico de Pesca 1985–2006). As a consequence, the cultivation and management of natural populations of the giant kelp, *Macrocystis pyrifera*, is re-emerging (Vásquez 2008). In northern Chile, management of natural populations is being done exclusively by communities of local fishermen who depend on this resource, thereby integrating social and economic concerns (Vásquez and Santelices 1990; Vásquez and Westermeier 1993; Vásquez 2008). However, unlike other kelps, *M. pyrifera* is typically collected by hand from small boats, the shore, or on SCUBA while still attached to the substrate. This often requires collecting entire individuals, including their reproductive sporophylls, potentially making it problematic for the persistence of the resource.

As the kelp harvesting industry continues to grow in northern Chile, the need for sustainable harvesting techniques will become of paramount importance to the persistence of this resource and the economic well being of the communities that rely on it. To begin addressing this, Romo et al. (1984) observed that techniques developed for the sustainable harvest of *M. pyrifera* in California, USA were also effective in maintaining *M. pyrifera* populations in southern Chile (Filun pers. comm). Specifically, the regulated extraction of the kelp “canopy” (i.e., the floating portion to 1.5 m below the surface) was found to have negligible impacts on either the kelps themselves or their associated ecosystems (Santelices and Ojeda 1984). In northern Chile, *M. pyrifera* harvesting only occurs along a relatively small portion of the coastline (between 26° and 32° South) (Vásquez 2008), where the populations grow in shallower water and where the ecomorphs are different from

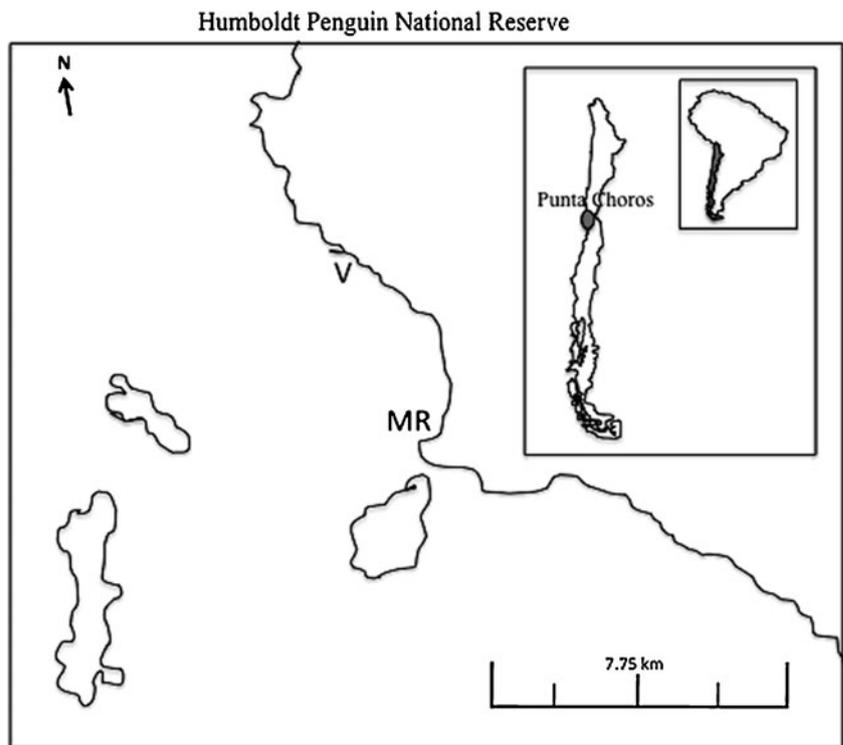
those in southern Chile or California, USA (reviewed in Demes et al. 2009). Consequently, harvesting the *M. pyrifera* canopy 1 or 2 m below the surface as done in California and proposed by Chile's Subsecretary of Fisheries (SUBPESCA) for southern Chile is not appropriated for this region and unfortunately, the method currently used to harvest *M. pyrifera* in this region does not consider demographic or ecological concerns.

In northern Chile, *M. pyrifera* grows mostly in shallow subtidal depths (2 to 11 m) (Vega et al. 2005) in protected, semi-exposed, or exposed areas where their ecological responses to harvesting have been well studied (Vásquez 1995; Vega et al. 2005; Graham et al. 2007; Villegas et al. 2008; Vásquez 2008). In contrast, the fragmented populations in moderately to highly exposed shallow waters that are accessible to fishermen have not been well studied. Thus, sustainable harvesting method designed specifically for these areas are sorely needed (Vásquez 2008). These methods should consider impacts to the re-growth of harvested individuals, recruitment of new individuals, diversity of understory algae, and the abundance of herbivores (Vásquez 1995). Following the studies of Vásquez (2008), this is the first approach for designing a sustainable harvesting technique for *M. pyrifera* in northern Chile that addresses not only demographic and ecological impacts, but also recommends how to best harvest these natural populations in lieu of the increasing demand for kelp in abalone aquaculture (Flores-Aguilar et al 2007; Vásquez 2008; Buschmann et al. 2008) and its potential use for alginate extraction and biofuel production in the future.

