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Effects of El Niño on beds of *Ulva lactuca* along the northwest coast of the Gulf of California, Mexico

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RESUMEN

Se estudió el efecto de El Niño 1997-1998 sobre la biomasa y tamaño de los mantos de *Ulva lactuca* L. en la costa noroeste del Golfo de California, del lado opuesto al Canal de Ballenas. Las evaluaciones se realizaron en el mes de mayo (primavera) de 1998 y se compararon con años previos (mayo 1995, 1996 y 2000). La investigación muestra que El Niño 1997-1998 tuvo un efecto negativo sobre el área y biomasa de los mantos estudiados. El área se redujo en 70% y la biomasa en 80% respecto a años previos. Se detectó un recobro completo de estos mantos para el año 2000. Se estudió el crecimiento de esta alga bajo condiciones controladas de laboratorio, pero no se detectó un efecto significativo de la irradiancia sobre el crecimiento. Sin embargo, la temperatura afectó significativamente su crecimiento. A 18°C se detectó el óptimo crecimiento y temperaturas de 14°, 22° y 26°C lo redujeron. Temperaturas de 30°C fueron letales para *U. lactuca*.

PALABRAS CLAVE: *Ulva lactuca*, El Niño, Golfo de California, biomasa, mantos, macroalgas.

ABSTRACT

The effect of El Niño 1997-1998 on the biomass and size of beds of the green alga *Ulva lactuca* L., along the northwest coast of the Gulf of California across the Canal de Ballenas, was evaluated in May 1998 and compared with May 1995, 1996 and 2000. The El Niño event (97-98) had a significant negative effect on size and biomass. The percent cover area was reduced by 70%, and biomass by 80%, with respect to previous years. A complete recovery was observed in 2000. Growth of the algae was studied under controlled conditions in the laboratory. No significant effect of irradiance was detected, but temperature did have a significant effect on growth. Optimum growth was found at 18°C. Temperatures of 14°, 22° and 26°C caused reduced growth. A temperature of 30°C was lethal to *U. lactuca*.

KEY WORDS: *Ulva lactuca*, ENSO, Gulf of California, biomass, beds, seaweed.

INTRODUCTION

More than 50 economically important species of seaweeds exist in the Gulf of California (Pacheco-Ruíz and Zertuche-González, 1996). The green alga *Ulva lactuca* L., the brown alga *Sargassum johnstonii* Setch. and Gard., and the red alga, *Gracilariopsis longissima* (S. G. Gmelin) Steentoft, L. M. Irvine et Farnham and *Chondracanthus squarulosus* S. et G. Hughey, P. C. Silva et Hommersand, are present in sufficient biomass for commercial use (Pacheco-Ruíz and Zertuche González, 1999). Previous studies on seaweeds from the central Gulf of California have found a strong biomass variation, with maximum biomass in spring and almost complete disappearance by late summer. This variation in seaweed biomass has been related to the extreme conditions of temperature and nutrients in summer. During the spring, upwelling results in an increase in nutrients due to cold water (14°C) from the Canal de Ballenas into the bays where seaweeds grow (Álvarez-Borrego *et al.*,

1978, Pacheco-Ruíz *et al.*, 1999). In summer, biomass is reduced due to temperatures that exceed 30°C in the region (Zertuche-González, 1988, Pacheco-Ruíz, 2000), causing the death of most seaweeds. Dead algal fragments are washed ashore during late summer (Pacheco-Ruíz and Zertuche-González, 1999).

The effect of El Niño events on seaweed beds in an extreme climate such as the Gulf of California has not been previously evaluated. El Niño is an event which can cause higher than normal temperatures, a reduction in nutrients, and catastrophic storms (Dayton and Tegner, 1984, Lada *et al.*, 1999). On the Pacific Coast of California and Baja California, the influence of El Niño has been documented in kelp beds of the brown algae *Macrocystis pyrifera* (L.) C. Ag., causing a reduction of bed size and biomass with up to 100% reduction in some areas (North, 1971, Dayton and Tegner, 1984, Tegner and Dayton, 1991, Lada *et al.*, 1999). The aim of this study is to evaluate the seaweed biomass and bed

size of *U. lactuca* during El Niño 97-98 and compare it with previous and later years (Pacheco-Ruíz *et al.*, 2000). Additionally, in order to test for a possible effect due to increase in temperature during El Niño 97-98, plants were grown in the laboratory under a temperature gradient representing typical El Niño conditions.

