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Effect of nutrient availability on understory algae during El Niño Southern Oscillation (ENSO) conditions in Central Pacific Baja California

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Abstract An experimental study of the effect of artificial nutrient supply on understory algae was made during 1997 El Niño Southern Oscillation (ENSO) at the Mexican Pacific coast of Baja California. Twelve quadrats of 1 m^2 were placed on the sea bed. Six quadrats were used as controls, and six were treatments with added artificial nutrients. Nutrients were supplied using polyvinyl chloride (PVC) pipes filled with slow-release inorganic fertilizer. The algae species composition and cover in each quadrat were estimated using the random point quadrat method. The percent of cover was tested using a multifactorial analysis of variance, and significant differences were obtained by post hoc Tukey's HSD test. The analysis was carried out annually, seasonally, and seasonal and monthly for each species. The seawater temperature was recorded, and compared with historical data. The bottom and surface seawater nitrate concentration were measured. Twenty-five species of macroalgae and one seagrass were identified. The most abundant species was *Corallina vancouveriensis* ($-N=19.8\%$ and $+N=26.6\%$ average cover). The other species had lower than 10% cover. Significant differences of species percent cover between experimental groups ($+N$ and $-N$) were detected in the annual analysis ($p=0.059$). Seasonal analysis did not showed significant differences for any season. Monthly analysis showed significant differences in average percent cover when nutrients were added in eight species in different months: *Bossiella orbigniana* (August); *Colpomenia sinuosa* (June); *Corallina officinalis* (August); *C. vancouveriensis* (June); *Dictyota flabellata* (September); *Eisenia arborea* (June); *Gracilaria marcialana* (June); *Macrocystis pyrifera* (October), and the seagrass *Phyllospadix torreyi* (September and December). In conclusion, not all seaweed species are sensitive to nutrient addition during the ENSO years. In this research, we found eight species and one seagrass that had a positive reaction to the nutrients during the most severe stage (summer) of the ENSO.

Keywords El Niño Southern Oscillation · Baja California Sur · Understory algae · Nutrients · Seawater temperature

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Introduction

Seaweed communities in rocky shores are strongly related to the physico-chemical condition of seawater and biological interactions between species (Bertness et al. 2000). Macroalgae growth is also related to light, temperature, salinity, and nutrient availability (Dean and Jacobsen 1984). Due to coastal development and sewage discharges, seaweed communities are often subject to increasing nutrient concentration (Palumbi 2003). Such anthropogenic nutrient increase often results in macroalgae blooms (Valiela et al. 1997; Lotze and Schramm 2000; McGlathery 2001; Piñon-Gimate et al. 2008) and similar effects have been reported for *Ulva* beds in naturally nutrient-enriched pristine zones (Pacheco-Ruíz et al. 2002). The effect of nutrient enrichment could affect the community as a whole or affect some species, such as dominant species (Palumbi 2003). Experimental manipulations of nutrient availability in rocky systems are not frequent (Guerry et al. 2009). Some researchers have documented important effects (Bosman et al. 1986; Diaz-Pulido and McCook 2005; Worm and Sommer 2000; Nielsen 2001; Kraufvelin et al. 2006), while others have seen little or no effect of enrichment (Wootton et al. 1996; Pfister and Van Alstyne 2003). The El Niño Southern Oscillation (ENSO) is associated to an anomalous increase of seawater temperature and a reduction of nutrient concentration (Hernández-Carmona et al. 2001). The disappearance of all (1982–1983) or part (1997–1998) of the *Macrocystis pyrifera* populations in the Baja California Peninsula in the Pacific Coast of Mexico was caused by the presence of the ENSO events (Ponce-Díaz et al. 2003). The effect of nutrient availability on *M. pyrifera* recruitment and survival of juvenile sporophytes was examined during the ENSO 1997–1998 off Baja California, Mexico, at the southern distribution limit of this species (Hernández-Carmona et al. 2001). Nitrate levels were inversely correlated with seawater temperature. When temperature was high, nutrients were low, and vice versa. Experimental seeding with sporophylls and fertilizing *M. pyrifera* plants produced successful recruitment during the ENSO, and survival of transplanted juveniles was higher when fertilized. The results indicate that nutrients directly affect recruitment and survival of giant kelp at its southern limit during the ENSO (Hernández-Carmona et al. 2001). However, little is known about the effect of nutrients on other understory species living in the same area, which may be sensitive to nutrient effects during the ENSO condition. The aim of this research was to assess the effect of artificial nutrient supply on understory algae and seagrass, during one of the strongest ENSO (1998) in the central Baja California Pacific coast.