## Material and methods

Experiments were done in the National Humboldt Penguin Reserve at the fishermen community of Punta Choros, Chile (Fig. 1) at two sites “Memo Ruz” and “Ventana” (29°14' 44.32" S; 71° 27' 59.27" W and 29°12' 32.95" S; 71°29' 00.84" W, respectively) during late austral summer and beginning of autumn 2009 (February, March, and April). Populations in this region are regularly exposed to strong wave action and are distributed in shallow waters, reaching a maximum depth of 2.5 m at high tide. The sites were randomly selected. The “Memo Ruz” kelp bed was 15×20 m in size, and “Ventana” was 10×20 m. Although harvesting *M. pyrifera* is no longer active at these sites, this is one of the few places with several fragmented populations that are accessible from shore. Unfortunately, wave exposure and weather conditions prevented access to the sites after May and thus did not allow continue temporal evaluation of the sites following this time. It is also important to note that unlike California, *M. pyrifera* populations in northern Chile grow mostly on boulders in shallow water, highly

**Fig. 1** Study sites in the Humboldt Penguin National Reserve, Chile. *MR* = Memo Ruz (29°14' 44.32" S; 71° 27' 59.27" W) and *V* = Ventana (29°12' 32.95" S; 71°29' 00.84" W). Sites were separated from one another by 4.42 km

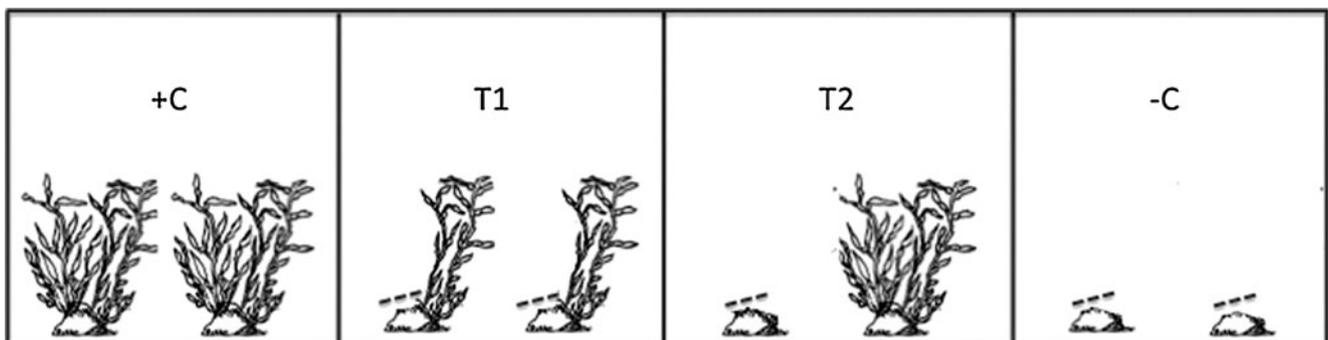


wave-exposed sites, and generally occur in very small patches. Thus, subtidal continuous monitoring was extremely complicated since it involved diving in 1 to 3 m depth within the surf zone. This factor in addition to the near extinction of northern populations forced us to design the experiments at a small spatial scale and a limited number (two) of sites.

**Harvesting treatments**

Continuous wave exposure and overlapping of holdfasts on the boulders made it logistically difficult to identify individual sporophytes in the study sites. Consequently, the term “algal units” (AU) is hereafter used to represent a group of fronds growing on a single boulder in place of kelp “individuals”. To

compare the effects of different harvest methods, four circular areas of 4-m diameter and separated from one another by 10 m were established at each study site. These consisted of three experimental harvesting treatments (T1, T2, -C) and one positive control (+C) where kelps were left un-manipulated. In the first harvesting treatment (T1), half of the fronds were removed from all AUs in the experimental area; in the second harvest treatment (T2), all of the fronds were removed from half of the AUs in the experimental area, removing AU that had approximately the same amount of fronds than the ones not manipulated, and in the third harvesting treatment (-C) all the fronds were removed from all the AUs in the experimental area (i.e., the method currently used by local fishermen) (Fig. 2). It is important to note that the actual process used by fishermen to harvest *M. pyrifera* at these sites, which



**Fig. 2** Experimental harvesting treatments. +C = un-harvested area, T1 = all fronds were removed from half of each AU in the site, T2 = all

fronds were removed from half of all AUs in the site, -C = all fronds were removed from all AUs in the site (current harvest method)

involves pulling the kelp fronds from the substrate by hand, was not modified because any major changes in this process would likely not be used. Therefore, irregular pieces of fronds and holdfast were left in each treatment (i.e., 5–10 cm long erect fronds and 3–10 cm diameter pieces of holdfast) and most of the time the entire individual was extracted including the holdfast. The first two treatments (T1 and T2) removed approximately the same amount of biomass from each area but resulted in different distributions of the remaining fronds, while the third (–C) removed all the biomass from the population. All experimental AUs ( $n=6$  to 10 per treatment) were tagged with a plastic ID number for future identification.