STUDY AREA

The study area was located on the northwest coast of the Gulf of California between Bahía Guadalupe (29° 14' 32" N, 113° 38' 10" W) and Ensenada Las Palomas (28° 25'

50" N, 113° 52' 30" W), in front of Grandes Islas (Figure 1). The coastal region presents bays and coves with sandy substrate, where beds of *U. lactuca* are located (Norris, 1975). The NW area of this region is influenced by cold tidally upwelled water from the Canal de Ballenas (Bray and Robles, 1991) which contain a high concentration of nutrients (Álvarez-Borrego, 1983, Álvarez-Borrego *et al.*, 1978). The minimal temperatures occur during winter and spring (14-18°C) and the maximal in summer and fall (26-30°C) (Bray and Robles, 1991, Pacheco Ruíz *et al.*, 1991). The nutrients in summer and fall are low and sea surface temperature reach 31°C (Álvarez-Borrego, 1983, Álvarez-Borrego *et al.*, 1978).

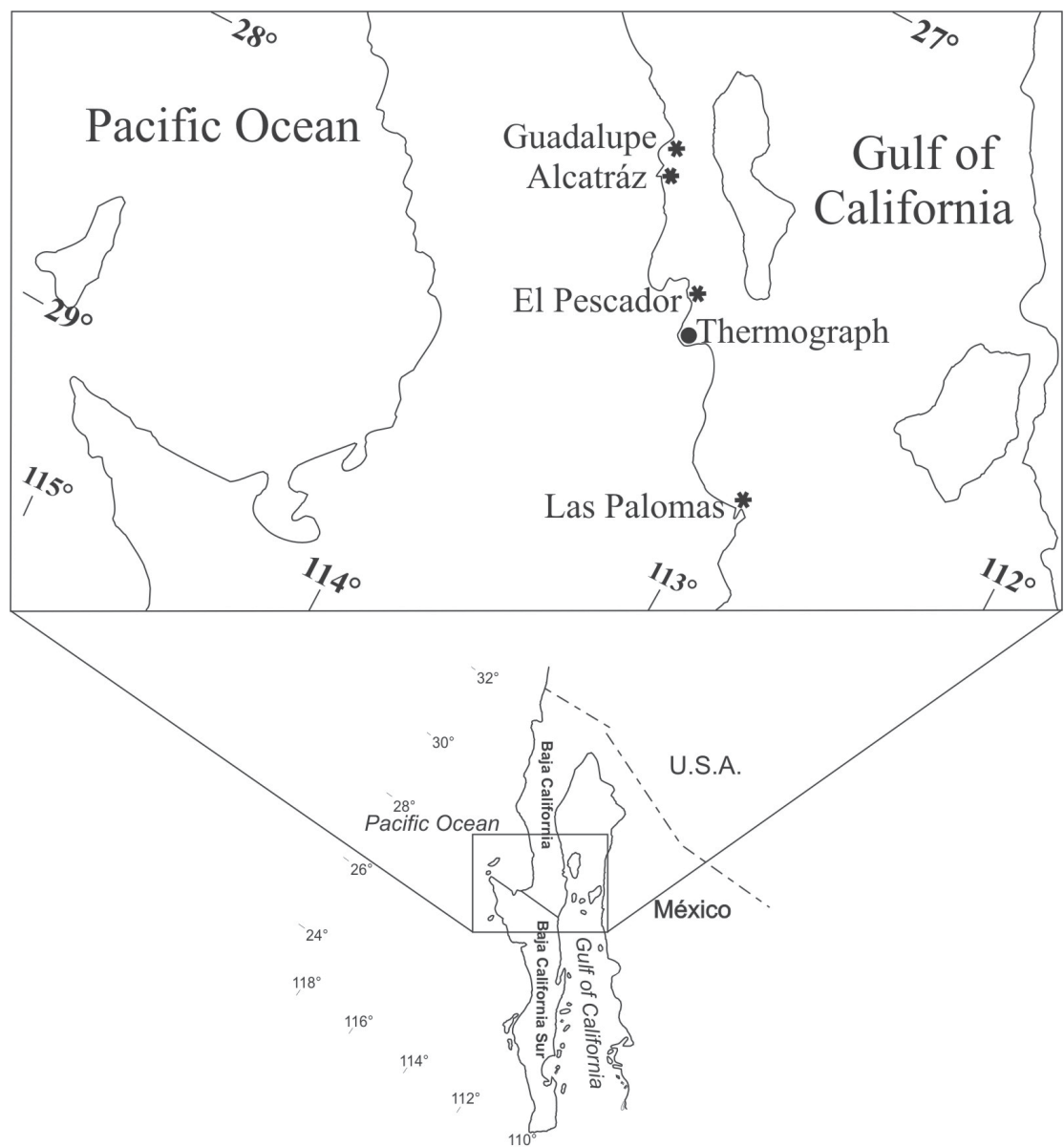


Fig. 1. Study site and *U. lactuca* beds localization.

MATERIALS AND METHODS

The beds of *U. lactuca* were evaluated in May when biomass and size were highest (Norris, 1975, Pacheco-Ruíz *et al.*, 2000). Seaweed biomass and bed size were determined using the methodology described in Pacheco-Ruíz *et al.* (1998, 1999), where a quadrat of 0.25 m² was used to estimate biomass. The number of samples required to achieve 15% error for each bed was calculated using the Downing and Anderson (1985) method. Thirty or more samples were performed randomly within the bed. Biomass (fresh weight) was recorded *in situ* using a dynamometer (500 g ± 10 g). Samples were taken to the laboratory and dried at 60 °C to constant weight to determine the dry:wet ratio.

Variance homogeneity and normality were calculated for all biomass data and compared using an ANOVA (Zar, 1997), at a significance level of $p = 0.05$ % and were reported as mean ± confidence interval of 95%.

