UNIVERSIDAD AUTÓNOMA DE BAJA CALIFORNIA

FACULTAD DE CIENCIAS MARINAS

RESPUESTA LOCAL DE BOSQUES DE MACROALGAS A VARIABILIDAD AMBIENTAL: BASES PARA INFORMAR MANEJO *AD HOC*

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KELP FOREST LOCAL RESPONSE TO ENVIRONMENTAL VARIABILITY: BASIS TO INFORM MANAGEMENT *AD HOC*

TRABAJO TERMINAL PARA OBTENER LA

ESPECIALIDAD EN GESTIÓN AMBIENTAL

PRESENTA

LCA ANDREA PAZ LACAVEX

ENSENADA, BAJA CALIFORNIA, OCTUBRE DEL 2020.

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Aprobada por:

Dr. Rodrigo Beas Luna
Co-director de tesina

Dr. Julio Lorda Solórzano
Sinodal

Dr. Hiram Rivera Huerta
Sinodal

ENSENADA, BAJA CALIFORNIA, OCTUBRE DE 2020.

ABSTRACT

Kelp forests are one of the most productive coastal ecosystems in the world. The brown algae *Macrocystis pyrifera* provides a great diversity of ecosystem goods and services to humans. One of the ecosystem services that has attracted recent attention is carbon sequestration. However, kelp forests are thought to be disappearing worldwide due to extreme marine heatwaves as well as its potential for blue carbon sequestration. Interestingly, kelp forests are affected not only by natural environmental variability but also by several other anthropogenic agents of change such as fishing, coastal development and run-offs. The synergy of climate variability and direct human disturbances make some kelp forests thrive while others disappear. Thus, there is a need for developing a better understanding of kelp forest adaptive capacity at different spatial and temporal scales. This study aims to explore how the integration of different sources of information can potentially help us understand environmental and direct anthropogenic impacts to inform adaptative management actions. Specifically, we evaluated the historical dynamics of kelp canopy biomass using remote sensing tools and estimated biomass and persistence response related to different sites affected by a combination of natural variation and anthropogenic impacts. Three sites with kelp beds were compared in Bahía Todos Santos: Sauzal, Punta Banda and Punta China. Sites were characterized according to their distribution, surface, kelp biomass and persistence, and carbon capture capacity. We found a variety of responses to the Marine Heatwave know as The Blob, among the three sites. This is likely attributed to geomorphology, environmental regime and anthropogenic impacts of each particular site. Through this exercise, we found data gaps and generated management recommendations and actions to sustain coastal ecosystem services.

Keywords: kelp forests, remote sensing, biomass, anthropogenic impact, local response, integrated ecosystem management.

Highlights

- Kelp forests are facing a diversity of responses in biomass density and persistence, due to differences in geomorphology, environmental regime and anthropogenic impacts.
- We show remote sensing information is valuable to inform changes in biomass of habitat forming species such as *Macrocystis pyrifera*.
- We used kelp forests around the Ensenada Region as a case study to better understand how different anthropogenic stressors influence these forests.
- We identified and discussed data gaps that need to be integrated in order to properly identify agents of change in kelp forests .
- We propose that in order to design climate smart management actions, the integration of multiple data sources is needed.

Object of study: kelp forests biomass dynamic, persistence and responses facing multiple stressors.

Geographical location: Kelp forests around Bahía Todos Santos in Baja California, Mexico: Sauzal, Punta Banda, and Punta China.

RESUMEN

Los bosques de macroalgas son uno de los ecosistemas costeros más productivos del planeta. El alga parda *Macrocystis pyrifera* provee una gran diversidad de recursos y servicios ecosistémicos. Uno de los servicios más importantes y que ha atraído reciente atención es el secuestro de carbono. Sin embargo, se sabe que los bosques de macroalgas han comenzado a desaparecer a nivel global debido a ondas de calor extremas, y con ellos, su potencial de secuestro de carbono. Interesantemente, los bosques de macroalgas están afectados no solo por la variabilidad ambiental, sino también por una gran variedad de agentes de cambio de tipo antropogénico, como pesquerías, desarrollo costero y deslave de sedimentos. La sinergia creada con la combinación de la variabilidad ambiental y los disturbios humanos provoca que algunos bosques de macroalgas prosperen mientras otros desaparecen. Por ello, existe una necesidad de desarrollar mejor entendimiento de la capacidad adaptativa de los boques de macroalgas a diferentes escalas espacio-temporales. Este estudio tuvo el objetivo de explorar como la integración de diferentes fuentes de información puedes potencialmente ayudar a entender los impactos ambientales y antropogénicos, y así, poder informar mejores acciones de manejo. Específicamente, se evaluó la dinámica histórica del dosel de los bosques de macroalgas utilizando herramientas de percepción remota y se estimó biomas y persistencia como respuesta, en diferentes sitios, a una combinación de variación natural e impactos antropogénicos. Los sitios se caracterizaron de acuerdo a su distribución, superficie, biomasa, persistencia y capacidad de captura de carbono. Se encontró una variedad de respuestas a una onda de calor conocida como El Blob en los tres sitios evaluados. Esto se atribuye probablemente a la geomorfología, régimen ambiental e impactos antropogénicos particulares. Por medio de este ejercicio, se encontraron vacíos de conocimiento y se enlistaron recomendaciones de manejo y acciones que conserven los servicios que éste ecosistema provee.