To examine the effects of the different harvest methods on frond density (growth), recruitment of new sporophytes, herbivore abundance, and benthic algal diversity, all AUs were monitored weekly for 9 weeks at Memo Ruz and 8 weeks at Ventana using SCUBA. Fronds were counted on each AU 1 m above the holdfast, and recruitment was assessed by counting the number of new sporophytes on each boulder; a “recruit” was defined as any sporophyte with three or fewer fronds that was not present during the previous survey (Druehl and Wheeler 1986). Once counted, recruits were tagged with plastic numbers.

To quantify the abundance of conspicuous herbivores around each of the AUs, a benthic survey was conducted on SCUBA during the first week of the study. The percentage cover of only the most abundant species, namely the gastropod *Tegula tridentata* (Potiez and Michaud, 1838) which comprised more than 90 % of all herbivore counts, was monitored weekly counting all individuals in five 0.25 m<sup>2</sup> quadrats randomly placed around each AU. Lastly, the percent bottom cover of benthic algae was also monitored around each AU. However, unlike California, USA, understory algae are not abundant in northern Chilean kelp forests and therefore responses of the understory algal community were expected to be low (Santelices and Ojeda 1984; Buschmann et al. 2006). In addition, considering the experimental time evaluated (2 months), it was unlikely to find substantial growth of understory species. Consequently, percent bottom cover of understory algae was measured only during the first and last week of the study to see any variation. To do this, five 0.25 m<sup>2</sup> quadrats were placed at randomly selected places within each treatment and the percent bottom cover of macroalgae other than *M. pyrifera* was estimated visually.

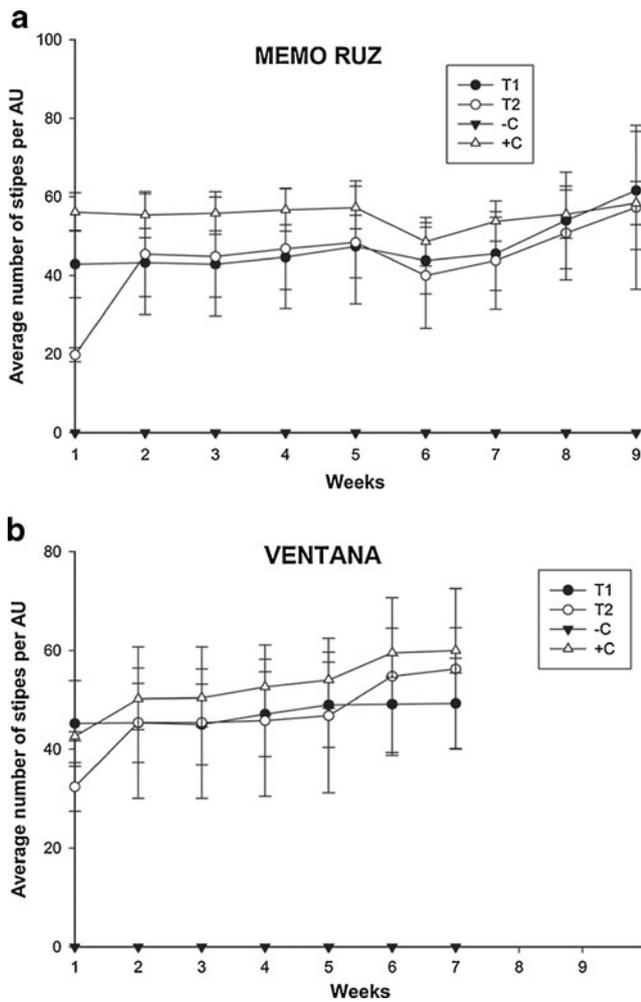
### Statistical analysis

All univariate statistical analyses were done using Systat version 12, and all multivariate analyses and permutation tests were done using Primer-E version 6. Data were tested for normality and homoscedasity prior to testing, and data not

meeting the assumptions of the analysis were transformed and retested to ensure problems were corrected. Because the sites were different with respect to their starting frond and herbivore densities, and because regulation of harvesting protocols is under site-specific control of the local fishing communities, we chose to keep the analyses for changes in frond number and herbivore density separate for each site. Thus, variation in frond density and herbivore abundance among different harvesting treatments through time was assessed using separate repeated measures ANOVAs followed by Tukey's pairwise comparisons. In contrast, because recruitment of new individuals is influenced by spore dispersal from both within and outside the sites and is not directly linked to the initial recruitment density, variation in recruitment was examined using site as a variable. Here, we consider individual AUs as replicates for each treatment at each site because we were interested in within-site variation for each treatment, how sites themselves varied, and whether site and treatment interacted. However, because of a large number of zeros in our kelp recruitment data, traditional univariate analyses were not possible. Therefore, variation in recruitment among treatments was assessed using a three-way PERMANOVA, with harvesting treatment, time, and site as factors. Following this, permutation pairwise comparisons were performed among levels of significant factors. Analyses of changes in percent cover of understory algal species between the initial and final concentration was done using a two-way PERMANOVA with site and harvesting treatment as factors.

