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Normal, The Blob, and El Niño conditions: Effects on macroalgal blooms in a subtropical zone of the Gulf of California

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A B S T R A C T

The different oceanographic conditions influence marine ecosystems, particularly on macroalgae communities. For this reason, this study explored the effect of oceanographic events such as Normal Conditions, The Blob, and El Niño in the Southwest Gulf of California, in terms of species richness and biomass of macroalgal blooms. Temperatures in 2013 (Normal condition) were lower than in 2014–2015. The high temperatures recorded in 2014 (22.8 °C–32 °C) are associated with a warming phenomenon known as The Blob, whereas 2015 was an El Niño year. The anomalies in these two years ranged from 0.1 to 2.8 and from 0.3 to 1.7, respectively, relative to the average for 2002–2021. It was evident that the co-occurrence of The Blob and El Niño modified the patterns of species richness and abundance in the macroalgal blooms recorded in Bahía de La Paz, compared to a year under the Normal condition. The lowest species richness was observed in 2014. Regarding seasonal variability, in 2014 the highest species richness was recorded in spring and the maximum biomass in summer, contrary to what is generally the case in the bay. Species of tropical affinity such *as Spyridia filamentosa*, *Padina durvillei*, and *Caulerpa sertularioides* significantly increased their biomass in the El Niño year.

1. Introduction

“The Blob” was a warmer-than-usual (>4 °C) water mass that appeared in the Northeast Pacific ocean in 2013 and comprised three phases: Blob 1 emerged in autumn 2013 off the coast of Alaska and persisted for approximately eight months; Blob 2 started in spring 2014, spreading over the entire North Pacific into the Behring Sea, south to the Transition Zone and into offshore waters of the California Current until winter 2014, including the Baja California Peninsula and the Gulf of California; Blob 3 was recorded in March 2015 with markedly warm temperatures that stretched across the southern portion of the California Current System, including a large spot observed off the Baja California Peninsula and affecting the Gulf of California (Bond et al., 2015; Whitney, 2015; Peterson et al., 2015, 2016 a, b; Kintisch, 2015). In 2015, high temperatures were also associated with the presence of a strong El Niño (Jacox et al., 2016; Jiménez-Muñoz et al., 2016).

The northward displacement of tropical and subtropical species occurred from the effect of The Blob; this included fish (moonfish, swordfish, sunfish, skipjack tuna, sockeye salmon, pomfret, pompano), squids, thresher shark, sea mammals, and green and olive turtles (Bond et al., 2015; Peterson et al., 2015, 2016 a, b; Cavole et al., 2016). Particularly, The Blob carried to the Northern California Current a total of 18 species of warm-water copepods; harmful algal blooms proliferated across a broad area, affecting populations of razor clams and dungeness crab. Surface chlorophyll in the transition zone (TZ) of the eastern Pacific showed a marked reduction (Whitney, 2015). Also, The Blob and subsequent positive Pacific Decadal Oscillation (PDO) temperature patterns had many negative economic effects on various fisheries including squid, whiting, pink shrimp and salmon (Peterson et al., 2016a, 2016b). To date the effect of ecological disturbances on macroalgae blooms has not been reported.

The effects of other oceanographic conditions such as “El Niño” and “La Niña” on phytoplankton have been documented in the Gulf of California (GC) (e.g., Espinoza-Carreón and Valdez-Holguín, 2017; Herrera-Cervantes et al., 2010; Pérez-Arvizu et al., 2013). In relation to macroalgae, Scrosati (2001) studied the effect of El Niño (1998) – La Niña 1999 on the abundance of *Caulerpa sertularioides*. Carballo et al. (2002) analyzed the composition of macroalgae assemblages during and after the 1997–1998 El Niño; while Iglesias-Prieto et al. (2003) evaluated the effects of the 1997–1998 El Niño Southern Oscillation (ENSO) on GC reef communities, including the macroalgae community associated with coralline red algae mats. More recently, Elorriaga et al.

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(2016a, 2016b) documented the presence of Guadalupe fur seals and pygmy killer whales in south GC, beyond their typical distribution, which was attributed to the warm waters associated with The Blob. Jiménez-Quiroz et al. (2019) studied the variations in the structure and phenology of plankton communities in response to the 2015–2017 water warming events in the SW of the Baja California Peninsula. It is well known that macroalgae presence, distribution and abundance respond to seasonal fluctuations in the water column temperature, salinity and nutrients (Darley, 1982; Josselyn and West, 1985; Kentula and De Witt, 2003). However, to the best of our knowledge, no studies are currently available about the effect of The Blob effect on macroalgae in the Gulf of California.

Considering the impacts of oceanographic conditions on marine ecosystems, particularly on macroalgae communities, this study focused on the response in terms of species richness and biomass of macroalgae blooms to Normal, The Blob, and El Niño conditions in the southwestern portion of the Gulf of California.