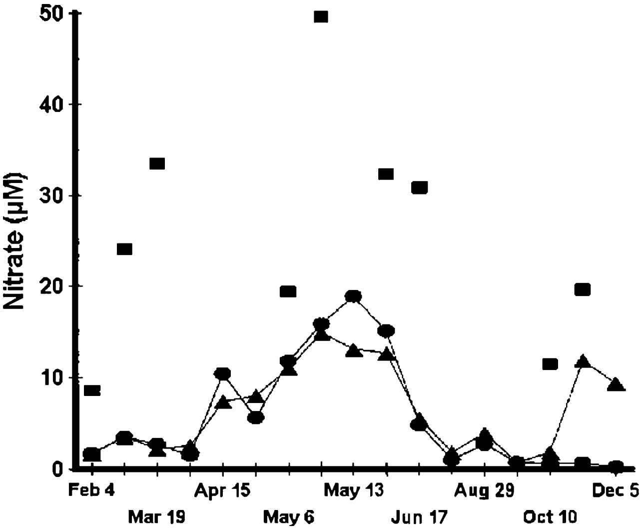

Fig. 1 Nitrate seawater concentration at Isla Asunción during the ENSO 1998: surface (*filled circles*), bottom (*filled triangles*), and bottom (10 m) fertilized area (*filled squares*)

Materials and methods

The experiment was carried out at Isla Asunción, Baja California Sur, Mexico (27°6′ N; 114°17′ W) at 10 m depth. For details of the location and simultaneous experiments carried out in the area, see Hernández-Carmona et al. (2001). To assess the effect of nutrient availability on understory algae, 12 quadrats of 1 m^2 were marked using a concrete base (56×36×12 cm), placed in the sea bottom