### Results

Experimental harvest treatments T1 and T2, and the positive control (+C) all exhibited significant increase in the number of fronds per AU (i.e., growth) at both Memo Ruz (Fig. 3a,  $p=0.05$ ) and Ventana (Fig. 3b,  $p=0.027$ ). The increase of fronds was more evident in Ventana between weeks 1 to 5, whereas in Memo Ruz, the amount of fronds was stable in this period except for T2 that shows a notorious increase after the first week (Fig. 3a). This could have been an error when fronds were counted the first week since weather was not favorable in any of the sites. In any case, a decrease of the number of fronds was not found between weeks 1 and 5. Following this, frond number decreased during weeks five through seven at the Memo Ruz site ( $p<0.001$ ), presumably due to an unusually strong summer storm that occurred during this week (e.g., Dayton and Tegner 1984). Thus, similar behavior was found between treatments and the positive control, and no initial major changes are found within the experimental period. In contrast, when all the fronds were removed from the harvest area (–C), no new fronds appeared on any of the AUs (Fig. 3a, b), indicating that unlike the other two harvest methods, the current



**Fig. 3** Experimental responses under different harvesting methods through time. **a** Average number of stipes (mean ± SE) per AU at Memo Ruz; **b** Average number of stipes (mean ± SE) per AU through time at Ventana

method of harvesting used by the fishermen did not result in new growth and is therefore not sustainable, at least in a short-term period. Monitoring of fronds in Ventana was only for 7 weeks since weather conditions did not allow divers to count stipes.

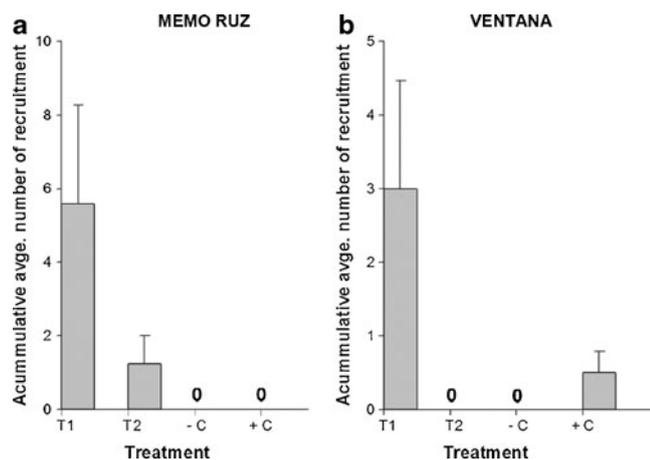
When both sites were considered together, recruitment of new sporophytes varied significantly among harvesting treatments ( $p=0.002$ ) but not between sites ( $p=0.396$ ; Table 1). Further, the relative differences among treatments were

consistent between the two study sites (treatment × site interaction  $p=0.621$ ). Specifically, recruitment of new sporophytes at Memo Ruz was only observed where half of the fronds were removed from each AU and where all the fronds were removed from half of the AUs (T1 and T2, respectively), but no recruitment was observed in either the positive control or where all the fronds were removed from all the AUs (−C) (Fig. 4a). Recruitment at Ventana was observed where half of the fronds were removed from each AU (T1) and where no fronds were removed from any AU (+C), but not in any of the other two harvest treatments (T2 and −C) (Fig. 4a, b). Specifically, recruitment was significantly greater in T1 than in any of the other treatments (T1 vs. T2,  $p=0.058$ ; T1 vs. −C,  $p=0.007$ ; T1 vs. +C,  $p=0.026$ ). Taken together, while no recruits were observed in the harvested areas where all the fronds were removed from all the AUs (i.e., current harvesting methods), the greatest recruitment of new sporophytes was observed in the two harvested areas where half of the fronds were removed from each of the AUs, again indicating this was the preferable harvest method.

Surveys conducted during the first week of the study revealed three potential benthic herbivores that might graze on *M. pyrifera* in northern Chile. Two of these were gastropods, *T. tridentata* and *T. atra*, and one was an echinoid, *Tetrapygus niger*. However, only *T. tridentata* was consistently present (more than 3 % cover) in the experimental areas and thus considered further. As such, an increase in the number of *T. tridentata* was observed in all three experimental treatments (T1, T2, and −C) and in the unharvested treatment control (+C). However, increases in these gastropods were considerably greater in areas where all the fronds were removed from each AU (−C) (Fig. 5a, b). Further, significant temporal differences were observed between the harvest treatments at each site (treatment × time interactions,  $p<0.05$  for each site). Interestingly, gastropod densities were greatest in the two treatments where all the fronds were removed from either from all the AUs (−C) or from half of the AUs (T2). This was likely because both treatments involved removing all of the fronds from the boulders, creating bare space and removing any existing fronds that physically scoured the boulder via a “whiplash effect”. Further, the lowest gastropod densities were observed in treatments where half of the fronds were removed from each AU (Fig. 5a, b), suggesting this method may yield the

**Table 1** Results of a two-way PERMANOVA testing differences in cumulative kelp recruitment between harvest treatments and sites

Sources	df	SS	MS	Pseudo-F	$p$ (Perm)	Unique perms
Treatment (Tr)	3	132.58	44.193	5.5484	0.002	998
Site (Si)	1	6.4391	6.4391	0.80843	0.396	998
Tr × Si	3	14.58	4.86	0.61016	0.621	999
Res	30	238.95	7.965			
Total	37	383.47				



**Fig. 4** Final number of *Macrocyctis pirifera* recruits in each harvest treatment. **a** Memo Ruz, **b** Ventana ( $n=5$ )

lowest grazing pressure and again indicating this is the preferable harvest method.