At one of the intermediate bays (Bahía de las Ánimas) of the area sampled, a thermograph was installed at 4 m depth and recorded temperature every 2 hours for 15 months (Figures 1, 5).

During May 1998, *U. lactuca* plants were collected (n=6) randomly, placed in plastic bags with seawater and transported to the laboratory. From each plant, vegetative tissue was collected, cleaned of epiphytes, and placed in a

gradient table experimental design described by Lee and Brinkhuis (1988) to detect growth effect by difference between irradiances and temperature. Material was randomly divided into 20 petri dishes with 35 ml of seawater enriched with Provasoli's media. The tissue (3 g sample) was exposed to an irradiance of 5, 80, 160 and 320 $\mu\text{mol quanta m}^{-2} \text{s}^{-1}$ and 14, 18, 22, 26 and 30 °C, generating a factorial of 4x5. Cold fluorescent lights were used to provide a photoperiod of 12:12 (Light: Dark). Tissue was agitated three times a day and media was changed every three days. Growth (% day⁻¹) in wet weight of each dish was calculated after six weeks as:

$$GS = [\ln (w_f/w_i)/t] \cdot 100 \quad (1)$$

(where GS is specific growth rate per day, W_i initial wet weight in grams, w_f final wet weight and t days; De Boer *et al.*, 1978). A non-additivity test was applied to the growth results of *U. lactuca* (Winer *et al.*, 1991). Normality and homogeneity of variances were tested and then ANOVA without replicates (Zar, 1997) of 4X5 was performed to determine the effect of irradiance and temperature on growth at $p = 0.05$.

RESULTS

U. lactuca beds were concentrated on the West Coast just in front of the Great Islands, (Figure 1) at depths of 2-8 m on sandy bottom. The northern bed was at Bahía de Guadalupe and the southern bed at Ensenada Las Palomas in

