

Restoration Techniques for *Macrocystis pyrifera* (Phaeophyceae) Populations at the Southern Limit of Their Distribution in México

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Following the 1982–83 El Niño, *Macrocystis pyrifera* (L.) C. Agardh, forests disappeared throughout their range in Baja California. The giant kelp forests subsequently recovered within this range except at their extreme southern limit, a region encompassing 50 km of coastline with a former giant kelp standing stock of 28,000 wet tons. Two techniques were tested to restore these forests: juvenile transplantation and seeding with sporophylls. For transplanting, juvenile *M. pyrifera* sporophytes were attached to *Eisenia arborea* stumps seasonally over a two-year period. Average survival of transplants ranged from 7% in spring to 41% in winter. After two years, the average number of basal fronds per plant increased from 2 to 64 per plant and surface fronds from 0 to 34 per plant. Average frond growth rate of the transplants ranged from 8.1 cm day⁻¹ in summer to 10.8 cm day⁻¹ in winter. No significant differences in growth rate were found among treatments (seasons) for the transplants, but control plants showed a seasonal variation, with higher frond growth rates in winter (13.3 cm day⁻¹) and spring (9.3 cm day⁻¹) and lower in summer (4.4 cm day⁻¹). The seeding technique was tested in a fully orthogonal-block design with three factors with two levels (factors: \pm sporophylls addition, \pm *Eisenia arborea* and \pm understory algae). *Macrocystis pyrifera* recruitment occurred only in treatments with added sporophylls. The highest recruitment occurred where all algae were removed from the bottom, followed by the treatments without understory algae but with *Eisenia arborea*. This results suggest that a lack of spores and the presence of understory algae were the main factors inhibiting *Macrocystis pyrifera* recruitment in the area. Lower sea water temperatures and high nutrient concentrations occurred in spring and high temperatures and low nutrients in summer suggesting, as in southern California, an inverse relationship between these two factors. The results suggest a combined approach of transplanting juveniles and seeding during spring would be most effective for restoring the *M. pyrifera* forests.

Introduction

The giant kelp *Macrocystis pyrifera* (L.) C. Agardh, forms extensive kelp forests in the North Pacific extending from Santa Cruz in Central California USA to Baja California, México (Druehl 1970). Along the western coast of the Baja California Peninsula, *M. pyrifera* is found from the USA-México border south to Punta San Pablo, southern Baja California (Hernández-Carmona *et al.* 1991). This species represents an important marine resource because of its high productivity, provision of habitat for other species, and economic value for recreational and commercial fisheries, particularly kelp harvesting (North 1971, Foster and Schiel 1985).

Observations over the last 40 years, however, indicate that populations of giant kelp can vary greatly in size. The largest reductions in population size, especially in southern California USA and Baja California México, occur during El Niño oceanographic conditions (North 1971, Foster and Schiel 1985, Mc

Gowan 1985). Giant kelp canopies were devastated in California during the 1982–83 El Niño and subsequent storms. For example, the Point Loma canopy in southern California, which covered 600 hectares, disappeared. In addition, storms removed entire plants from the substratum, becoming entangled with attached plants either ripping them free or causing extensive stipe loss (Tegner and Dayton 1987, Dayton and Tegner 1989). A survey at Catalina Island in December 1984 also showed the complete loss of *Macrocystis pyrifera* at all depths (Foster and Schiel 1992). Although not well documented, similar devastation occurred in kelp forests from Santa Cruz, California to Isla Asunción, southern Baja California, the entire range of *Macrocystis pyrifera* forests in North America (Dayton and Tegner 1989). This damage resulted in the lowest kelp standing stock ever recorded by kelp harvesters in the USA (McPeak, Kelco Co., pers. comm.) and México (Armenta, Productos del Pacífico, pers. comm.).

Several attempts have been made to restore or enhance stands of giant kelp in USA, including urchin control, culturing and transplanting kelp plants, and control of competitive seaweeds. The transplant of adult or juvenile kelp plants has been of special interest in California (McPeak 1977, Rice *et al.* 1989), because this technique can rapidly promote a nucleus of fertile plants to serve as a proximal source of propagules. However, this technique has not been very successful in California because transplants tend to attract grazers and it is expensive in time and labor (Schiel and Foster 1992). On the other hand, spore seeding has also been used by placing fertile sporophylls in mesh bags and attaching them to the substratum (Dayton *et al.* 1984). It may be necessary to repeat this several times so that spore release coincides with the environmental conditions necessary for sporophyte recruitment (Schiel and Foster 1992). Deysher and Dean (1986) defined the best conditions within which sporophytes can be produced under natural conditions as the 'recruitment window'. In southern California this 'recruitment window' occurred only at temperatures below 16.3 °C and irradiance above 0.4 E m⁻² day⁻¹ (Deysher and Dean 1986).

The first assessment of the *Macrocystis pyrifera* kelp beds in México estimated a potential harvest (biomass within 1 m of surface) of 80,000 t (wet weight) (Casas Valdez *et al.* 1985). The highest harvest biomass was estimated near the southern limit, from Isla de Cedros to San Hipólito (64,722 t). All this kelp was lost after the 1982–83 El Niño (Hernández-Carmona 1987). The kelp forests in northern Baja California recovered but at its southern limit of distribution in Bahía Asunción and Punta Prieta it did not. In 1986 a seasonal assessment of *M. pyrifera* for the Baja California Peninsula estimated a maximum harvest in summer (98,000 t; Hernández-Carmona *et al.* 1991). Based on 1982 and 1986 estimates, kelp forests were very reduced along the 50 km coast in the most southerly region (approx. 28,000 t, wet kelp lost), an area that never recovered after the 1982–83 El Niño.