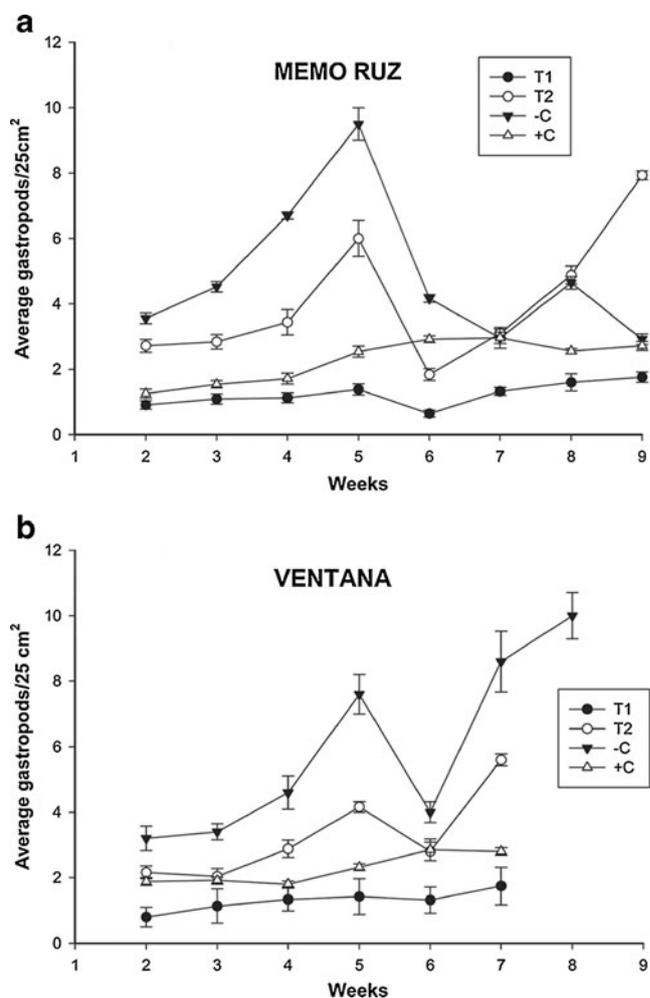
Consistent with patterns observed with other areas of Chile, understory algae were not common on the boulders in either site during this study. In particular, two individuals of the subtidal kelp *L. trabeculata* were found on boulders where half of the fronds were removed from each AU (T1), while some red algal turfs of the Orders Gelidiales and Corallinales and a few small patches of *Halopteris* spp. were also observed in the study sites (Figs. 6 and 7). However, no significant differences in their abundances were observed either between sites ( $p=0.144$ ) or sample times ( $p=0.174$ ), but the composition of these understory species was significantly different between treatments (PERMANOVA:  $p=0.002$ ). It is hard to attribute this significant difference to the harvesting treatments used since the period of evaluation was too short (2 months), and these changes would likely be greater after several months of evaluation. In addition, changes in percentage cover shown are likely not biologically important since the understory algae were rare and no patterns related to the harvesting process were identified (Figs. 6 and 7). Further, the three-way treatment  $\times$  sites  $\times$  time interaction was not statistically significant ( $p>0.71$ ), again suggesting that harvesting did not impact biodiversity differently in the treatments through time (see also Table 2). Altogether, this suggested that harvest method had little effect on understory diversity in these sites at least in a short-term period of evaluation.

## Discussion

Ecological consequences of kelp harvesting have been discussed for more than 20 years (Mcclenaghan and Houk 1985; Schiel and Nelson 1990; Foster and Barilotti 1990; Vásquez 1995; see review Kirkman and Kendrick 1997; Rothman et al. 2006) and most studies have shown little to

no significant impacts to the ecosystem compared to those expected from natural meteorological and biological disturbances (Santelices and Ojeda 1984). In Chile, the effects of implementing specific harvesting techniques and their potential impacts on ecological patterns such as re-growth of the kelps, recruitment, and herbivore interaction have not been considered in targeted species despite their potential importance. This is important because the impacts of different harvest methods may differ from those currently used in many places of the world, and thus it is crucial to consider the broader biological impacts of these different methods if we are to better manage kelp resources.