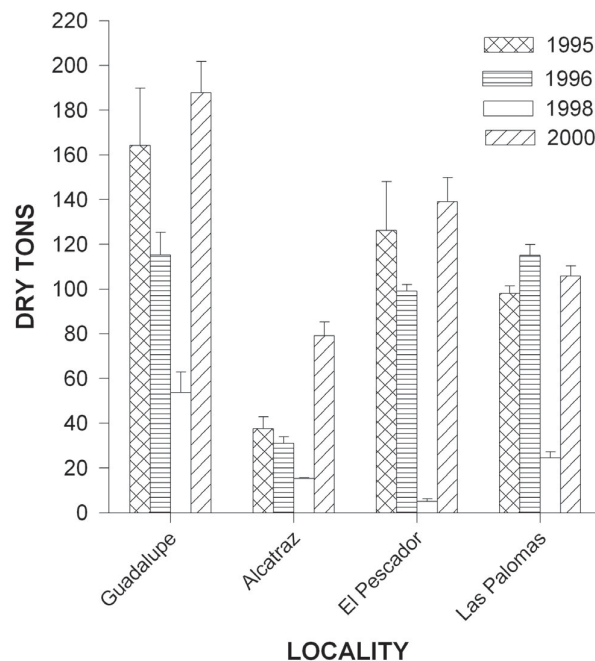


Fig. 2. Biomass of *U. lactuca*, in the different beds (\pm CI, $n \geq 30$).

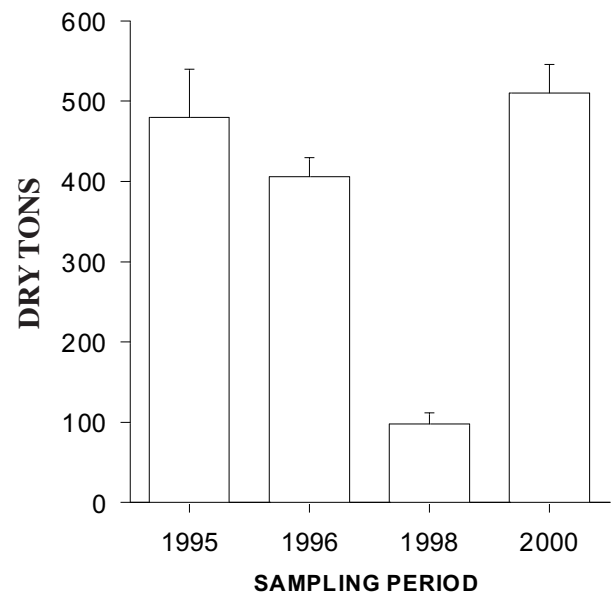


Fig. 3. Total biomass of *U. lactuca*, in the NW coast of California Gulf (\pm CI, $n \geq 150$).

San Francisquito (Figure 1). Total length of *U. lactuca* beds was about 12 km, covering an area of 2.2 km² (Table 1).

The area of the beds was reduced 64% during the El Niño event (149 vs 74 ha) when compared with 1995 and 1996. Maximum biomass measured in May 1998 was 77% less than May 1995 (99 vs 426 dry tons) and 73% less than 1996 (360 dry tons). In May 2000, a total biomass of 512 dry tons and an area of 118 ha were measured (Table 1, Figures 2, 3). No significant differences were found between previous years to El Niño related to the area (1995-96) ($p=0.7656$) or the biomass ($p=0.9164$). A significant difference was found between area ($p=0.00001$) and biomass ($p=0.00001$) between previous years to El Niño and the anomalous El Niño year. A difference was also found in area ($p=0.00001$) and biomass ($p=0.00001$) between May 2000 vs May 1998 and 1995. No significant differences were found between areas ($p=0.9531$) or biomass ($p=0.8345$) between May 2000 and May 1995. The ratio of wet to dry weight was 1:5.6.

No additivity was found in the laboratory growth experiments ($p=0.1563$) and data were normal and had homogeneous variances (Zar, 1997). The ANOVA without replicates did not determine any significant difference between irradiances ($p=0.0885$), but did detect an effect of tempera-

ture ($p = 0.00001$), and in this way the irradiances could be taken as replicates. The greatest growth ($\approx 80\%$ day⁻¹) occurred at 18°C. Lower (14.0 °C) and higher (>22.0 °C) temperatures inhibited growth (≈ 6.0 -4.0 % día⁻¹) and 30 °C was lethal for *U. lactuca* (Figure 4). Plants reproduced between 20 and 21 °C at an irradiance of 320 $\mu\text{mol quanta m}^{-2}\text{s}^{-1}$. The maximum temperature detected *in situ* was in September 1998 (31°C) and the minimum in February 1999 (13.5°C). A 2°C difference was found between March 1998 and 1999, with March 1998 being greater (Figure 5).