Palabras clave: bosques de macroalgas, percepción remota, biomasa, impactos antropogénicos, respuesta local, manejo integral de ecosistemas.

Destacados:

- Los bosques de macroalgas se están enfrentando a una diversidad de respuestas en densidad de biomasa y persistencia, debido a diferencias en geomorfología, régimen ambiental e impactos antropogénicos.
- En este estudio se muestra como la percepción remota puede generar información valiosa sobre cambios en biomasa de una especie formadora de hábitat como *Macrocystis pyrifera*.
- El caso de estudio se enfocó en la región de Ensenada, para entender cómo diferentes estresores antropogénicos pueden afectar los bosques de macroalgas.
- Se identificaron y discutieron los vacíos de conocimiento que deben ser integrados para identificar adecuadamente agentes de cambio en los bosques de macroalgas.
- Se propone que para lograr acciones de manejo *climate Smart* la integración de múltiples fuentes de información es necesaria.
- **Objeto de estudio:** dinámica de biomasa de bosques de macroalgas, persistencia y respuestas ante múltiples estresores.
- **Ubicación geográfica:** bosques de macroalgas de la región de Ensenada, Baja California, México: Sauzal, Punta Banda y Punta China.

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INTRODUCTION

Kelp forests are one of the most productive ecosystems in the world; providing a variety of environmental goods and services including fisheries, coastal protection, biogenic habitat, research and education (Foster and Shield, 2015). Global and local environmental drivers of change influence these forests and compromise it ecosystem services. These changes occurred in a variety of ways and its effects depend on the resistance and resilience characteristics at local scales (Cavanaugh et al., 20019). For instance, some kelp forests are more sensitive to elevated temperature while others to storms, hypoxic events, or invasive species. In addition to environmental changes, each kelp forest is threated to a mosaic of direct anthropogenic impacts such as fishing, runoffs, coastal developments, and aquaculture. Interestingly, these effects are also occurring at different spatial and temporal scales. Thus, understanding and potentially informing management actions to mitigate kelp forest effects is complex and requires an integration of a sweep of information regarding environmental and anthropogenic sources of variation at different scales.

Currently, little is known about the synergy that the agents of change create in the Northern Mexican Pacific kelp forest. Similar prospective studies on this matter end at the border between California and Baja California (Ramirez-Valdez *et al*., 2017). Moreover, decision makers do not easily access information that does exist. This study aims to understand how the integration of different sources of information can potentially help us understand environmental and direct anthropogenic impacts and potentially inform adaptative management actions and secure ecosystem services such as carbon sequestration. Specifically, we explore sea surface temperature (SST) variability for this region from 2014 throughout 2016. With this data, we characterized Marine Heatwaves (MHW) during this period (Hobday *et al.,* 2016). Additionally, we compare how canopy kelp biomass derived from remote sensing from each of the kelp beds in this region respond to MHWs. Finally, we investigate information gaps that need to be filled to properly integrate interdisciplinary information to enhance kelp bed resilience under different stressors and to support ecosystem services such as carbon capture and sequestration. This study can help to expose the basis needed to inform integrated ecosystem management techniques that pursue coastal adaptability of kelp forests in the changing environment of the Northern Mexican Pacific.

Kelp forest

Kelp forests dominated by *Macrocystis pyrifera* in the northern hemisphere are distributed in temperate rocky reefs along the coast from Alaska to Baja California (Carr and Reed, 2016). Usually found in depths between 5 and 20 meters, where cold-water rich in nutrients surge and creates optimal conditions for a great diversity of species to thrive. *M. pyrifera* creates complexity in the water column and thus provides biogenic habitat and food for birds, mammals, fish, invertebrates and other species of algae (Foster and Shield, 2015). Among the species associated with kelp forests, we can find several highly value fisheries resources such as abalone, lobster, sea cucumbers, sea urchins and different species of snails. In addition to provision services such as fishing, kelp forests provide other types of ecosystem services. For example, 1) regulation services such as carbon cycling and oxygen production; 2) protection services such as wave attenuation for coastal protection; and 3) cultural services such as recreation, inspiration and education (Beas *et al*., 2019). The consequences of the reduction of these ecosystem services can have severe effects for food security and the economy of coastal fishing communities, therefore the need to integrate and inform management actions at relevant scales.