Ecological observations at southern Baja California revealed that the understory kelp *Eisenia arborea* Areschoug and calcareous algae in this region increased after the disappearance of *Macrocystis pyrifera* plants (Hernández-Carmona 1987). *Eisenia arborea* persisted probably because it maintained higher nitrogen tissue levels for longer periods than *Macrocystis pyrifera* (personal observation) and survived and recruited better in the absence of competitors for space and light with *M. pyrifera* (personal observation). The increase of *Eisenia arborea* and other understory algae may have reduced light and substratum availability, preventing the settling and development of new *Macrocystis pyrifera* sporophytes (McPeak 1981, Reed and Foster 1984). Although giant kelp eventually may recover in the region, re-

storation techniques can speed up this process and contribute to the availability of food for important fisheries (i. e. abalone) and as a source of raw material for the alginate industry.

Our objective was to test transplantation of juvenile plants and seeding with sporophylls as techniques for restoring giant kelp populations at their southern limit of distribution in southern Baja California, México.

Material and Methods

Juvenile transplant technique

Surveys in the Bahía Asunción area revealed that no natural *Macrocystis pyrifera* recruitment had occurred after 5 years following the 1982–83 El Niño, although oceanographic conditions had returned to normal values (at least temperature) and Punta San Pablo was the southern limit of the *M. pyrifera* distribution at Baja California peninsula.

Isla Asunción (Fig. 1) was selected as the experimental site because it was inhabited by *Eisenia arborea*, had rocky substrata, moderate wave action, and was near to a sea lion colony, which might reduce fish grazing on transplanted giant kelp. The transplants were done in: winter 1987–88 (21 Febru-

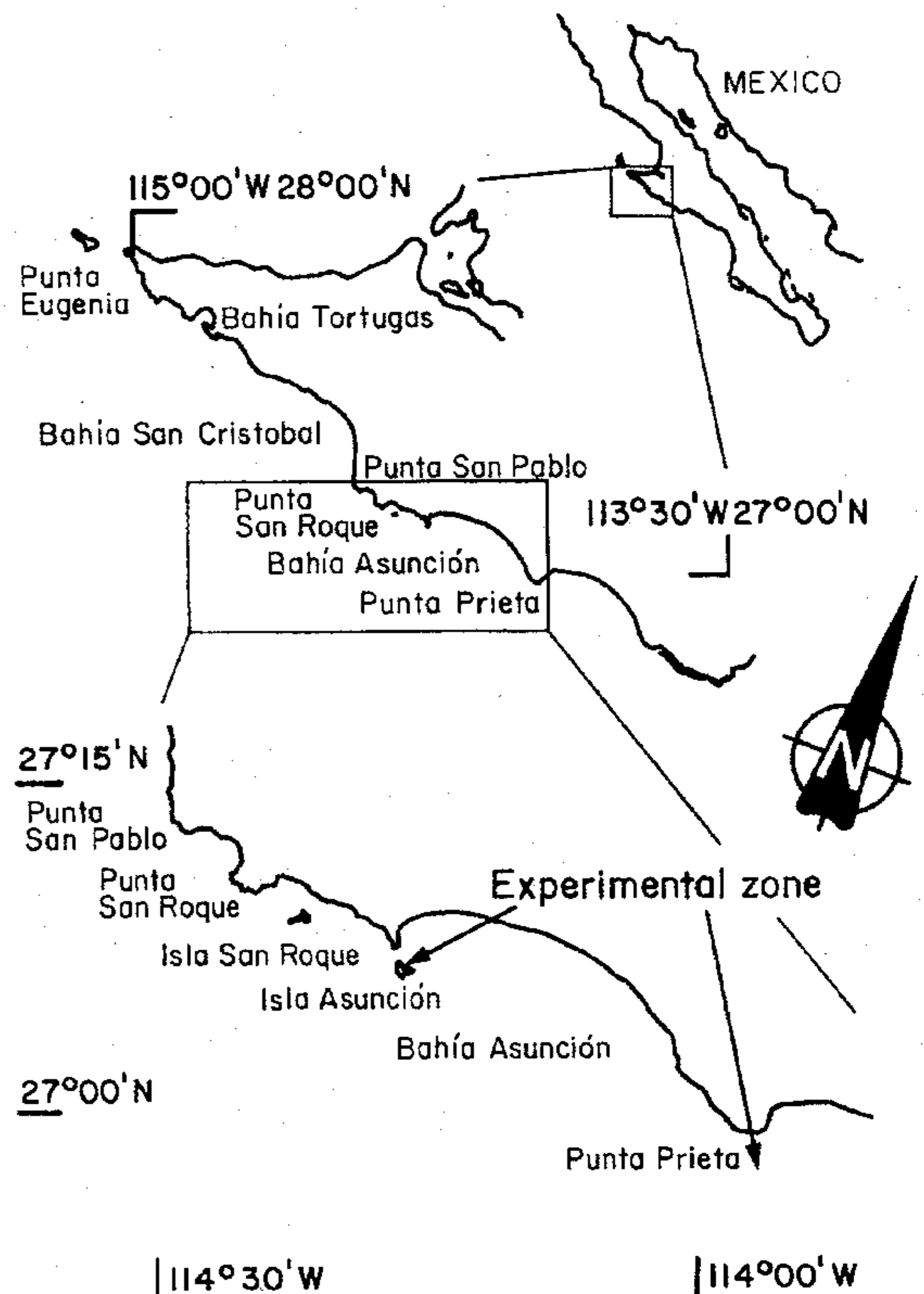


Fig. 1. *Macrocystis pyrifera* restoration area at southern Baja California using juvenile transplants (Isla Asunción) and seeding experiments (Isla Asunción and Punta Prieta).

ary – 6 March); spring 1988 (15–24 June); summer 1988 (11–22 September); winter 1988–89 (7–20 January) and spring 1989 (15–22 April).