DISCUSSION

U. lactuca, along with the rest of seaweeds from the central region of the Gulf of California, shows a strong biomass seasonally (Norris, 1975, Littler and Littler, 1981). Most of the seaweed becomes loose and washes ashore during late Summer (Pacheco-Ruíz and Zertuche-González, 1999) when the water temperature reaches between 28 and 30°C (Zertuche-González, 1988, Pacheco Ruíz *et al.*, 1992).

U. lactuca grows well at 18°C, in nutrient rich environments (Neori *et al.*, 1991, Riccardi and Solidoro, 1996, Hernández *et al.*, 1997). El Niño causes higher temperatures and lower nutrient concentrations than normal, as well as

Table 1

General data of beds of *Ulva lactuca* in this study (\pm =Confidence interval 95%)

Name of region	Beds geographic distribution N and S limits	Sampling year (spring)	Length km	Width km	Area ha	Wet weight Kg m ⁻²	Wet tons	Dry tons
Bahía Guadalupe	29°14'32'' N	1995	5.62	0.12	67.4	1.4 \pm 0.2	938 \pm 147	164 \pm 26
	113°38'10'' W	1996	5.62	0.12	67.4	1.0 \pm 0.1	658 \pm 58	115 \pm 10
	29°12'11'' N	1998	3.56	0.05	18.0	1.70 \pm 0.3	307 \pm 52	54 \pm 9
	113°38'46'' W	2000	4.00	0.10	40.0	2.7 \pm 0.2	1 073 \pm 79	188 \pm 14
Bahía Alcatraz	29°09'57'' N	1995	2.15	0.08	17.2	1.2 \pm 0.2	215 \pm 30	38 \pm 5
	113°37'30'' W	1996	2.15	0.08	17.2	1.0 \pm 0.1	178 \pm 17	31 \pm 3
	29°09'42'' N	1998	3.40	0.08	27.0	0.3 \pm 0.01	87 \pm 1	15 \pm 0.3
	113°36'46'' W	2000	2.15	0.08	17.2	2.5 \pm 0.2	452 \pm 36	79 \pm 6
Ensenada El Pescador	28°55'58'' N	1995	2.52	0.20	50.4	1.4 \pm 0.3	721 \pm 125	126 \pm 22
	113°23'11'' W	1996	2.52	0.20	50.4	1.1 \pm 0.03	566 \pm 17	99 \pm 3
	28°55'01'' N	1998	0.50	0.05	23.0	1.3 \pm 0.3	29 \pm 7	5 \pm 1
	113°23'48'' W	2000	2.40	0.18	43.2	1.8 \pm 0.1	795 \pm 62	139 \pm 11
Ensenada Las Palomas	28°26'16'' N	1995	1.71	0.08	13.7	4.4 \pm 0.2	561 \pm 19	98 \pm 3
	113°52'49'' W	1996	1.71	0.08	13.7	5.1 \pm 0.2	657 \pm 29	115 \pm 5
	28°25'50'' N	1998	1.30	0.02	6.0	2.2 \pm 0.2	141 \pm 15	25 \pm 3
	113°52'30'' W	2000	1.71	0.10	17.1	3.5 \pm 0.1	601 \pm 25	106 \pm 5

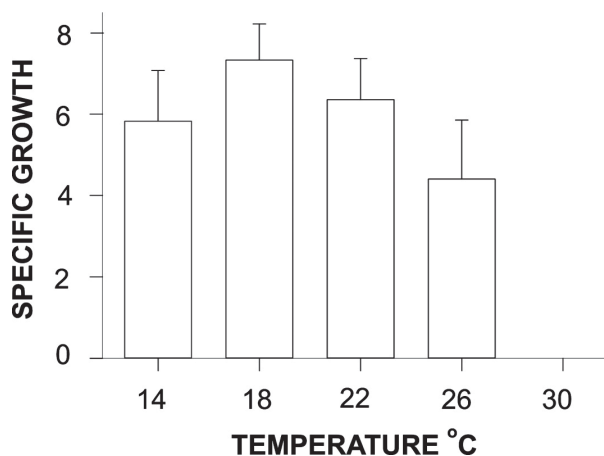


Fig. 4. Specific growth in *U. lactuca* exposed at different temperatures (\pm SE, $n=4$).

catastrophic storms (Dayton and Tegner, 1984). These changes in oceanographic conditions caused the reduction of *U. lactuca* in the Gulf of California. Similar effects have been reported in events of this type in *M. pyrifera* forests along the coasts of California and Baja California, attributed to the same climatic disturbances (Dayton and Tegner, 1984, Ladah *et al.*, 1999, Guzmán del Prío *et al.*, 2000).