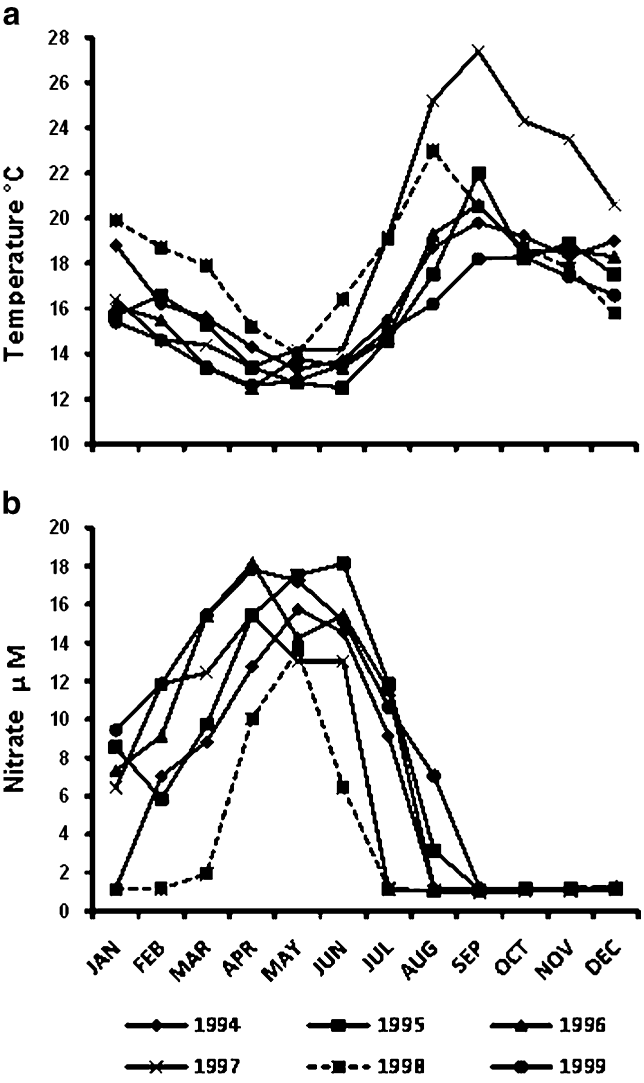

Fig. 2 **a** Average monthly of the sea bottom temperature at Bahía Asunción, B.C.S., México (1994–1999). Data were obtained from thermometer (1994–1996) and hobo sensor (1997–1999). **b** Nitrate concentration of the bottom sea water, estimated from the equations described for the area by Hernández-Carmona et al. (2001)

separated by 20 m. Six of the quadrats were selected at random as control plots, and the other six were treatments with added artificial nutrients. Nutrients were supplied using PVC pipes (15 cm diameter×40 cm long), drilled with 50 holes along the sides and also the caps. Pipes were filled with 8 kg slow-release inorganic fertilizer (Multicote™). Multicote contained a blend of ammonium nitrate, phosphate, and potassium salts (17% each). To maintain a constant supply of nutrients, two of these pipes were attached to the sides of each concrete base with two rubber bands, and refilled every month. Pipes filled with rocks were also attached to the control plots. The algae species composition and cover in each quadrat were estimated using the point quadrat method for subtidal sampling (Foster 1975). Ten random points (knots in a loose string tied to a PVC bar) were sampled in each quadrat. Each knot was pulled tight and pressed to the

Table 1 Average cover (%) of the species of macroalgae and one seagrass sampled in a control (without nutrients (−*N*)) and experimental (with nutrients added (+*N*)) quadrats in Isla Asunción, Baja California Sur, during the ENSO (1998)