The transplant site at Isla Asunción was delimited with a nylon rope into a $20 \times 20 \text{ m}^2$ quadrat and marked at the surface with buoys. *Eisenia arborea* was cleared by cutting the stipe near the base, leaving short stumps ($\sim 20 \text{ cm}$) which were used to anchor *Macrocystis pyrifera* sporophytes. A systematic sampling of *Eisenia arborea* was done during the cutting to estimate the density (plants m^{-2}). Two 25 m transects were used in a cross pattern in the quadrat delimited, one parallel to the coast and the other perpendicular to the coast, and *E. arborea* counted in every other square meter along the transect. To determine average weight and length, 18 plants were collected seasonally.

Healthy sporophytes of *Macrocystis pyrifera* were collected from the nearest kelp forest at Punta San Pablo and Punta San Roque, B. C. S. (Fig. 1). The intact plants, including holdfast, were removed from the bottom by hand, placed in sacks for transport to the boat, and transported in black bags inside an insulated box with ice to the transplant site.

The *Macrocystis pyrifera* plants were anchored to the *Eisenia arborea* stumps within two days of collection, using the technique described by McPeak (1977): briefly, the holdfasts of *Macrocystis pyrifera* were tied to *Eisenia arborea* stumps with thick rubber bands, first beneath and then over the top portion of the *Macrocystis pyrifera* holdfast and firmly holding the holdfast to the substrate to ensure rapid attachment. Individual plants and fronds on plants were tagged with numbered plastic rings (method described in Hernández-Carmona 1996) The surrounding area was used as control and observed to determine if natural recruitment occurred.

One new quadrat at the experimental site was used each season in order to detect seasonal variation in the response to the transplant. The number of juvenile plants transplanted varied depending on the availability of juvenile plants, environmental conditions and the effort of two divers, but it was at least 38 plants per season.

The success of the transplant technique was assessed in a number of ways. For each seasonal site, the average growth rate (cm day^{-1}) of transplanted *M. pyrifera* fronds was determined from measurements of 7 to 30 fronds randomly selected from among transplants. Generally one to two fronds per plant were tagged and measured seasonally. The collection area was used as a control, and 8 to 13 *M. pyrifera* fronds were tagged as described above and measured during the same period as the transplanted fronds. Multiple comparison among elevations and slopes was used to compare frond growth rates (Zar 1984). ANOVA was used to compare average growth rates among treatments and times, and post-hoc HSD Tukey analysis was used to detect differences

among seasons and controls (Zar 1984). After the first transplant, the percentage of survivors was calculated every season. Plant development was determined by computing the average increase in the number of basal fronds (one meter above the holdfast) and the average number of cutting level fronds (one meter below surface). The cutting level fronds refers to the usual depth for mechanical harvesting of *Macrocystis pyrifera*.

Seeding technique

This experiment began in April 1997, usually the best time to obtain fertile sporophylls, and ended in September 1997, when the El Niño conditions reached their maximum temperature. The effect of spore source, understory algae and *Eisenia arborea* on the *Macrocystis pyrifera* recruitment in Bahía Asunción were examined using a three factor orthogonal-block design, with two levels of each factor ($2 \times 2 \times 2$): with sporophylls ($\pm E. arborea$, \pm understory algae); without sporophylls ($\pm E. arborea$, \pm understory algae). Three blocks were used with one replicate of each combination of treatment levels in each block. Each combination of treatment levels (i. e. + sporophylls + *E. arborea* – understory algae; 8 total combinations) was 1 m^2 .

The entire area was devoid of giant kelp *M. pyrifera*, and *Eisenia arborea* plants were removed just above the holdfast with knife and understory algae were removed using a scraper and metallic brush.

Treatment level combinations were distributed at random in each block. Two experimental blocks were set up at Isla Asunción on April 1997, and one at Punta Prieta, in June 1997 (Fig. 1).

A concrete base ($56\text{W} \times 38\text{L} \times 12\text{H cm}$) with a cage-like small lobster trap with 2.5 cm mesh was placed in each treatment. For the treatments with sporophylls, at least 50 mature reproductive blades per quadrat were collected from adult *M. pyrifera* in the nearest kelp forests (between Punta San Roque and Punta San Pablo; Fig. 1) and placed in the cage. The sporophylls were transported to the experimental site in a wet, cool dark insulated box and placed in the cages according to treatment every month.

The number of *Macrocystis pyrifera* recruits was recorded in July, 1997. The term 'recruit' as used here is based on visual observation of macroscopic *M. pyrifera* (plants $> 0.7 \text{ cm}$ height) in the experimental quadrants. At this size, the single blade of these two species can be distinguished because *M. pyrifera* blade has a lighter greenish color and *Eisenia arborea* blade is dark brown and thicker.

No recruitment occurred in treatments without sporophylls. In addition, some treatments with sporophylls had very low or no recruitment. As a result, a parametric, blocked ANOVA could not be used for statistical analysis. Instead, a Kruskal-Wallis ANOVA test was used to detect significant difference

among treatments (Zar 1984), and a Wald-Wolfowitz run test (StatSoft 1995) was used to test differences between the treatments with sporophylls.

In order to compare *Eisenia arborea* density among years, a systematic sample was taken as described above (juvenile transplant experiment) and 18 plants were collected for weight and length measurements. ANOVA test was used to detect significant differences among seasons-years.

Environmental conditions

During both experiments oceanographic conditions were measured in the nearest kelp forest (control) and at the experimental sites. During the juvenile transplant experiment, surface and bottom water temperatures were recorded during each dive using a thermometer. A thermistor attached to the bottom (10 m depth) was used in the seeding experiment. Long-term sea surface temperature data from different years were used to compare among years. Nitrate ($\mu\text{g at L}^{-1}$) was determined from seawater samples collected seasonally from the surface and bottom. The samples were placed in high density polyethylene bottles (500 mL; pre-rinsed with 10% HCl, distilled water and with sampled seawater), frozen, transported to the laboratory, and analyzed for nitrate concentration using the cadmium reduction technique (Strickland and Parson 1972). During the seeding experiment stipes and blades of ~10–25 plants of *Eisenia arborea* and *Macrocystis pyrifera* were analyzed for nitrogen content using a CHN analyzer as an indicator of nitrogen in the environment. The samples were collected every month from the sporophyll collection sites and the experimental site, dried and ground prior to analysis. Variation among plants was assessed by analyzing tissue from 4 plants. The standard error was lower than 0.07%.