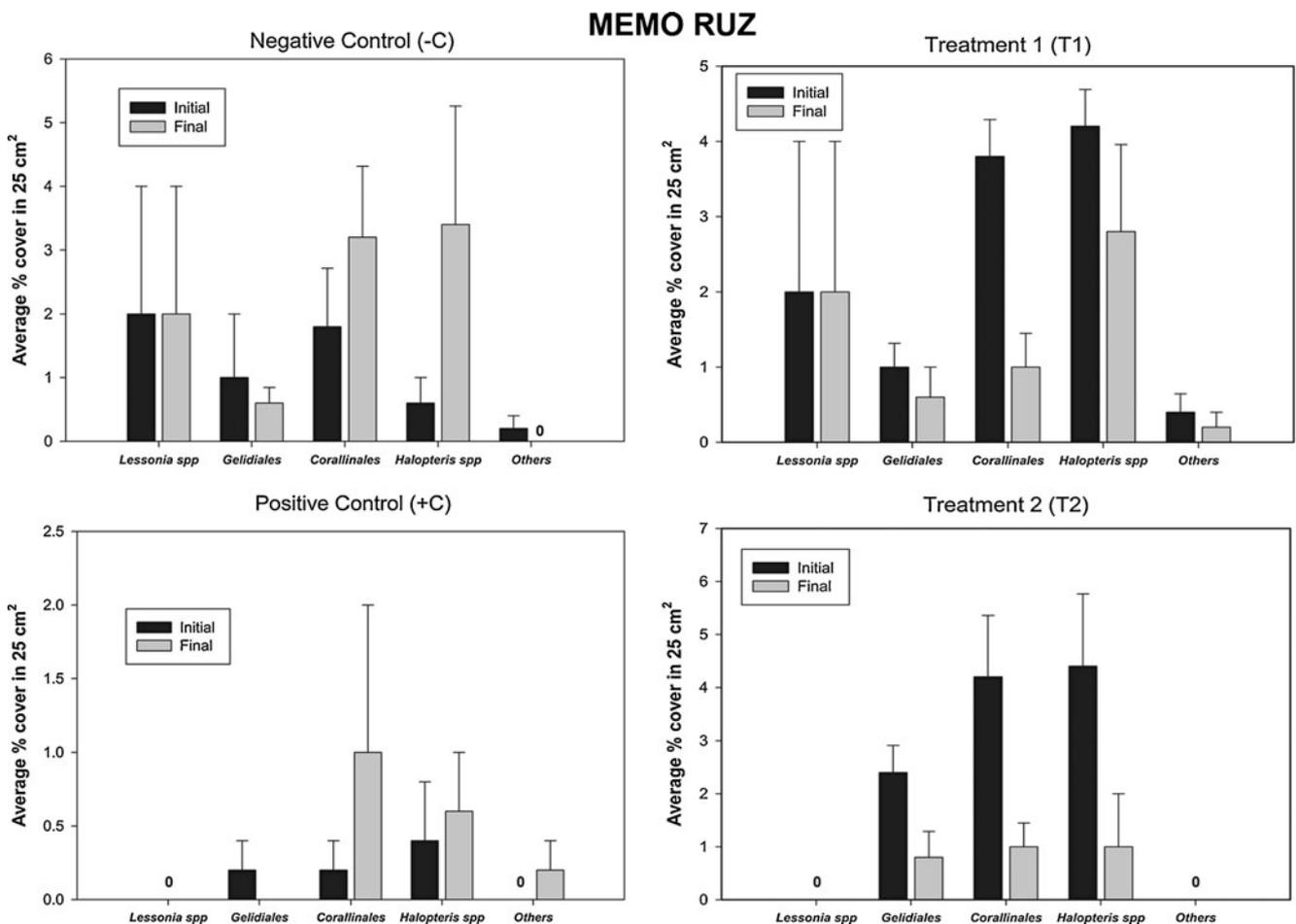
In northern Chile, *M. pirifera* typically grows on boulders and according to our data, harvesting of only half of the fronds per boulder (i.e., AU) showed considerably more benefits to the population than the methods currently used by local harvesters where all the fronds are removed from all the boulders. The harvesting methods where half of the



**Fig. 5** Average number of *Tegula tridentata* at each treatment through time. **a** Average *Tegula tridentata* (mean  $\pm$  SE) per 25 cm<sup>2</sup> per site at Memo Ruz site. **b** Average *T. tridentata* (mean  $\pm$  SE) per 25 cm<sup>2</sup> at Ventana site