Code	Species of macroalgae and one seagrass	Spring				Summer				Autumn				Significance
		May		Jun		Aug		Sep		Oct		Dec		
		−*N*	+*N*	−*N*	+*N*	−*N*	+*N*	−*N*	+*N*	−*N*	+*N*	−*N*	+*N*	*p*
1	*Amphiroa beauvoisii* Lamouroux *and Amphiroa misakiensis* Yendo	2	5	2	8	16	15	17	8	3	7	10	13	0.6216
2	*Bossiella orbigniana* (Decaisne) Silva	0	0	15	12	*0*	*8*	0	0	0	0	0	0	*0.0267*
3	*Botryocladia pseudodichotoma* (Farlow) Kylin	0	0	0	0	2	0	0	0	0	0	0	0	0.2518
4	*Callophyllis violacea* J. Agardh	0	0	0	0	0	2	0	0	0	0	0	0	0.4823
5	*Chondracanthus canaliculatus* (Harvey) Guiry=*Gigartina canaliculata* Harvey	0	0	0	0	0	0	2	2	1	5	0	0	0.7539
6	*Chondria nidifica* Harvey	10	20	15	3	*18*	*3*	0	0	0	0	0	0	*−0.0150*
7	*Codium cuneatum* Setchell & Gardner	0	0	0	0	0	0	2	5	4	2	0	0	0.7621
8	*Colpomenia sinuosa* (Mertens ex Roth) Derbès & Solier	7	3	*2*	*13*	0	0	0	0	0	0	0	0	*0.0017*
9	Corallines non-geniculated	7	8	20	8	6	3	12	3	4	5	5	5	0.1855
10	*Corallina officinalis* var. *chilensis* (Decaisne) Kützing	0	0	0	2	*2*	*13*	9	1	0	0	0	0	*0.0006*
11	*Corallina vancouveriensis* Yendo	43	35	*7*	*36*	15	28	33	35	3	0	18	36	*0.0410*
12	*Cystoseira osmundacea* (Turner) J. Agardh	0	0	0	0	2	0	0	0	0	0	0	0	0.4374
13	*Dictyopteris undulata* Holmes	0	0	0	0	0	0	6	2	11	13	0	0	0.9656
14	*Dictyota flabellata* (Collins) Setchell & Gardner	7	10	3	5	10	2	*5*	*24*	0	6	0	0	*0.0095*
15	*Eisenia arborea* Areschoug	2	2	*2*	*15*	4	5	0	0	0	0	3	0	*0.0021*
16	*Galaxaura* sp.	0	0	2	0	0	0	0	0	0	0	0	0	0.4374
17	*Gelidium robustum* (Gardner) Hollenberg & Abbott	0	0	0	0	2	3	0	0	0	0	3	0	0.7600
18	*Gracilaria marcialana* Dawson	0	0	*0*	*3*	0	0	0	0	0	0	0	0	*0.0438*
19	*Iridaea lineare* (Setchell & Gardner) Kylin	0	0	*3*	*0*	0	0	0	0	0	0	0	0	*−0.0438*
20	*Macrocystis pyrifera* (Linnaeus) C. Agardh	0	2	0	0	0	0	4	7	*3*	*9*	0	0	*0.0392*
21	*Padina durvillaei* Bory	3	0	5	2	6	7	2	2	2	7	3	3	0.6600
22	*Peyssonnelia orientalis* (Weber-van Bosse) Cormaci & G. Furnari = *Peyssonnelia rubra* var. *orientalis* Weber-van Bosse	0	2	0	0	0	0	1	5	37	41	0	0	0.9888
23	*Phyllospadix torreyi* S. Wats	0	2	7	3	4	5	*2*	*11*	2	4	*5*	*14*	*0.0188*
24	*Plocamium cartilagineum* (Linnaeus) Dixon	3	3	0	0	0	0	0	0	11	0	0	0	0.0542
25	*Sargassum horridum* Setchell & Gardner	5	0	5	7	2	0	2	0	15	0	25	3	0.4953
26	*Ulva lactuca* Linnaeus	2	3	2	3	0	3	0	0	0	0	0	0	0.8424

$n=6$ quadrats per treatment. Entries in set in italics indicate significant statistical differences after multifactorial ANOVA substratum, and the algae in each point were recorded. The identification of the species was carried out using the appropriate taxonomic keys (Abbott and Hollenberg 1976; Riosmena-Rodríguez 1999). The scientific names were verified in ALGAEBASE web site, to consider any recent change on the species described (Guiry and Guiry 2010). Sampling was carried out during spring (May and June), summer (August and September), and autumn (October and December) during the ENSO conditions in 1998. Winter months (January–April) were not sampled, because ENSO conditions were not present yet. July and November were not sampled, because of bad weather conditions. Cover was computed as the average percent of each species in the six quadrats of $-N$ and $+N$ treatments for each sampling month. The statistical analysis was carried from the database (n= 1918) using a multifactorial ANOVA with Statistica 7 (StatSoft 2004): annually (cover as dependent variable and species and treatment as categorical predictor or factors), seasonally (cover as dependent variable and species, season, and treatment as categorical predictor or factors), and seasonally and monthly for each species (cover as dependent variable and season or month and treatment as predictor or factors). The last analysis was monthly (cover as dependent variable and month and treatment as predictor or factors). Post hoc Tukey's HSD test was used to detect specific significant variation by month. The results are discussed considering the functional form groups, including leathery, erect corallines, corticated, and foliose corticated species (Littler and Littler 1984; Steneck and Dethier 1994). Temperature was recorded using a Hobo (Onset) sensor during the studied year and was compared with historical temperature data (1994–1999) measured by thermometer. The correlation coefficient between the Hobo data and the data recorded daily within Bahía Asunción with thermometer was r=0.952 (n=704) (Ponce-Díaz et al. 2003). Bottom and surface seawater nitrate concentrations were analyzed in control quadrats and experimental quadrats using the cadmium reduction technique (Strickland and Parson 1972). Nitrate concentrations were also computed using the equations for the correlation temperature-nutrients, proposed by Hernández-Carmona et al. (2001) for the same area.