2. Materials and methods

2.1. Study area

Macroalgae blooms were located at three sites in La Paz Bay, Baja California Sur, Mexico: 1) San Juan de la Costa (24° 21′ N, 110° 40′ W), 2) Casa del Marino (24° 10′ N, 110° 18′ W), and 3) El Tecolote (24° 20′N, 110° 18′ W) (Fig. 1). The area of each macroalgal bloom was measured and georeferenced with a GPS (Garmin, Ltd., Olathe, Kansas, USA). The surface area of each bloom was as follows: San Juan de la Costa: 3000 m^2, Casa del Marino: 10,000 m^2, and El Tecolote: 2000 m^2. In each locality, macroalgae samples were collected in winter, spring, summer, and autumn (February, May, July, and October) of 2013 (Normal Condition), 2014 (The Blob), and 2015 (El Niño); each locality was visited during low tide, and 36 sampling events were performed.

2.2. Sea surface temperature

Monthly sea surface temperature (SST) data were recorded across the water column at each sampling site, from January 2013 to December 2015; these were measured according to Chávez-Sánchez et al. (2017), as well as the National Oceanic and Atmospheric Administration (NOAA) remote satellite sensor databases (SST, Aqua MODIS, NPP, 0.0125°, West US, Day time (11 μm), 2002 - present (Monthly Composite), Lon ±18), for June 2002 to December 2021.

Anomalies (deviation from the mean value) of mean monthly temperatures for 2013, 2014, and 2015, relative to the average for 2002–2021, were calculated using the following equations:

$$A_{ij} = X_{ij} - \overline{X}$$

$$\overline{X} = \sum_{i=1}^{n} X_{ij} \Big/ n$$

where: A_{ij} = is the anomaly in the month i of year j; X_{ij} = temperature of the month i of year j; $\overline{X}$ = average temperature in the month i over n

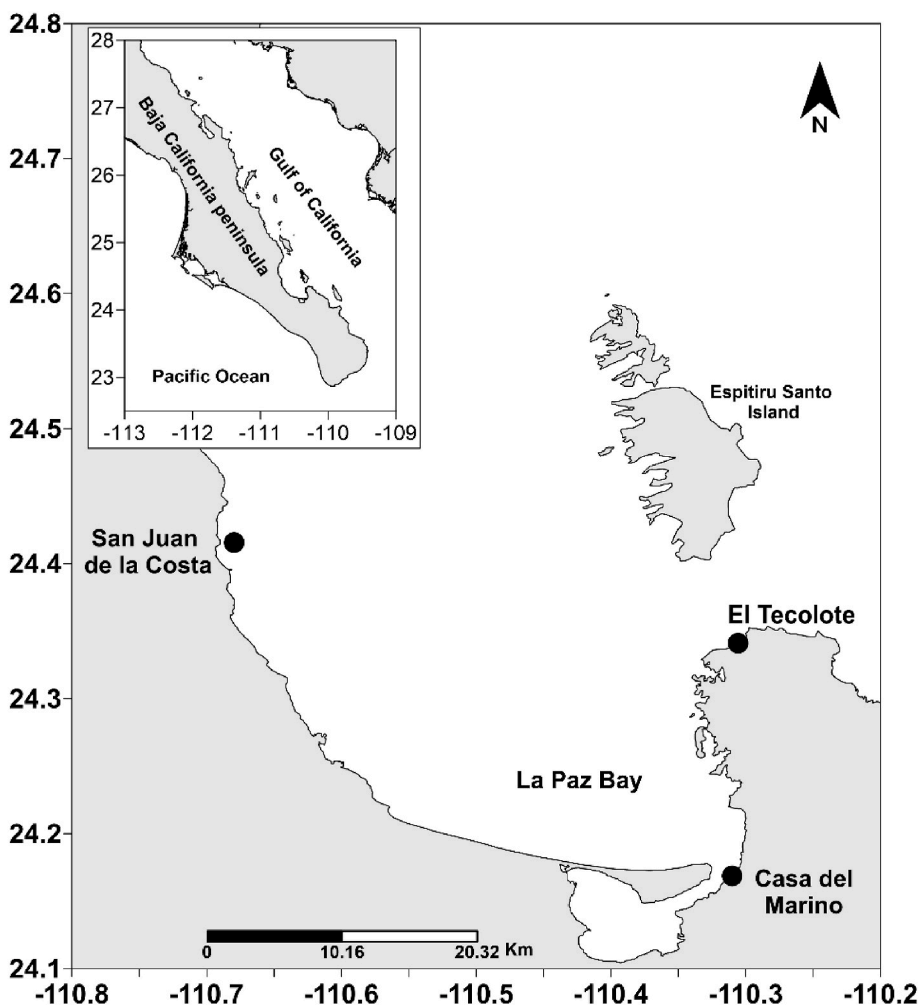

Fig. 1. Study area.

years.

Differences in monthly values for 2014 and 2015 were also calculated relative to 2013 values.

2.3. Specific richness

Specific richness was determined by counting the number of different species observed at a given season of the year or in a particular year, as applicable.

To calculate the percentage of algae by taxonomic Division for a given year, the total number of species recorded in that year was added up, and this value was considered as 100%. Then, we calculated the percentage corresponding to each Division, depending on the number of algae recorded (green, brown, red).

A macroalgal species observed in only one of the three years (2013, 2014, or 2015) was called unique species.