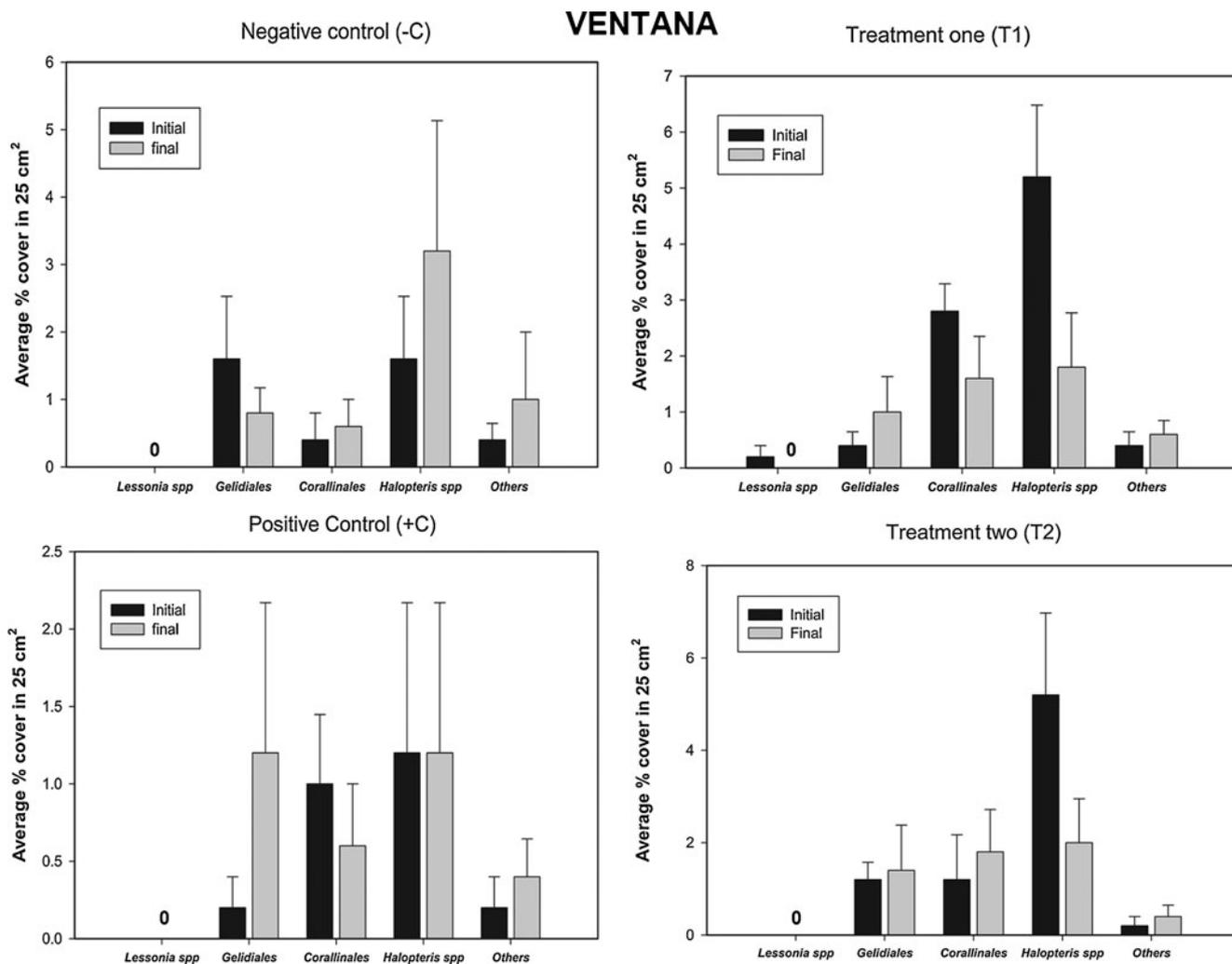
fronds are removed from each AU, and where all of the fronds are removed from half of the AUs were designed based on to the actual process of harvesting these populations (i.e., pulling the fronds from the surface). Within each harvest treatment with remaining fronds, no significant differences in frond number over time were observed between sites, suggesting a relatively consistent rate of frond production on each algal unit when a portion of the individuals were left on the boulders. This growth of new fronds may facilitate the spread of existing individuals, and thereby result in an alternative method of recovery for the population. This type of asexual reproduction has been supported when natural (Lobban 1978a, b) and artificial (Druehl and Kemp 1982) fragmentation occurs. The lack of new fronds growing on boulders where all the fronds were removed, in contrast, suggests no asexual reproduction, and thus may slow or inhibit population recovery, at least in the short-term, and therefore could partially explain the decline of these populations over the last few decades following intense harvesting pressure (Vega 2005; Vega et al. 2005).

In addition to vegetative growth, kelp populations recover from disturbances by recruitment of new individuals. These arise from zoospores that are released from reproductive sporophylls on nearby adults, settle on the benthos and undergo gametogenesis. Consequently, recruitment of *M. pyrifera* can be limited to short distances from the remaining sporophytes (Reed et al. 1992). However, recruitment of new *M. pyrifera* sporophytes was not expected since our experiments were conducted in summer when the spore production is reduced and recruitment is low (Buschmann et al. 2004). It may be that the recruitment observed during this experiment may have come from zoospores that were able to settle prior to the experiment (e.g., Edwards 2000) or from sporophytes that were so small they were not observed at the beginning of the experiment. For *M. pyrifera*, presence of “seed banks” and the possible delayed development of gametophytes (reviewed in Carney and Edwards 2010) may explain the rapid recruitment of new individuals in such a short period of time. If this would be the case, in the treatment where all individuals were removed, a higher



**Fig. 6** Average density (mean ± SE) of understory algae within each harvest treatment observed at Memo Ruz. Black bars indicate the initial concentration by each taxonomic group at the beginning of the

experiments. Gray bars indicate the final concentration at the end of the 2-month experimental period



**Fig. 7** Average density (mean  $\pm$  SE) of understory algae within each harvest treatment observed at Ventana. *Black bars* indicate the initial concentration by each taxonomic group at the beginning of the

experiments. *Gray bars* indicate the final concentration at the end of the 2-month experimental period

rate of recruitment should have been found considering the high amount of light penetrating. However, the high grazing activity may be impeding the growth of new recruitment. Further experiments need to be conducted in order to see if this is the case. Regardless, our data indicates that removing all biomass from the boulders, as is currently done, inhibits recruitment of new sporophytes presumably due to limited zoospore settlement, but removing only half of the fronds from each of the boulders results in the greatest recruitment.