Results

Nutrients concentrations measured in fertilized quadrats were always higher (8.52 to 49.6 μM) compared with the control quadrats (1 to 19 μM) (Fig. 1). Minimum temperatures were recorded during spring (March–June) and maximum temperatures during summer (June–September). This trend was consistent during the study time period, but temperatures were significantly higher during the ENSO year (1997–1998) (Fig. 2a). Computed nitrates suggests low concentrations in winter (<3.5 μM), summer (<2.6 μM), and autumn (<0.65 μM) and substantially higher in spring (4.8–18.8 μM) (Fig. 2b).

Twenty-five species of macroalgae and one seagrass were collected during the study period (Table 1). The table also shows the annual average percentage cover of each species sampled in the control quadrats (without nutrients) and experimental quadrats (with nutrients added) and the p values obtained. The sum of percentages was generally less than 100% (87–98%), because the differences corresponded to the percentage of bare rock in the quadrats. In two cases, the percentage cover was higher than 100% (103% and 106%), which means that more than one species was found in the same point. The most abundant species was *Corallina vancouveriensis*. The bare rock and other seven species had an annual average cover higher than 5%: *Amphiroa beauvoisii*, *Chondria nidifica*, *Codium cuneatum*, *Dictyota flabellata*, *Peyssonnelia orientalis*, *Sargassum horridum*, and the seagrass *Phyllospadix torreyi*. Other species were lower than 5% in the annual average (Fig. 3).

The statistical analysis comparing the two experimental groups annually showed significant differences (p=0.0059). Seasonal analysis showed no significant effect (p=0.8775), neither the seasonal analysis by specie. Monthly analysis showed significant differences in average percent cover when nutrients were added in eight species in different months: *Bossiella orbigniana* (August, $-N$=0 and $+N$=8), *Colpomenia sinuosa* (June, $-N$=2 and $+N$=13), *Corallina officinalis* (August, $-N$=2 and $+N$=13), *C. vancouveriensis* (June, $-N$=7 and $+N$=36), *Dictyota flabellata* (September,

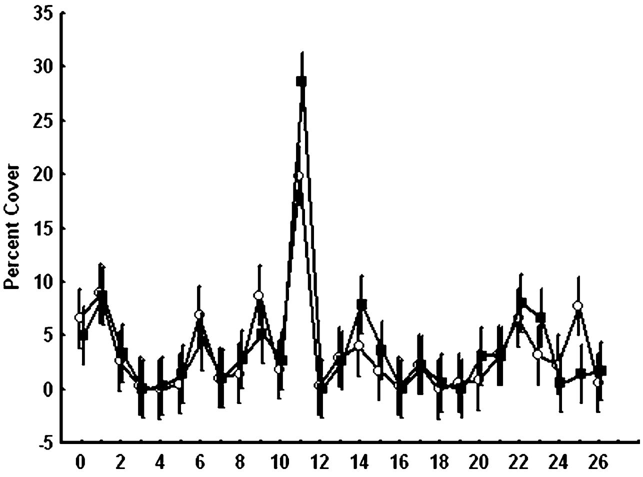

Fig. 3 Annual average cover (%) of the macroalgae and one seagrass in control quadrats without nutrients added (*filled squares*) and the experimental quadrats with nutrients added (*empty circles*). Isla Asunción, Baja California Sur, Mexico, during the ENSO (1988). The numbers in x-axis correspond to the species coded in Table 1. The zero corresponds to the percentage cover of bare rock

−*N*=5 and +*N*=24), *Eisenia arborea* (June, −*N*=2 and +*N*= 15), *Gracilaria marcialana* (June, −*N*=0 and +*N*=3), *M. pyrifera* (October, –*N*=3 and +*N*=9), and the seagrass *P. torreyi* (September, −*N*=2 and +*N*=11 and December, −*N*=5 and +*N*=14). Two species showed significant lower percentage cover ($p<0.05$) when artificial nutrients were supplied: *Chondria nidifica* (August, −*N*=18 and +*N*=3) and *Iridaea lineare* (June, −*N*=3 and +*N*=0) (Table 1; Figs. 4 and 5).