Results

Environmental conditions

In the period 1988–89, the minimum recorded temperatures in Isla Asunción occurred in spring, 1988 (13°–13.5 °C). Temperatures increased rapidly to 22–24 °C in autumn, 1989 (Fig. 2 a). Surface and bottom temperatures were similar (largest difference was 1 °C in summer 1989). In the control area (Punta San Pablo and Punta San Roque) the trend was similar (Table I), but the temperature was lower in Punta San Roque during spring, 1988 (11.5 °C bottom), and the difference became more evident between surface and bottom especially in summer (3 °C). This trend continued for 1992–1997, with minimum temperatures in spring (March–June) and maximum in late summer and early autumn (July–October), however the difference among years varied markedly (Fig. 2 a,b). The lowest summer temperature (17.4 °C)

was recorded in September, 1988 associated with La Niña conditions. The highest Summer temperature (27.4 °C) was recorded in September, 1997 associated with El Niño conditions. Thermograph readings showed that during 1997 temperature increased rapidly from June, peaking in September. Incursions of relatively cold water were detected in July and

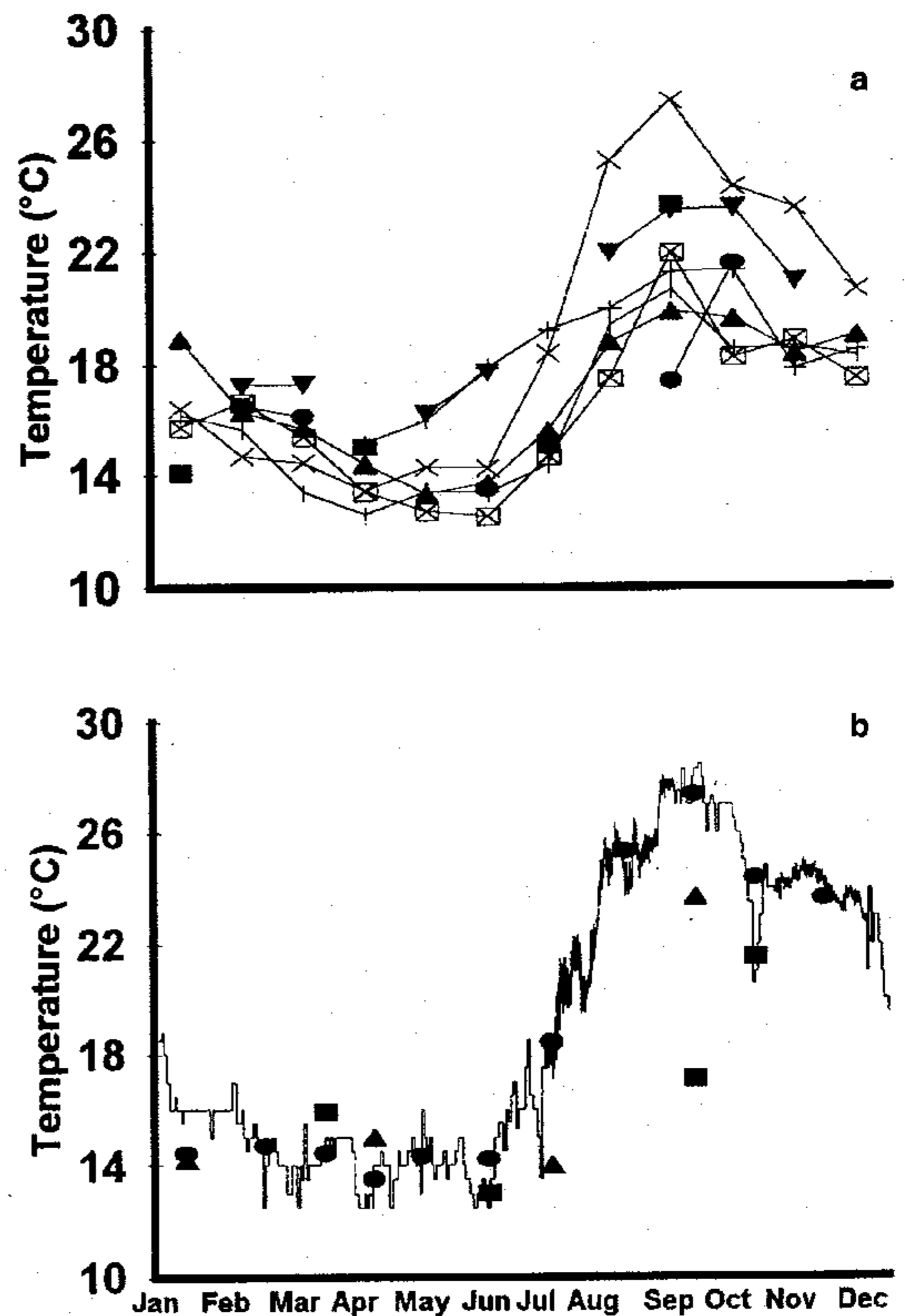


Fig. 2. a) monthly average surface seawater temperature at Bahía Asunción: ● 1988, ■ 1989, ▼ 1992, + 1993, ▲ 1994, ☐ 1995, | 1996, × 1997. b) bottom seawater temperature (10 m deep) at Isla Asunción, B. C. S. during 1988 (■), 1989 (▲) measured with thermometer, and 1997 (solid line) measured with a thermograph. Part of the graph was completed with bottom temperatures measured with thermometer. ● Average daily surface seawater temperature measured with thermometer.