U. lactuca presented a maximum biomass at the end of spring (May-June) concordant with that found by other researchers (Hernández *et al.*, 1997, Pacheco Ruíz *et al.*, 2000). However, the high temperatures of summer/fall ($\geq 30^{\circ}\text{C}$) in the Gulf of California were lethal for *U. lactuca* as shown in this study where temperatures higher than 26°C reduced growth or were lethal for this and other algae of the region. For this reason, many algae of the Gulf are considered annuals (Littler and Littler, 1981, Pacheco-Ruiz *et al.*, 1992, Espinoza-Ávalos, 1993). The common survival strategy of algae of this region is to reproduce before the high summer temperatures kill the tissue causing it to be deposited on the beach or remain as floating organic material (Pacheco-Ruiz *et al.*, 1998, 1999, Pacheco-Ruiz, 2000). The optimum temperature and irradiance for *U. lactuca* under controlled conditions were 18°C and $320 \mu\text{mol quanta m}^{-2} \text{s}^{-1}$, also concurring with other studies (Niesembaum, 1988). Therefore it is feasible that from March to June, 1997-98, the increase in temperature, the reduction in nutrients in the region (López-Cortés *et al.*, 2000) and hurricane Nora affected the reproduction (fecundity and fertility) of this algae. Niesembaum (1988) showed that negative changes in fecundity and fertility in *U. lactuca* can be seen directly as a reduction in the biomass produced in the area and in the productivity of the water column when reproduction is altered. In the majority of the beds, the biomass per unit area after the

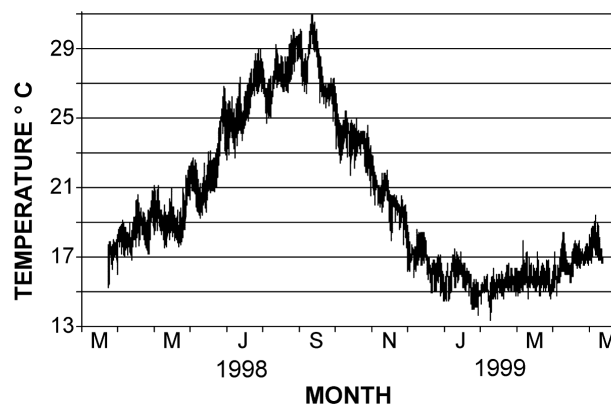


Fig. 5. Water temperature in Bahía de las Ánimas at 4 m depth.

event was reduced. This can be attributed to a reduction in the number of propagules released, high mortality, low recruitment, and/or low survival and growth of recruits due to the changes in the oceanographic conditions in the region.

Independently, the effect of the event is reflected directly in the reduction of area (64% less) and a production of $\approx 77\%$ less biomass than in normal years. However, sampling in May 2000 showed rapid recovery of the beds as oceanographic conditions returned to normal in the region. In this sense, the biomass variation observed in normal years (May 1995, 1996 and 2000), is attributed to interannual oscillations while the reduction in biomass and dimension of the bed areas in May 1998 were due to the presence of the El Niño event. Similar effects were detected in beds of *G. squarrulosus* from the region. Five beds evaluated during 1995-6, that showed a biomass of 4500 dry tons, were reduced to only one bed at "Las Animas" in 1998 with only 10 dry tons (Phykos S.A de C.V., personal communication), indicating that over 99% of the biomass of *G. squarrulosus* disappeared due to the effect of El Niño 1997-98 (Pacheco-Ruiz *et al.*, 1999, Phykos S.A de C.V., personal communication). This demonstrates the serious effect of El Niño in the algal beds of the Gulf of California and shows that it is necessary to take precautionary and preventive measures during future (e.g. no harvest in the area). The El Niño 1997-98 in particular, reduced the macroalgae fishery in more than 90% in the Gulf of California (Pacheco-Ruiz *et al.*, 2002).

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