2.4. Biomass

The macroalgal biomass data were obtained according to Chávez-Sánchez et al. (2018): "three transects were laid out perpendicular to the shore line according to the length of each bloom mat and five equidistant points were defined for each transect. At each point all macroalgae were collected by free diving from four, non-overlapping, randomly placed quadrants (0.25 m^2)". The macroalgae were washed, the different morphotype were separate and weighed on an electronic scale with a precision of ±0.1 g. Species identification was carried out using the appropriate keys for the Gulf of California based on external and internal morphological anatomical characters (Abbot and Hollenberg, 1992; Guidone et al., 2013; Norris, 2010).

Biomass was analyzed using the following equations (Cruz-Ayala et al., 1998):

Mean Total Annual Biomass

$$MTAB = \sum_{j=1}^{S} MTBj$$

where: MTAB = Mean Total Annual Biomass, j = 1 to s number of species; MTBj = Mean Total Biomass of species j, s = species present.

Mean Seasonal Biomass

$$MTSB_k = \sum_{j=1}^{S} MSBjk$$

where: $MTSB_k$ = Mean Total Seasonal Biomass at season k; k = season 1 to 4; j = 1 to s number of species; MSB_{jk} = Mean Seasonal Biomass of species j.

For the specific biomass analysis, 17 species of macroalgae were selected based on the following criterion: mean biomass values higher than 1 g m^{-2} in any of the three years, for comparison.

2.5. Statistical analysis

Significant differences in SST, species richness, and biomass between the years of study (2013, 2014, and 2015) and seasons (winter, spring, summer, autumn) were established using one- and two-way analysis of variance (ANOVA) and post hoc Tukey's tests (α = 0.05). These analyses were performed after confirming the normality (Kolmogorov-Smirnov test) and homoscedasticity (Levine test) of the data using the software STATISTICA 10.0 (Statsoft, 2013).

3. Results

3.1. Sea surface temperature

The temperature recorded *in situ* throughout this study showed significant differences ($F_{(2, 105)} = 15,368$, $p < 0.05$) between years; the maximum temperature was recorded in 2014 and the minimum temperature in 2013 (Fig. 2a). In each of the three years of study, the SST showed a unimodal cycle, increasing from spring to peak in late summer and early autumn, and then decreasing significantly in winter ($F_{(3, 104)}$=35,057, $p < 0.05$); however, the magnitude of temperature in each season differed between years ($F_{(6.96)} = 9.8076$, $p < 0.05$). As shown in Fig. 2b, when the mean monthly surface temperatures from NOAA for the period 2002–2021 are compared with those for 2013, 2014, and 2015 included in this study, 2013 was the year with the lowest temperatures in all months: in 2013, temperature ranged from 20.4 °C to 29.1 °C; in 2014, from 21.1 °C to 30.6 °C; and in 2015, from 21.8 °C to 30.3 °C. The anomalies for these years ranged from −0.7 to 0.1, 0.1 to 2.8, and 0.3 to 1.7, respectively (Fig. 2c). A Hövmoller Diagram is also presented in order to observe changes in temperature in two decades (Fig. 3).