Table I. Seawater temperature (°C) in the collection sites for transplanting experiment.

		P. San Pablo		P. San Roque	
		Surface	Bottom	Surface	Bottom
1988	Mar	16.8	16.7		
	Jun	14.5	14.5	13.1	11.5
	Sep	17.8	15	16.7	14.7
1989	Jan			14.4	14
	Sep			24	23.9

early autumn (Fig. 2b). However, these were not enough to reduce the temperature to 'normal values'. Without the two extreme years (1988 and 1997), the average maximum temperature for September was 21.8 °C, which might be considered 'normal'. Whereas the temperature in September 1997 was 5.6 °C above this normal value.

Nitrate concentration was inversely related to temperature, with high values in spring 1988 (4.5 μg at L^{-1}) and low values in summer (< 1 μg at L^{-1}) (Fig. 3a). Nitrate concentrations decreased in 1989 and did not exceed 2.5 μg at L^{-1} . An indicator of environmental nutrient concentration for the 1997 experiment was the nitrogen tissue content (Fig. 3b). The nitrogen in *Macrocystis pyrifera* was high during spring, with a maximum in April (2.2%), and then declined rapidly in summer to 1.45%. In a period of one week in August, tissue nitrogen was reduced by 20% and then all the *M. pyrifera* in the area died. *Eisenia arborea* seems to have a lag time in the nitrogen content (Fig. 3b). Its maximum occurred in May (2.09%) and then declined constantly during the rest of the year, reaching a low in December (1.59%). As in the seawater, the trend was high nitrogen concentrations in spring and low in summer and autumn.

Eisenia arborea was one of the more abundant algae in these areas and reduces light at the bottom to

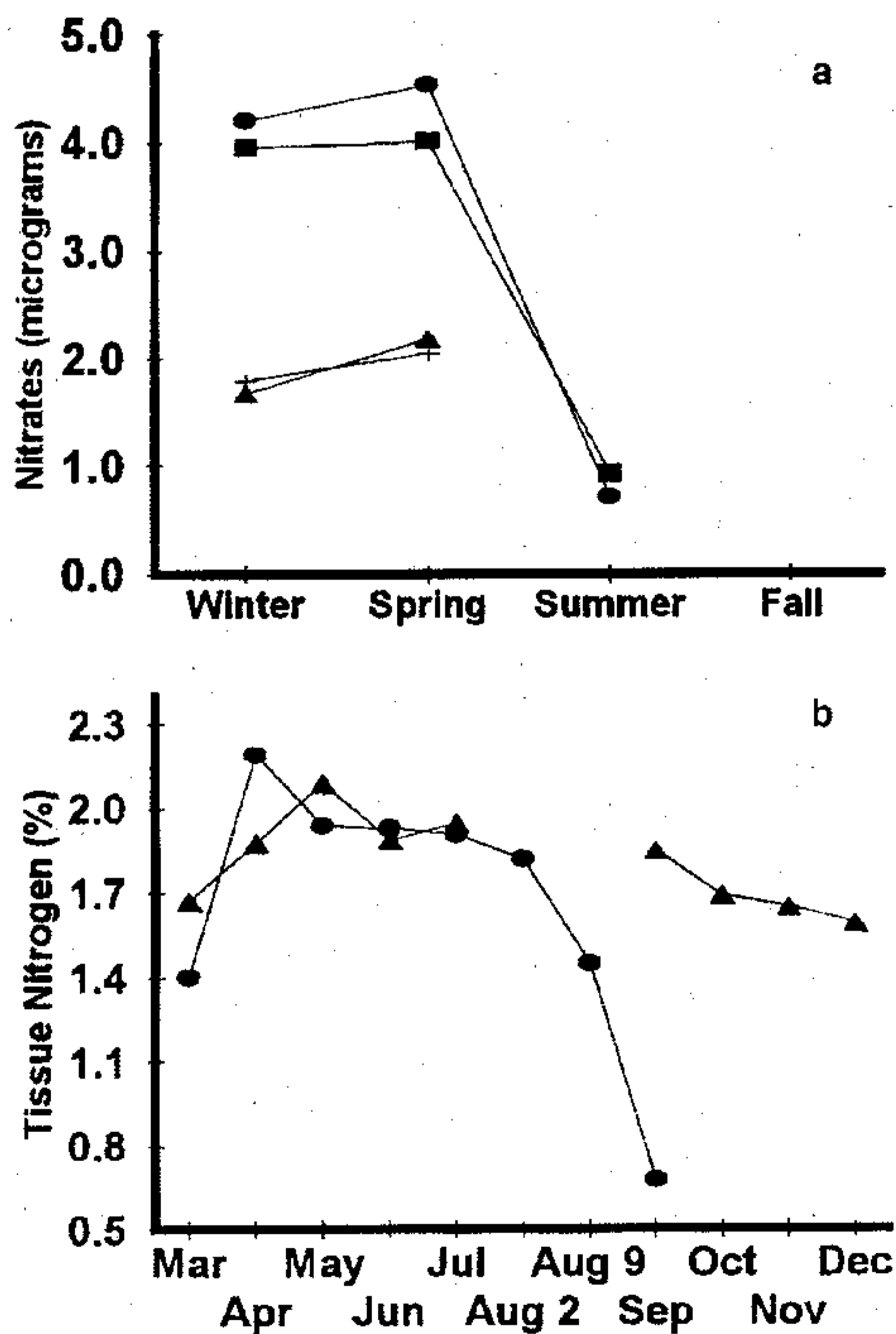


Fig. 3. a) Nitrate seawater concentration. Isla Asunción: ■ 1988 surface, ● 1988 bottom, ▲ 1989 surface, + 1989 bottom. b) Algal tissue nitrogen content from Isla Asunción, B. C. S during 1997: ● *Macrocystis pyrifera*, ▲ *Eisenia arborea*.