Discussion

Sea temperature clearly showed a seasonal cycle in which April and May had the lowest temperatures, whereas August, September, and October had the highest temperatures. The lowest temperatures in spring coincided with the upwelling phenomenon reported for the region, which results in nutrient enrichment of surface water (Walsh et al.

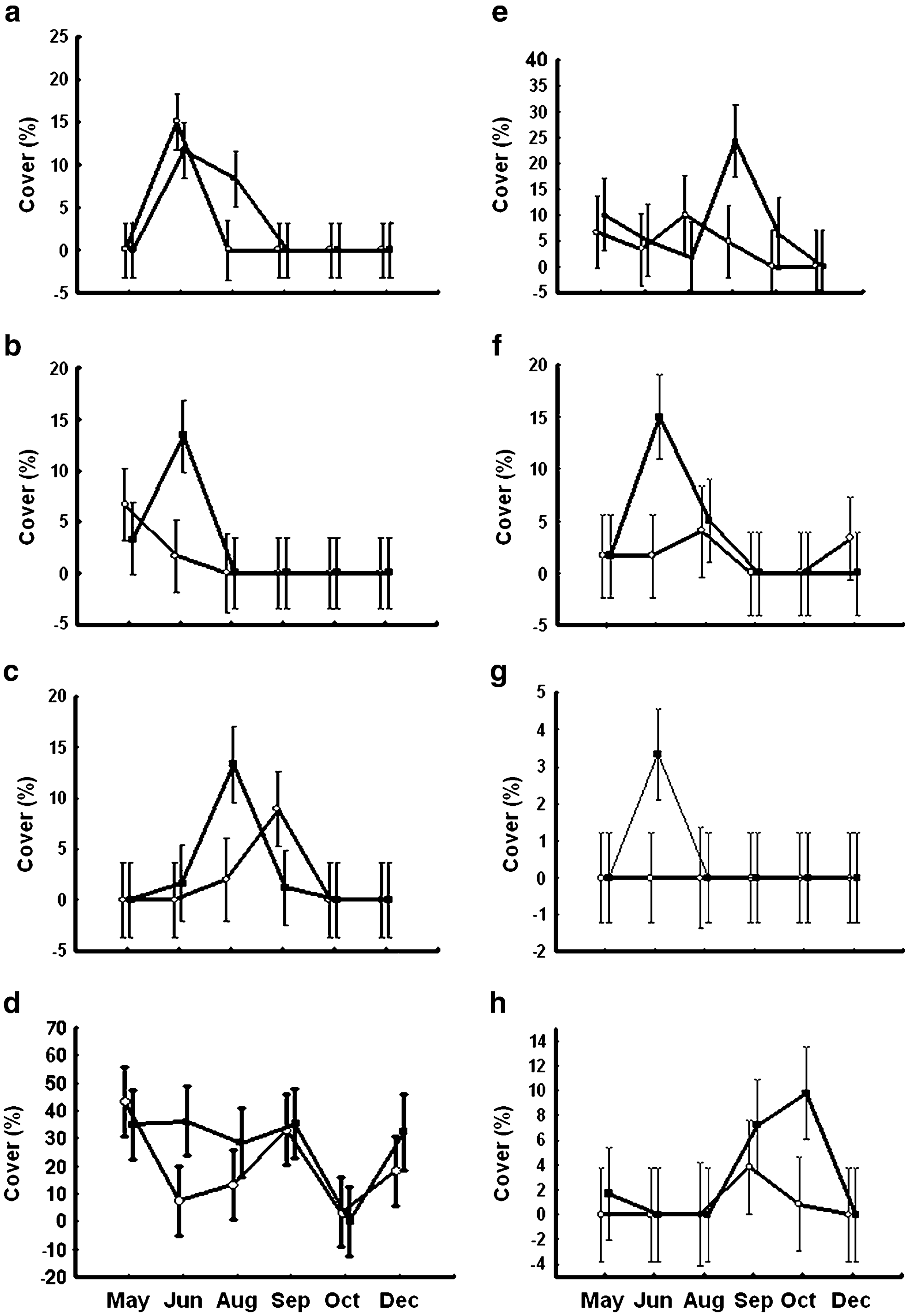

Fig. 4 Monthly variation of cover (%) of the macroalgae with significant effect ($p<0.05$) in control quadrats without nutrients added (*filled squares*) and the experimental quadrats with nutrients added (*empty circles*). Isla Asunción, Baja California Sur, Mexico, during the ENSO (1988). **a** *Bossiella orbigniana,* **b** *Colpomenia sinuosa*, **c** *Corallina officinalis* var. *chilensis*, **d** *Corallina vancouveriensis*, **e** *Dictyota flabellata*, **f** *Eisenia arbórea*, **g** *Gracilaria marcialana*, and **h** *Macrocystis pyrifera*

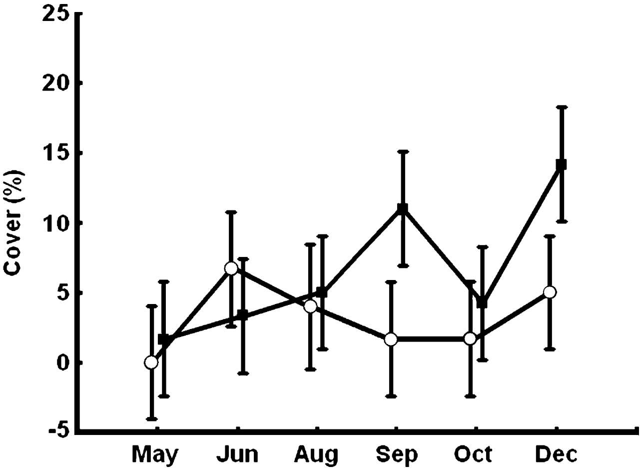

Fig. 5 Monthly variation of cover (%) of the Seagrass *Phyllospadix torreyi* with significant effect ($p<0.05$) in control quadrats without nutrients added (*filled squares*) and the experimental quadrats with nutrients added (*empty circles*). Isla Asunción, Baja California Sur, Mexico, during the ENSO (1988)

1974, 1977). A more detailed analysis of daily temperature carried out by Ponce-Díaz et al. (2003) for the same site and using 2000 as reference year shows a positive deviation during the 1997–1998 ENSO year, which was followed by a period of lower temperature. The same authors pointed out that the differences in the amplitude of the daily cycle were lower during the ENSO 1997–1998 than in any other period. Furthermore, during these years high temperature remained relatively constant as opposed to other years; also, there was greater variation in temperature towards winter. Nitrate concentration in control quadrats was relatively high in May (14 µM), and it was reduced drastically from June (1 µM) and remained in low concentrations until December (13 µM). Those concentrations indicate the presence of the ENSO with critical condition for the algal growth and survival from June to October.