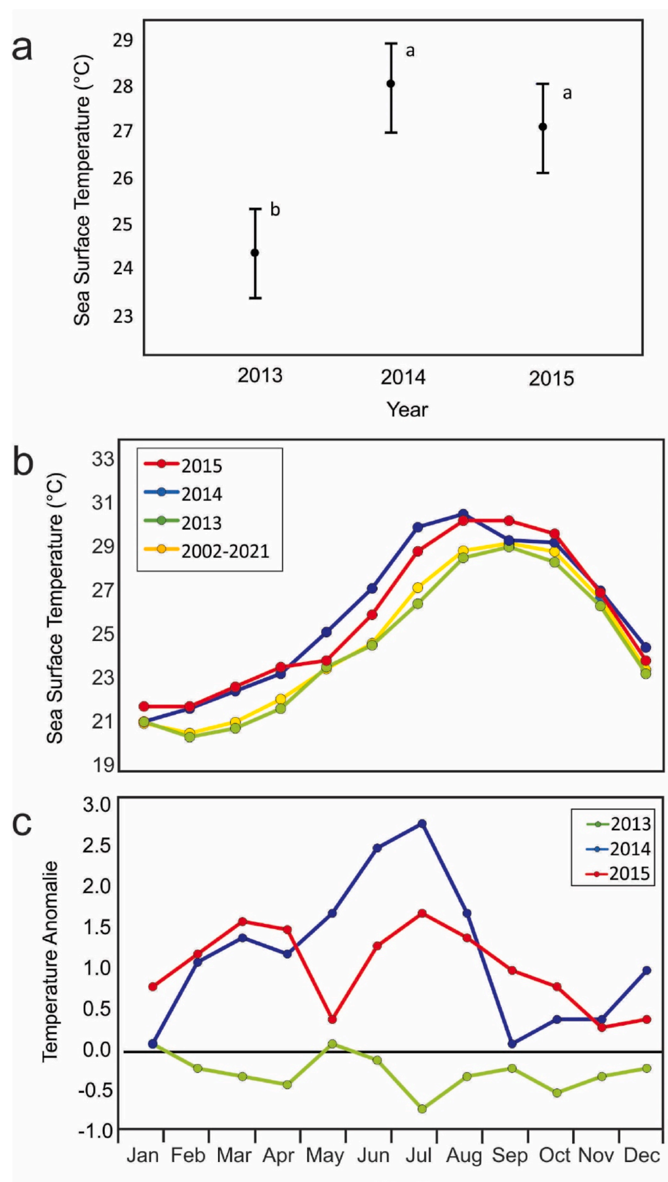

Fig. 2. Sea Surface Temperature (SST) for Bahía de La Paz, (a) *In-situ* observations from 2013 to 2015, (b) monthly temperatures obtained from satellite observations for 2013, 2014, and 2015, along with the average for the period 2002–2021, (c) anomalies in monthly SST with respect to the period 2002–2021.

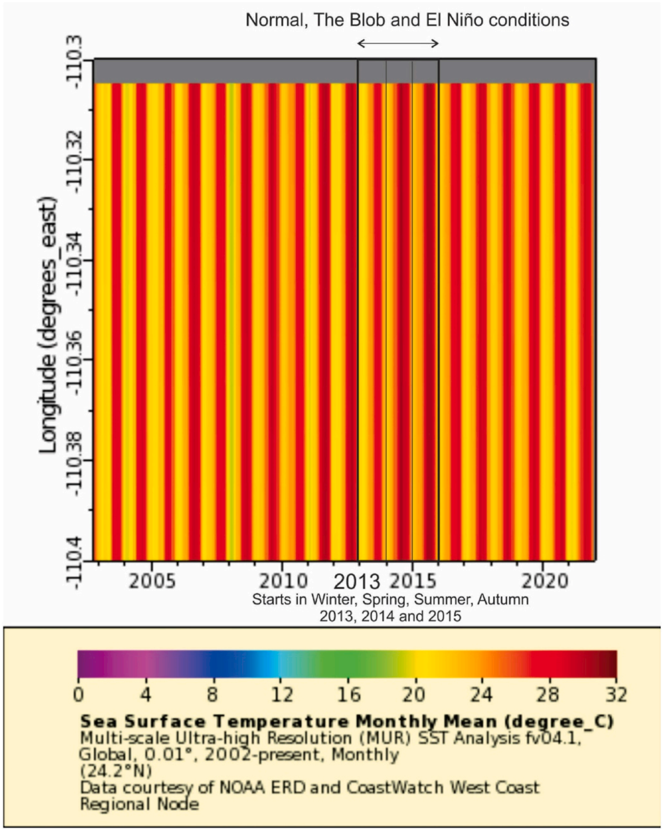

Fig. 3. Hövmoller Diagram, black lines represent the sampled years (2013, 2014 and 2015). Credits embedded in the figure.

3.2. Specific richness

A total of 56 species of macroalgae were identified in the algal blooms observed from 2013 to 2015: 31 belonging to the Division Rhodophyta, 11 to Ochrophyta, and 14 to Chlorophyta. The highest species richness was recorded in 2013 (46 species), decreasing by 27% in 2014 (33), and then increasing by 21% in 2015 (40) ($F_{(2, 30)} = 4.1051$, $p < 0.05$), relative to the previous year. The largest number of unique species occurred in 2015 (11), while 2014 recorded a single unique species. The percentage of green, brown, and red algae was similar in 2013 and 2014. In 2015, green and brown algae decreased by 44% and 39%, respectively, compared to the previous two years, whereas red algae recorded a 53% increase (Table 1).

Table 2 lists the macroalgae species that occurred in only one of the years under the Normal Condition (8), The Blob (1), and El Niño (11). To note, almost all of the species recorded in 2015 belong to the Division Rhodophyta.

With regards to the seasonal variation in species richness over the study period, this increased progressively from winter to spring to summer, then decreasing significantly during autumn ($F_{(3, 30)} = 5.2207$, $p < 0.05$) (Fig. 4). This same behavior was observed in 2013 and 2015; however, it was different in 2014, i.e., species richness increased significantly in spring and decreased at similar levels during the rest of the year ($F_{(6.24)} = 2.6115$, $p < 0.05$) (Fig. 5).

Table 1
Species richness, unique species, shared species, and annual percentage of algae by taxonomic Division in the macroalgal blooms in Bahía de La Paz, B.C.S.

	Normal 2013	The Blob 2014	El Niño 2015
Total no. of species	46	33	40
Unique species	8	1	11
% green algae	32.6	30.3	17.5
% brown algae	21.7	27.3	15
% red algae	45.6	42.4	67.5

Table 2
Unique species in years of Normal Condition (2013), The Blob (2014), and El Niño (2015) observed in the macroalgal blooms in Bahía de La Paz, B.C.S.