a level that could prevent *Macrocystis pyrifera* recruitment. From 1988–1997 the average length of adults of this species ranged from 213 (summer, 1988) to 156 cm (winter, 1997) (Fig. 4a) and average weight ranged from 3,265 g (summer, 1988) to 1,183 g (winter 1997) (Fig. 4b). *Eisenia arborea* grew on Isla Asunción at a density of above 3 plants m^{-2} from winter 1987 to a maximum of 6.0 plants m^{-2} in spring 1988 (Fig. 4c). During the rest of 1988–1989 plant density was around 2.2–2.6 plants m^{-2} . During the 1997 El Niño, *E. arborea* density started at 6.6 plants m^{-2} in the summer and was reduced to 3.8 plants m^{-2} in winter with a significant reduction in weight, because of the lost of branches. The density in spring 1988 was not significantly different from spring 1997, but were significantly higher than those from summer 1988, 1989, and winter 1997 (ANOVA, $p < 0.05$; Tukey HSD tests).

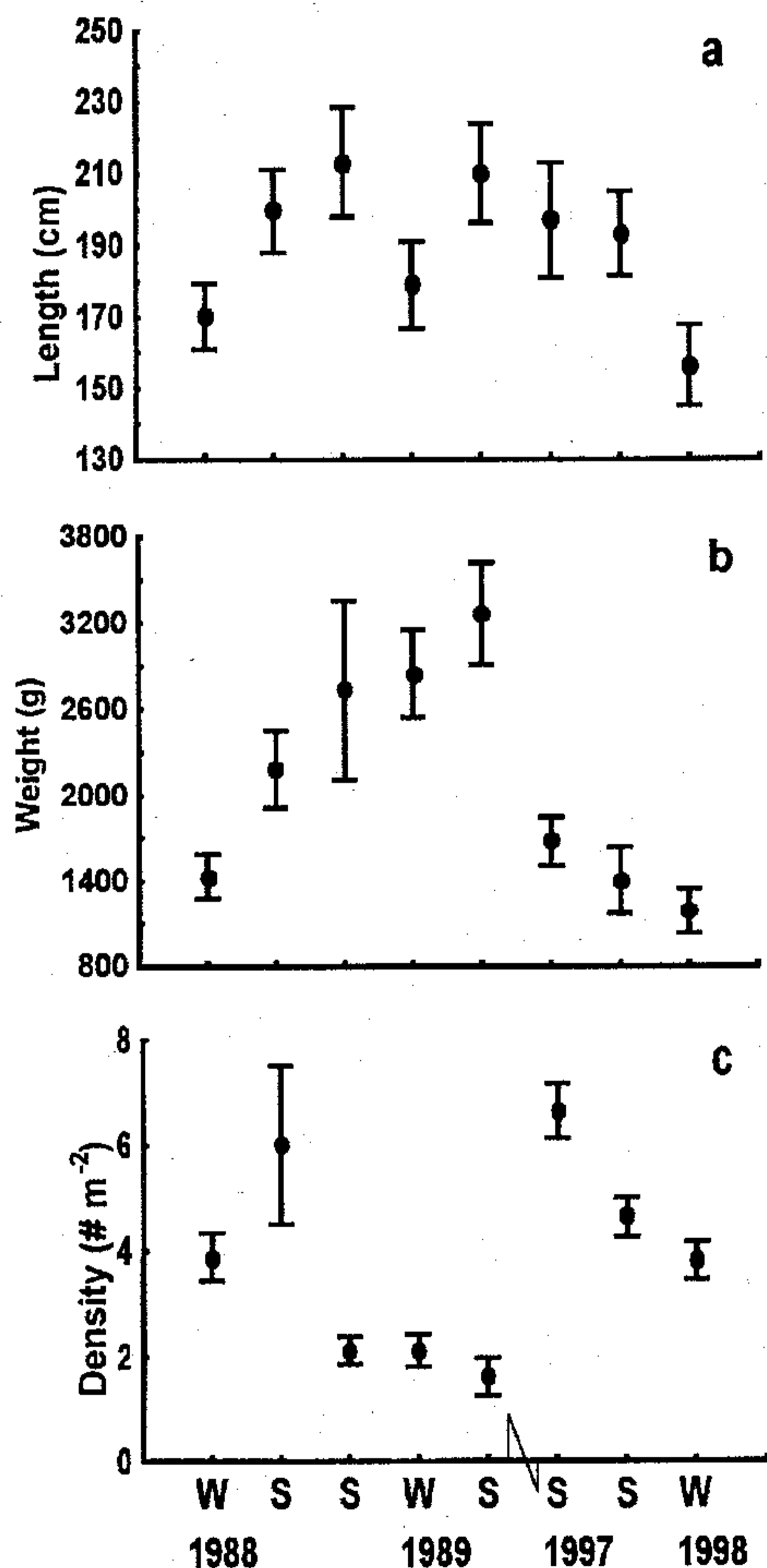


Fig. 4. Seasonal variation of average length a), weight b) and c) density of *Eisenia arborea* ($n = 18$) from Isla Asunción B. C. S. in winter, spring and summer 1988; winter and summer 1989; spring and summer 1997 and winter 1997–98. Jagged line to emphasize lack of data between 1989 and 1997.

understory algae alone (treatment II). Manipulation of the sea bottom by removing the understory algae also enhanced recruitment even when *E. arborea* was present (treatment III: without understory algae and with *E. arborea*). Finally, the modification of all the algae (treatment IV: without understory algae and without *E. arborea*) was not statistically different from the treatment III, but the highest number of

recruits occurred in this treatment. The largest recruit in the experimental quadrat was 70 cm long and the shortest was 0.75 cm.

Unfortunately the El Niño conditions, with strong swells, high temperature and low nutrients negatively affected the recruits, resulting in complete mortality by 9 August. It was thus not possible to follow the development of plants to the adult stage.