Macrograzers can be a significant biological factor controlling the abundance and distribution of benthic macroalgae (see review by Lawrence 1975; Dayton 1985b; Schiel and Foster 1986; Johnson and Mann 1988 and review by Vásquez and Buschmann 1997) For instance, sea urchins have a major role in shaping the structure of many kelp communities around the world (see also Mann 1977; Estes et al. 1978). However in

Chile, sea urchin communities do not appear to have as much of a role in shaping *M. pyrifera* communities

**Table 2** Results of a three-way PERMANOVA testing differences in understory algal abundance between harvest treatments, sites, and sample times

Source	df	SS	MS	Pseudo-F	p (Perm)	Unique perms
Ti	1	4.09	4.09	1.59	0.174	999
Si	1	4.4	4.4	1.71	0.144	999
Tr	3	28.56	9.52	3.7	0.002	999
Ti $\times$ Si	1	1.68	1.68	0.65	0.603	999
Ti $\times$ Tr	3	17.75	5.92	2.3	0.012	998
Si $\times$ Tr	3	7.34	2.45	0.95	0.509	999
Ti $\times$ Si $\times$ Tr	3	5.52	1.84	0.72	0.71	997
Res	64	164.66	2.57			
Total	79	234.01				

(Castilla and Moreno 1982; Vásquez et al. 1984; Dayton 1985b). In northern Chile, sea urchins control deeper kelp communities such as those dominated by *L. trabeculata* (Vásquez 1989, 1992, 1993), whereas *T. tridentata* may be far more important in shallow *M. pyrifera* communities (Fariña et al. 2005; Villegas et al. 2008). In this case, *T. tridentata* responded differently to different harvesting methods, increasing on boulders where all the fronds were removed, but remaining lower on boulders where some or all of the fronds remain. This suggests that removing only half of the fronds per AU may effectively reduce grazing pressures by reducing herbivore abundances. This likely occurred due to the physical abrasion caused by the remaining fronds and sporophylls, especially during periods of strong wave action. This “whiplash effect” may be important in clearing gastropods from the boulders thereby preventing them from dominating the available space. This process has been described as a natural indirect defense strategy against herbivory from sea urchins populations (Vásquez and McPeak 1998; Konar 2000; Taylor and Schiel 2005) and as an artificial mechanism for kelp restoration (Vásquez and McPeak 1998). It is also described in Chile for species such as *L. trabeculata* (Vásquez 1992; see also Vásquez and Buschmann 1997 a review). Consequently, where all the fronds were removed from half of the boulders (T2), gastropods were more abundant than in areas where half of the fronds were removed from each of the boulders. This is also supported by the higher number of gastropods observed where all the fronds were removed from all the boulders (−C) and thus no whiplash effect presumably occurred. Furthermore, this crucial physical interaction may enhance recruitment and lateral occupation of the space by *M. pyrifera* while acting synergistically with the correct harvesting method (T1).

Understory biodiversity is known to have a strong relationship with the foundational species that construct the three-dimensional habitat where they occur (Hughes 2010). No significant variation has been shown for algal understory in *M. pyrifera* for populations in southern Chile after canopy removal (Santelices and Ojeda 1984) and results from this study seem to reaffirm this pattern. The decrease of Corallinales, Gelidiales, and *Halopteris* spp. in both experimental treatments was negligible. An alternative explanation is that with more *M. pyrifera* stipes and/or sporophylls coming in contact with the benthos, understory species become exposed to scouring via the “whiplash effect” that was not present in the past as has been observed with other kelp species in the world (Kennelly 1989; Taylor and Schiel 2005; Hughes 2010) as well as in Chile (Santelices 1990). However, the opposite response was observed in Ventana for Corallinales and Gelidiales (Fig. 5b) suggest that this variation may be more influenced by local conditions and/or stochastic processes. Further investigation needs to be conducted to conclusively identify physical

abrasion as being responsible for this variation in the algal community.

While the fishermen communities in Chile that are extracting *M. pyrifera* are generally smaller than the communities extracting *Lessonia* spp., there will likely be an increase in harvesting of this species with the increasing demand for kelp as food in abalone aquaculture (Flores-Aguilar et al 2007). This socio-ecological aspect (Estevez et al. 2010) will be important in promoting a sustainable kelp harvesting industry as the need for kelp products increases. Our research strongly indicates that, relative to the methods currently used, removing only half of the fronds from each AU is far superior for the sustainability of *M. pyrifera* populations in Chile. It results in continuous growth of remaining individuals and greater recruitment of new individuals, reduces herbivore abundances, and does not impact understory algal diversity. It is the perfect time to make this information available to fishing communities through educational outreach programs. If kelp populations can recover, and the harvesting community can implement these methods, a sustainable industry of this resource may succeed.

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