2013	2014	2015
Ulva tepida	*Ganonema farinosum*	*Cladophora microcladioides*
U. nematoidea		*Sargasum horridum*
Cladophoropsis sp.		*Centroceras clavelatum*
Sargassum spp.		*Corallina oficinalis*
Rosenvingea intricata		*Dasya pedicellata*
Digenea simplex		*Galaxaura ramulosa*
Hypnea cervicornis		*Gelidium crinale*
H. marchantae		*Gelidium* sp.
		Gracilaria vivesii
		Hypnea pannosa
		Laurencia panniculata

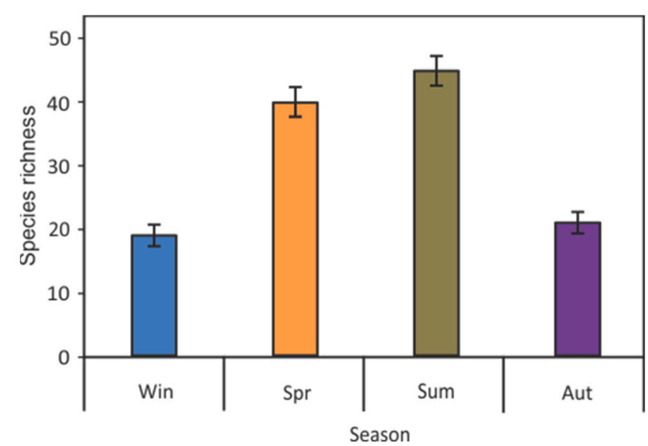

Fig. 4. Species richness in the different seasons of the year. Win = winter, Spr = spring, Sum = summer, and Aut = autumn, in the macroalgal blooms in Bahía de La Paz, B. C. S., over the study period.

3.3. Biomass

In Bahía de La Paz, the mean annual biomass of the species in macroalgae blooms decreased slightly from 2013 (236 g m^{-2}) to 2014 (215 g m^{-2}) and then increased in 2015 (295 g m^{-2}); however, these differences were not significant.

As regards the seasonality of biomass, a cycle is generally evident throughout the year. Biomass increased from winter (183 g m^{-2}) to spring, when it reached the peak value (475 g m^{-2}), then decreased in summer (283 g m^{-2}) and autumn (119 g m^{-2}) ($F_{(3, 404)} = 16{,}455$, $p < 0.05$) (Fig. 6). This same behavior was observed in 2013 and 2015; however, it was different in 2014, when the maximum biomass was recorded ($F_{(6.398)} = 4.3270$, $p > 0.05$) in summer, not in spring as in the other years studied (Fig. 7).

It was found that 17 species had mean total biomass exceeding 1 g m^{-2} in any of the years studied. Of these, eight species were in the Division Chlorophyta, 3 Ochrophyta, and 6 Rhodophyta. The species with the highest mean total biomass in macroalgae blooms in Bahía de La Paz were *Ulva ohnoi*, followed by *U. acanthophora*, *Spyridia filamentosa*, *Acanthophora spicifera*, *Gracilaria crispata*, *Sargassum sinicola,* and *Gracilaria pinnata.*

U. ohnoi showed the highest mean biomass in each of the three years of sampling, with 98 g m^{-2}; *U. acanthophora* also showed similar biomass in the three years, with 31 g m^{-2} in 2013, 26 g m^{-2} in 2014, and 36 g m^{-2} in 2015. The biomass of *S. filamentosa* increased significantly in 2014, to 16.3 g m^{-2} (138%), and in 2015 to 56.2 g m^{-2} (701%),

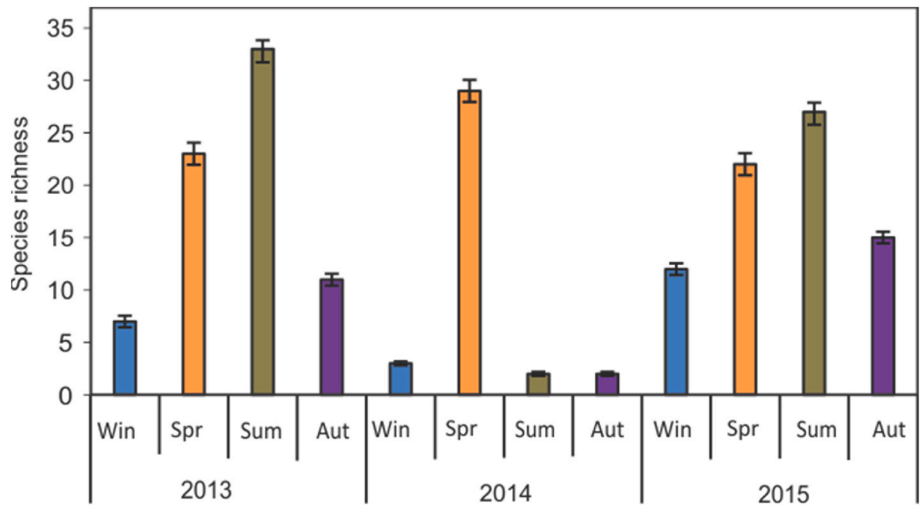

Fig. 5. Seasonal variation of species richness in the four seasons of the year during the macroalgal blooms in Bahía de La Paz, B.C. S., for years 2013, 2014, and 2015. Win = winter, Spr = spring, Sum = summer, and Aut = autumn.