Table V. A. Experimental design: + = presence, - absence. B. Number and average length of *Macrocystis pyrifera* recruits in areas where sporophylls added. C. reallocation of data from the plants growing on the cage and the concrete base. Block 1 and 2 = I. Asuncion, Block 3 = Punta Prieta. Substratum = Location of plants. In one substratum one or two different size plants were observed.

A. Treatments.

	Treatments							
	I	II	III	IV	V	VI	VII	VIII
Sporophylls	+	+	+	+	-	-	-	-
<i>E. arborea</i>	+	-	+	-	+	-	+	-
Understory Algae	+	+	-	-	+	+	-	-

B. Data before reallocation.

Block	Substratum	Treatment I		Treatment II		Treatment III		Treatment IV	
		No. of Plants	Length (cm)	No. of Plants	Length (cm)	No. of Plants	Length (cm)	No. of Plants	Length (cm)
1	Bottom	0		0		0		13	9
	Cage	1	70	20	13	0		40	1
	Base	20	13	6	60	85	1	0	
		15	1	16	1			1	60
	Total	36		42		85		124	
2	Bottom	0		0		0		0	
	Cage	0		0		0		0	
	Base	0		28	0.75	14	0.75	50	1
	Total	0		28		14		50	
3	Bottom	0		1	22	10	1	0	
	Cage	0		6	1	0		0	
	Base	0		0		0		0	
	Total	0		7		10		0	

C. Data after reallocation.

Block 1	0	0	85	124	0	0	0	0
2	0	0	14	50	0	0	0	0
3	0	7	10	0	0	0	0	0
4			36	42				
5				28				
Average	0	2.3	36.3	48.8	0	0	0	0

Discussion

Juvenile transplant technique

During the 1982–83 El Niño, *Macrocystis pyrifera* kelp forests in much of California and all of Baja California were lost due to the combination of high temperature, low nutrients and storms (Zimmerman and Kremer 1984, Dayton and Tegner 1989, Foster and Schiel 1992). After three years, most of these forests had recovered to their former distribution, except in the area between Punta San Pablo and Punta Prieta, southern Baja California, where giant kelp did not return for five years.

Our results show that it was possible to restore a small kelp forest in southern Baja California. Successful recruitment indicates suitable environmental conditions for development of *Macrocystis pyrifera* sporophytes. No other forests were found near Isla Asunción, indicating that the recruits were produced by our experimental manipulation. Therefore, the lack of recovery in previous years, before our transplants, may have been due to the lack of spore sources for *M. pyrifera* to persist, as suggested by our seeding experiment.

It has been documented that survival of juvenile *Macrocystis* can be affected by algal competitors, such as species of *Laminaria*, *Pterygophora*, *Eisenia* and *Agarum*, which compete with *Macrocystis pyrifera* for light and substrate (McPeak 1981). Our results support the idea of a competitive substitution since *Eisenia arborea* populations were found at very high densities (6.0 plants m^{-2}) and average plant lengths of 213 cm were higher than the maximum length reported for this species (200 cm) (Abbott and Hollenberg 1976). In addition disturbances such as El Niño may cause clearance of kelp canopies due to the combination of high temperature, low nutrients and storms (Zimmerman and Kremer 1984, Dayton and Tegner 1989, Foster and Schiel 1992). Also, increases in understory algae, interspecific competition, and changes in grazing patterns, may result in between-area variation in recovery rates (Dayton *et al.* 1992, Foster and Schiel 1985, 1992). Schiel and Foster (1986) reviewed the structure of subtidal algal stands in temperate waters, and concluded that there are important effects among algal species. These effects are more pronounced between species of different canopy heights. The number of plants required to exert an effect increases as canopies (and plants) decrease in size. For example, a closed canopy of *Macrocystis pyrifera* at 1 plant per $10 m^{-2}$, may exert an effect similar to a *Pterygophora californica* Ruprecht canopy at 8 plants per m^2 (Dayton *et al.* 1984, Reed and Foster 1984).

Transplant success requires the study of the population dynamics over the time, however the response of the plants to the new environment is crucial, because the growth rate will determine the development of the transplants into adults that eventually will pro-

duce a new generation. In this regard, the initial response of the transplants indicates success as no significant differences in growth rate was found when compared to the control plants (except in winter 1988–89 when the plants were measured only one week after transplanting). The significant difference found in winter suggests a lag between transplantation and initial attachment. In all other seasons the plants quickly reached high growth rates similar to the average growth rate described for the Bahía Tortugas kelp forests (from $12.8 cm day^{-1}$ in summer to $20.8 cm day^{-1}$ in winter) (Hernández-Carmona 1996). The years 1988–1989 were classified as La Niña years (Wolter and Timlin, 1998) which are characterized by relatively high nutrients conditions, and this may have help support the high growth rates in the transplants.

Growth rates were highly variable within seasons in the transplant area. Statistically significance differences were not detected among the growth rates of fronds on transplants in different seasons in the same experimental area. However, there was a trend of higher growth rates during spring ($13.7 cm day^{-1}$) and low in summer ($8.1 cm day^{-1}$), this lack of significance is due to the high variability when frond growth rates are measured in the same giant kelp forest and it is considered normal (North 1971, Hernández-Carmona 1996). In the control area, where the transplants were collected there was a significant difference among seasons, with higher frond growth rates in winter ($13.3 cm day^{-1}$) and lower rates in summer ($4.4 cm day^{-1}$). The high winter-spring and lower summer growth rates may have been related to the seasonal variation in temperature and nutrient concentration as described for southern California by Zimmerman and Kremer (1984, 1986).

In the area from Punta San Pablo to Punta San Roque, juvenile abundance is usually highest in spring and summer. In southern California *Macrocystis pyrifera* liberates spores throughout the year with peaks in spore production during the late spring and early summer and a smaller peak during the autumn months (McPeak 1981). Also, Reed and Foster (1984) reported substantial recruitment only in spring. Since the transplanting season did not have any significant effect on juvenile growth, this restoration technique is best used in spring and early summer, when juveniles are abundant. The presence of *Eisenia arborea* was an advantage because it supplied an appropriate substrate for attachment. Without this it would be necessary (and more difficult) to use artificial substrates or install structures on the bottom.