The number of algal species found in this study (25) suggests that the total number of species may have been reduced because of the ENSO conditions, since previous studies mentioned a total number of 113 benthic algal species (Mateo-Cid and Mendoza-González 1994), although the sampling effort (six quadrats) was lower and only in subtidal level, and therefore the probability to collect all the species from the area was reduced. The annual analysis of algal species cover showed statistically significant differences ($p=0.059$), which indicate that in some species there was some effect of the nourishing treatment. Seasonal analysis did not detect any differences because the effect of treatment was short (1 or 2 months) and for unknown reason, the effect was not sustained for more than 1 month. Therefore, monthly analysis was more informative. During May, there was no significant ($p>0.05$) positive response in any of the algae species or the seagrass to artificial nutrients supply. This could be related to the relatively high nutrients concentration in the environment during spring. Therefore, in May the algae may not have yet been nutrient limited. Starting in summer, the ENSO arrived with high water temperature and low nutrient concentration. During the next summer months, sampled (June, August, and September) seven algal species and one seagrass presented significantly higher cover in nourished areas than the same species in the control quadrats. This suggests that those species had the ability to incorporate the nutrients and survive under stressing conditions. The nutrient-sensitive species were four brown algae (*C. sinuosa*, *D. flabellata*, *E. arborea*, and *M. pyrifera*), three red algae (*C. vancouveriensis*, *C. officinalis*, and *G. marcialana*), and one seagrass (*P. torreyi*). But no relation was found according to the taxonomic groups. Two species showed a significant negative effect (*C. nidifica* and *I. lineare*) during 1 month, but no published information is available about negative effects of nutrients on that species. When comparing the $+N$ versus $-N$ treatment, we found that in 35, the trend was to obtain a higher cover in quadrats with nutrients. This suggests that obtaining significant statistical differences for only ten may be due to a low number of replicates (quadrats). Nevertheless, one should not rule out those species that did not show significant differences that may be able to incorporate nutrients and survive during an ENSO. More research is needed to assure the effect of nutrients on those cases. The case of *M. pyrifera* is special, because at the time of the experiment, no adult plants were in the area. In a simultaneous experiment, we transplanted juveniles and sporophylls to the experimental quadrats, so the results come from the survivors and recruits obtained in the experiment. Nevertheless, the effect of nutrients was statistically significant (see details in Hernández-Carmona et al. 2001). The next analysis considers the functional form groups (Littler and Littler 1984; Steneck and Dethier 1994). The first functional group would be the leathery, heavily corticated species (*E. arborea* and *M. pyrifera*), of these, juvenile (Wheeler and North 1980) and adult (Jackson 1977; Gerard 1982; Zimmerman and Robertson 1985; Zimmerman and Kremer 1986) sporophytes of *M. pyrifera* are more affected during the ENSO by nutrient depletion than by high temperature, and they can survive if nutrients are supplied (Hernández-Carmona et al. 2001). That may be due to the intercellular connections between the inner cortical cells and medullary cells (North 1994) that allow the translocation of nutrients to different parts of the algae. In the case of *E. arborea*, a reduction of tissue nitrogen from 1.81% before the ENSO, to almost half during the ENSO (1.07%) has been demonstrated (Hernández-Carmona et al. 2001). The second functional form group would be erect coralline algae (*C. vancouver-*

iensis and *C. officinalis*). The former was always the more abundant species in this study, and was also favored by the nutrients supplied. These seaweeds adopt morphological features that maximize their fitness in a wide variety of habitats without being developmentally committed (Taylor and Hay 1986), even during the ENSO years with low nutrients concentration. The third group would be the corticated (*C. sinuosa*), corticated foliose (*D. flabellata*), and corticated macrophyte (*G. marcialana*). No published information is available to explain why these species are more sensitive to nitrate addition during the ENSO conditions; therefore more research is needed to understand why they are nutrients sensitive. Foliose algae such as *Ulva* or *Porphyra* that have high surface area volume ratios, and some of the highest half-saturation constants for *N* (Lobban and Harrison 1994) are thought to be the most likely to do better in nutrient-enriched conditions (Guerry et al. 2009), but in our experiment those forms did not show any positive reaction. It was documented that seagrasses like *Zostera marina* and *Ruppia maritima* respond positively when fertilized, especially to phosphate, and when they are isolated from other plants (Harlin and Thorne-Miller 1981). In our study area, *P. torreyi* was partially isolated from other algae, because there was a significant reduction (25) of the former number of species (113) found during no ENSO years (Mateo-Cid and Mendoza-González 1994).

In conclusion, not all seaweed species are sensitive to nutrient addition during the ENSO years, but at least eight of them and one seagrass had a positive reaction to the nutrients during the most severe stage (summer) of the phenomenon. For some of those species (kelps, coralline, and seagrass), a number of evidence exists that may explain physiological changes, but more research is needed to confirm and understand why other species can react positively to nutrients addition at the southern limit of kelp distribution in Baja California.

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