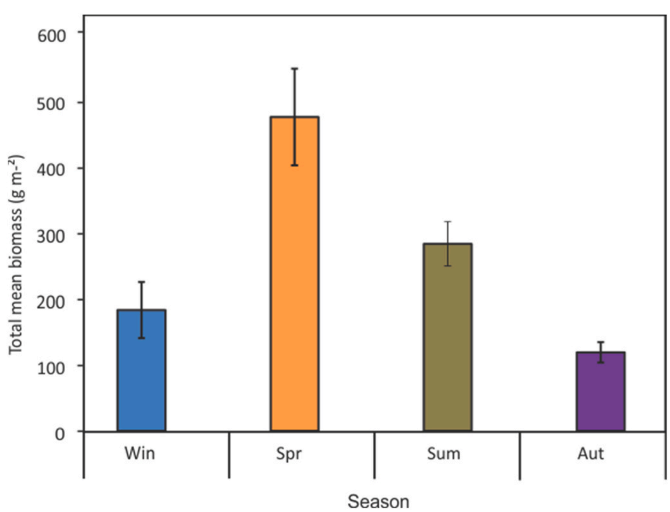

Fig. 6. Mean Seasonal Biomass in the different seasons of the year in the macroalgal blooms in Bahía de La Paz, B. C. S., over the study period. Win = winter, Spr = spring, Sum = summer, and Aut = autumn.

compared to 2013; *Dyctiota crenulata* also increased in biomass in 2015 (14.4 g m^{-2}) vs. 2013 (1.44 g m^{-2}). In contrast, the biomass of *G. pinnata* decreased to 5.9 g m^{-2} (44%) in 2014 and 0.6 g m^{-2} (94%) in 2015. Separately, the biomass of *Halimeda discoidea* increased significantly in 2014, while that of *G. crispata* and A. *spicifera* decreased significantly in 2014. The biomass of *Padina durvillei* increased to 11.9 g m^{-2} (946%) in 2015 from 2013, while for *Caulerpa sertularioides* it increased to 3.2 g m^{-2} (730%) over the same period ($F_{(20,\ 447)} = 2.5283$, $p < 0.05$) (Table 3).

Changes depending on year and conditions present during any given year could be resumed as in Table 4. Usually, Normal conditions showed moderate indicators and seasonal variations accordingly. However, both The Blob and El Niño conditions tend to show either maximum or minimum values depending on the indicator. Only the minimum biomass was recorded in autumn for the three conditions.

4. Discussion

4.1. Temperature

The variation in sea surface temperature (SST) recorded in the three years of the study showed a unimodal cycle, consistent with Cruz-Ayala et al. (1998) and Chávez-Sánchez et al. (2018). It has been observed that it increases progressively from March to August–September and then decreases from October to February; the maximum temperatures are recorded from July to September (summer, 30 °C) and the minimum occur in winter (20 °C); this cycle is due to the subtropical location of Bahía de La Paz (Cervantes-Duarte et al., 2001).

Sea surface temperatures in Bahía de La Paz were lower in 2013 vs. 2014–2015 throughout the year; according to the Oceanic Niño Index for the Niño 3.4 region, these corresponded to a neutral year (Normal Condition) (Ludescher et al., 2014). Coincidentally, Zaba and Rudnick (2016) found ocean temperatures corresponding to a neutral condition in the Southern California Current System (SCCS) in 2013. The higher temperatures recorded in 2014 (22.8 °C–32 °C) were associated with the warming condition known as The Blob (Bond et al., 2015; Kintisch, 2015; Peterson et al., 2016a, b). For its part, 2015 was influenced by The Blob, but it also was an El Niño year according to the NOAA Fisheries, being rated as “very strong” by McPhaden (2015), Jacox et al. (2016), Jiménez-Muñoz et al. (2016), and Peterson et al. (2016a, b).

The positive anomalies recorded in this study for the years 2014 and 2015 (up to 2.8), had also been reported by Elorriaga-Verplancken et al. (2016a, b) whom also reported positive anomalies exceeding 1.5 °C in 2014 and 2015 for the southern portion of the Gulf of California, including Bahía de La Paz.

According to our results, the Blob 2 (Peterson et al., 2015), should have influenced the warming events recorded in Bahía de La Paz from March to August 2014, while The Blob 3 (Peterson et al., 2015), must have influenced the warming event from March to September 2015, coupled with the El Niño effect in the latter year (Peterson et al., 2016b). The year 2015 showed positive anomalies in the Niño 3.4 Index of 0.5–2.3 °C between March and September (Jacox et al., 2016), such as we observed in our study.