The survival rate of transplanted juvenile *Macrocystis pyrifera* was relatively low (7–10% during spring and summer). However, once these plants attached firmly to the bottom most of them survived and contributed to new recruitment after one year. With the effort of two divers it was possible to restore

a kelp forest of 1,875 m² in two years. A massive transplanting would be necessary to yield better results. As observed by Schiel and Foster (1992) an increase in fish, particularly *Oxyjulis californica* Günther (señorita), may have caused some damage as it fed on invertebrates on plants in the canopy-midwater zone. In the other hand, sea lions (*Zalophus californianus* Lesson) were occasionally observed biting and breaking *Macrocystis pyrifera* fronds. Nevertheless, these effects were never enough to destroy the new kelp bed formed, and should not discourage the use of this technique.

The labor cost with this technique should not be a problem in Baja California. Moreover, the fisheries cooperatives might become involved in massive transplants, since fisherman are very interested in restoring the kelp forests as a source of food for abalone. Suo *et al.* (1986) reported growing giant kelp on submerged floating ropes, and mention that after building a kelp forest of about 7000 m², the number of sea urchins increased 20 times, sea cucumbers 17 times and abalone 10 times, illustrating the potential ecological and economical importance of restoring the kelp forests. Considering the cost of these marine products, the kelp restoration cost should be worthwhile.

Seeding technique

The results from experimental seeding suggest *Macrocystis pyrifera* spore recruitment was inhibited by understory algae other than *Eisenia arborea*. This is evident from the higher recruitment observed in treatment III when compared to treatment II. Contrary to our expectations the effect of *E. arborea* on the recruitment process was minimum. This could be related to a density reduction by 42% after large ocean swells in the spring-summer of 1997. Kennelly (1987) found that on experimentally cleared substrata, turf algae can dominate and inhibit kelp recruitment until kelp encroached at the edges and developed a canopy, leading to the decline of turf species. Although, *Eisenia arborea* may have produced a reduction of light the movement of blades allows light penetration to the bottom. Many of the *Macrocystis pyrifera* sporophytes that recruited in the seeding experiment were growing on the vertical edges of the cement blocks, probably as a result of the water flow patterns (Foster 1975).

Although coralline algae were not quantitatively assessed, they were very abundant and may have inhibited recruitment of *M. pyrifera*. Dayton *et al.* (1984) found that turfs of articulated coralline algae preclude the recruitment of large brown algae. In the same regard, Reed and Foster (1984) found that a dense canopy of either *Macrocystis* or *Pterygophora* inhibited algal recruitment because of the reduction of irradiance, however, higher recruitment occurred in treatments where coralline algae were removed,

suggesting that coralline branches impede spore-fall, reduce irradiance to the substratum, or harbor micrograzers that ate recruits. From our observations small *M. pyrifera* sporophytes (< 10 cm) on coralline branches did not survive longer than a month. Moreover, we observed that coralline algal branches up to 15 cm long, where easily broken off the plant, especially in areas with frequent surge. Therefore it is likely that small *M. pyrifera* attached to such fronds were lost before developing a holdfast large enough to reach and attach to the bottom.

The largest plant growing in the experimental quadrat was 70 cm long and the shortest was 0.75 cm, indicating that our first recruits occurred in April, three months before the monitoring date (July) and recruitment continued until June. All plants started to degenerate in August and by September 1997 (when the El Niño conditions reached the maximum influence) all had died. This short period of recruitment was correlated with low temperatures and high nutrients, and degradation was clearly an effect of the 1997–98 El Niño. Tissue nitrogen of *Macrocystis pyrifera* and *Eisenia arborea* was a good indicator of environmental nitrate and showed a negative correlation with temperature. In Californian *Macrocystis* kelp forests, the quantity and quality of spore production tracks resource availability within and among years, and reproductive allocation and spore standing stock are negatively correlated with seawater temperature and positively correlated with the nitrogen content of adult plants (Reed *et al.* 1996).

In the coastal areas of southern California, the thermocline dropped below kelp forest depths as indicated by anomalously high bottom temperatures (> 16 °C) during late summer and autumn of 1983 and through most of 1984 (Dayton and Tegner 1989). It seems that warm water *per se* does not harm *Macrocystis* which may grow well even at 25 °C under nutrient sufficient conditions (Zimmerman and Kremer 1984). However, growth is limited when a high temperature (> 15 °C) is correlated with low nutrients, particularly nitrate (Jackson 1977, Gerard 1982, North *et al.* 1982, Zimmerman and Kremer 1984). The results obtained with the seeding technique suggest that under normal years (with the maximum temperature below 24 °C) this technique could be used to produce a successful recruitment in the study area. The disadvantage of having to repeat the spore release several times during the year (Schiel and Foster 1992) could be overcome if a recruitment window is selected for seeding. In Bahía Asunción, seeding results could be enhanced during spring by scraping the substrate to reduce understory algae.

In both techniques used to restore *Macrocystis pyrifera* at southern Baja California the cost-benefit is about the same. Two divers could collect and transplant about 400 juveniles in three days, yielding

40 adult plants (10%). This estimate is close to those mentioned by McPeak (1977), who estimated that six divers could collect and transplant 1,500 young plants to pre-cleared substrate in three days. With the seeding technique, two divers could collect and distribute enough sporophylls to seed 12 m² in three days, yielding 36–48 adult plants. If understory kelps like *Eisenia arborea* are too rare to provide attachments sites a combination of transplanting juveniles on artificial substrates as proposed by Barilotti *et al.* (1991) and seeding might be most successful. Such a combination would increase the chance of restoring the kelp forests.

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