4.2. Species richness

The Normal Conditions recorded the highest species richness; while the higher temperatures found during The Blob were associated with lower species richness. However, an increase in the number of species from 2014 to the El Niño year 2015 was observed and it was closely

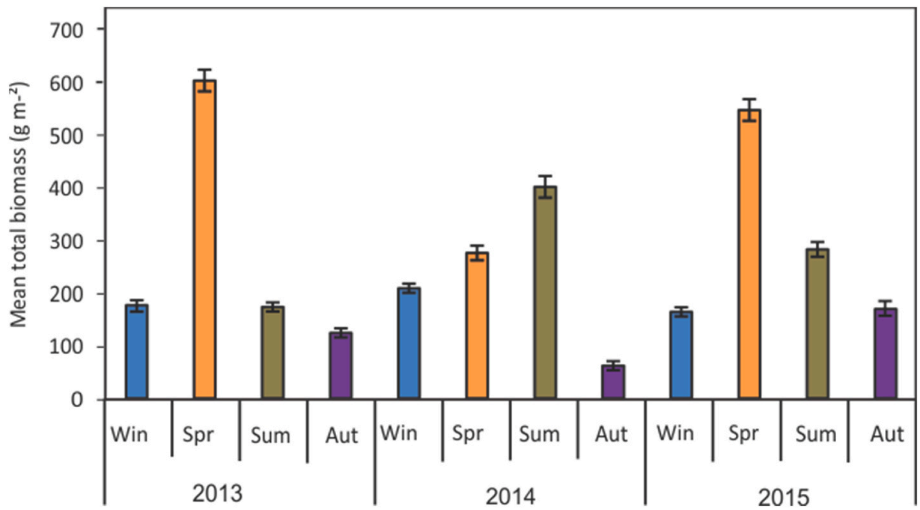

Fig. 7. Seasonal variation of biomass in the four seasons of the year during the macroalgal blooms in Bahía de La Paz, B.C. S., for years 2013, 2014, and 2015. Win = winter, Spr = spring, Sum = summer, and Aut = autumn.

Table 3
Mean total annual biomass (g m^{-2}) for the main species in macroalgae blooms in Bahía de La Paz, B.C.S.

Species	Year		
	2013	2014	2015
	Normal	The Blob	El Niño
Acantophora spicifera	27.36	2.36	13.48
Gelidium johnstonii	0	3.29	0
Gracilaria pinnata	10.49	5.93	0.64
G. pachydermatica	0	0.75	1.09
Hypnea spinella	0.59	1.44	1.84
Spyridia filamentosa	7.02	16.27	56.25
Dyctiota crenulata	1.44	1.39	14.26
Padina durvillei	1.14	0.27	11.93
Sargassum sinicola	4.45	14.73	5.31
Caulerpa sertularioides	0.39	0.1	3.24
Codium simulans	0	0.93	2.16
Halimeda discoidea	1.05	4.39	0.74
Ulva acanthophora	30.84	26.31	35.93
U. lobata	0.71	0.19	2.37
U. tepida	2.6	4.31	4.24
U. torta	11.38	0	0.31
U. ohnoi	97.95	98.02	97.64
Total Average	236.16	215.08	294.87

Table 4
Results obtained for the principal indicators.

Indicator	Normal condition	The Blob	El Niño
Temperature *in situ*	Moderate 24.5 °C	Very High 28 °C	High 27.1 °C
Temperature NOAA data	20.4°- 29.1 °C	21.1° - 30.6 °C	21.8° - 30.3 °C
Anomaly	−0.7° – 0.1 °C	0.1–2.8 °C	0.3–1.7 °C
Specific richness	High	Low	Medium
Biomass	Mean	Minimum	Maximum
Season of the highest specific species richness	Summer	Spring	Summer
Season of minimum specific species richness	Winter	Summer	Autumn
Season of maximum biomass	Spring	Summer	Spring
Season of minimum biomass	Autumn	Autumn	Autumn
Presence of macroalgae of tropical affinity			High
Species of tropical affinity that were most abundant			*Caulerpa sertularioides* and *Spyridia filamentosa*

related to the presence of more Rhodophyta species than the brown or green algae. The increase in the number of red algae in an El Niño year (1997–1998) had been previously documented by Mazariegos-Villarreal et al. (2012) in the Chester Rock and Cardoncito area, B.C.S., and Carballo et al. (2002) at Mazatlán bay. The reduction of green and, above all, brown algae was noticeable in El Niño year, compared to 2013 and 2014. Significant reductions in the abundance of brown algae have been documented in previous El Niño events (Ladah et al., 1999; Hernández-Carmona et al., 2001).

For Bahía de La Paz, Huerta-Muzquiz and Mendoza-González (1985) suggested that, under normal conditions, the upwelling events and low temperatures in winter promote the proliferation of temperate species. While the rising temperatures in summer, added to the latitudinal location in the tropical zone, favor the growth of tropical species, leading to a marked seasonality (Casas-Valdez et al., 2000). Such as we observed in this study. The increases in summer could be explained by the mixture of species of temperate and tropical affinity; in contrast, we observed a significant drop in autumn, because the considerable rise in temperature in late summer (>30 °C) would not be favorable to the presence of macroalgae. However, this pattern could be modified by thermal anomalies along the water column, like those observed with oceanographic phenomena such as The Blob (2014). In 2014, the highest species richness in Bahía de La Paz occurred in spring, and not in summer, as in other years (e.g. Casas-Valdez et al., 2000); this change may be explained because the temperature in spring was higher (29.2 °C) in 2014 than in previous years, which may have promoted the presence of temperate and tropical species mixed up.

In macroalgae, these deviations from the typical patterns had previously been observed as a result of anomalous temperature conditions, such as the presence of warm waters in "El Niño" years (Carballo et al., 2002; Iglesias-Prieto et al., 2003); the same has also been reported for other species (Guajardo et al., 2013). Jiménez-Quiroz et al. (2019) mention that the alteration (disruption) of seasonal and spatial patterns of abiotic variables, phytoplankton, and zooplankton recorded SW of the Baja California Peninsula were a likely consequence of the prolonged warming from 2015 to 2017 related to The Blob and El Niño.

4.3. Biomass

In Bahía de La Paz, the macroalgae biomass decreased in 2014 (The Blob), and increased in 2015 (El Niño). Carballo et al. (2002) also found that the biomass of macroalgae assemblages of the Mexican Pacific was higher during the 1998 El Niño (139 g dry weight/m^2), compared to the 1999 Non-El Niño year (42 dry weight/m^2); this high biomass during El Niño was related to the abundance of species of tropical affinity. This is consistent with the findings in this study since the biomass of *S. filamentosa* increased significantly in 2014 and 2015 compared to 2013 (+138% and +701%, respectively); the abundance of *Dyctiota crenulata* also increased in 2015 (14.4 gm^{-2}) relative to 2013 (1.44 gm^{-2}), same as *Padina durvillei* (+946%) and *Caulerpa setularioides* (+731%). Regarding this latter species, Scrosati (2001) mentions a high population abundance in April–June of 1998 (El Niño), with biomass of 134 g m^{-2}, and reported its absence during La Niña events (April–June 1999 and April 2000) in Bahía de La Paz, also Carballo et al. (2002) found a high abundance of *C. sertularioides* in the El Niño (1998) and absence in La Niña events (1999) at Mazatlán bay. However, species widely distributed, such as *Ulva ohnoi,* which is highly tolerant to sun radiation, salinity, and temperature (Nakamura et al., 2019), maintained high abundance levels over the three years.

Biomass cycles of macroalgae abundance have been reported, with peak values in spring and disappearance in autumn for most species (Cruz-Ayala et al., 1998; Casas-Valdez et al., 2016), including *Ulva* species (Chávez-Sánchez et al., 2018) at Bahía de La Paz. These changes were related to variations in temperature and nutrients (Piñón-Gimate et al., 2017). However, 2014 was a different year, as the maximum biomass was recorded in summer ($p < 0.05$) and not in spring as in the other years, likely due to the presence of The Blob.

In spring, when the highest abundance of macroalgae was recorded in the bay, biomass fluctuated between a maximum of 603 g m^{-2} in 2013 and a minimum of 276 g m^{-2} in 2014, then increasing to 548 g m^{-2} in 2015. This is consistent with the pattern observed for total biomass in the bay in the three years. It is in spring that the effect of the Normal Condition, The Blob, and El Niño events on the biomass of macroalgal blooms is most evident. The considerable reduction in biomass observed in spring 2014 is likely due to the fact that temperature in this year was higher (29.2 °C) than spring temperature recorded in the other years of study (23.6 °C and 25.1 °C). Moreover, nutrient concentrations may have been lower, given the inverse relationship between temperature and nutrient levels (Hernández-Carmona et al., 2001).

Species richness is lower and biomass is higher in spring; according to Carballo et al. (2002), this can be explained as a result of the competitive dominance of some species, which limit the substrate for the recruitment of new species. In Bahia de la Paz, this role is considered to be played by *Ulva* species; these are opportunistic macroalgae that dominate macroalgal blooms (Chávez-Sánchez et al., 2017, 2018), showing high photosynthetic, reproduction, growth, and nutrient uptake rates (Lotze and Shramm, 2000), in addition to a broad range of reproductive strategies (Sousa et al., 2007), which allow them to build large biomasses (Liu et al., 2013; Huo et al., 2015; Nakamura et al., 2019). By contrast, when the abundance of *Ulva* decreases in summer, the presence of a larger number of species is recorded (Chávez-Sánchez et al., 2017) although, as mentioned above, this did not occur in 2014 likely because of the presence of The Blob.

5. Conclusions

In Bahía de La Paz, the highest temperatures were recorded in 2014, associated with the oceanographic phenomenon called The Blob, while one El Niño event co-occurred with the permanence of The Blob in 2015, although temperatures were not as high as in 2014. It was evident that The Blob and El Niño modified the patterns of species richness and abundance in the macroalgal blooms recorded in the bay. In the El Niño year (2015), algae in the Division Rhodophyta showed a sharp rise, particularly in the case of the unique species. In 2014, the highest species richness was observed in spring, contrasting with 2013 and 2015, when it occurred in summer. Besides, the maximum biomass in 2014 occurred in summer, while in 2013 and 2015 it was observed in spring, as is generally the case in the bay. In the El Niño year, the abundance of species of tropical affinity, such *as Spyridia filamentosa*, *Padina durvillei*, *Caulerpa sertularioides*, increased significantly, while the biomass of *Gracilaria pinnata* (temperate affinity) decreased.

CRediT authorship contribution statement

Chávez-Sánchez Tonatiuh: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Piñón-Gimate Alejandra:** Investigation, Conceptualization, Formal analysis, Visualization, Methodology, Writing – original draft, Writing – review & editing. **Casas-Valdez Margarita:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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