Blue Carbon

As part of one of the most important ecosystem services that kelp forests provide, blue carbon sequestration has gained attention on recent years (Milenium Ecosystem Assessment, 2005). Kelp carbon is transported down the trophic web. A section of this carbon end up in deep waters; other section is recycled in the trophic web (Bayley *et al,* 2017); finally some is incorporated into the atmosphere due to algae and organisms degradation processes. Accounting for carbon in this interexchange of matter and energy is a present challenge. Unfortunately, kelp forests ecosystem services including carbon capture and sequestration are threatened by the combination of human and environmental agents of change working at different spatial and temporal scales (Reed and Brzezinski, 2009).

Agents of Change

Kelp forests are highly dynamic and resilient ecosystems, however, its structure and functionality are threatened by the combination of increased frequency and intensity of the environmental stressors and anthropogenic pressure. Environmental agents of change that affect kelp forests and associated species include: nutrients and substrate availability (Carr and Reed 2015), light interference and turbidity (Sanchez *et al.,* 2020), waves and storms (Byrnes et al., 2011), extreme water temperature increments (Cavanaugh *et al*., 2019), ocean acidification (Kroeker *et al*., 2010), sedimentation (Torres and Escofet, 2015) and invasions (Marks *et al*., 2018). Direct anthropogenic sources of change include: fishing, poaching, harvest, eutrophication, runoffs, competition with introduced species, mariculture, diseases, and more (as compiled by Steneck *et al*. 2012). Specifically, sediment input affects kelp forest productivity (bottom-down effects). Rocky substrate gets covered by sediments flowing to marine coastal areas after rains, and naturally migrates to the coast afterward, leaving exposed rocky substrate for organisms to settle (Connell *et al*. 2008). Each year, urban and industrial development increases pressure over coastal ecosystems, and with it, an increasing input of these runoffs. On a long term, this can affect kelp recruitment and juvenile settlement due to a decrease in available substrate and light, caused by sediment transportation and turbidity in the water column (Devinny and Volse, 1978).

Unprecedented sources of variation have resulted in a great diversity of responses of kelp forests at different scales. These effects include mass mortalities (Micheli *et al.,* 2012), range shifts (Lonhart *et al.,* 2019) and a suite of winner and loser species depending on habitat, timing and intensity of the stressor (Micheli *et al.,* in press). Interestingly, one of the factors that have received most recent attention is the extreme temperature increment defined as Marine Heatwaves (MHW; Hobday *et al*., 2016). It has been suggested that MHWs can drive drastic changes in kelp biomass (Cavanaugh *et al.,* 2019) and the associated communities (Arafeh *et al.,* 2019). Additionally, has been documented that has trigger range shift movements (Lonhart *et al.,* 2019) and novel species interactions (Sanford et al., 2018). Depending on the particular characteristics of the kelp forest, these changes can result in full ecosystem shifts (Rogers & Catton 2019).

Marine Heatwaves

As agents of change strengthen, the ecosystem's resilience, or its ability to withstand change, weakens. Pulse perturbation events, which may be natural or anthropogenic in origin, can precipitate a regime shift, particularly when interacting with chronic drivers (Hicks *et al*, 2016). Marine heatwaves are a pulsing perturbation, which is increasing in frequency, and strength, characterized by prolonged, extreme warm water events with disruptive consequences in for marine ecosystems (Hollowed *et al*., 2020). The Blob was a warming event between 2014 and 2016 that lasted 711 days with an intensity of 2.56 degrees (Hobday *et al*, 2018).

As cited by Harley and collaborators (2012), "increased temperature is generally thought to have negative effects on spore production (Buschmann et al. 2004), germination (Buschmann et al. 2004), recruitment (Deysher and Dean 1986a, Buschmann et al. 2004), and sporophyte growth (Rothausler et al. 2009, 2011) and context-specific effects on gametogenesis depending on the source population and degree of warming (Luning and Neushul 1978, Deysher and Dean 1986b, Mun˜oz et al. 2004). Warming has also been linked to mortality of spores, gametophytes, eggs, and sporophytes (Ladah and Zertuche-Gonzalez 2007)".

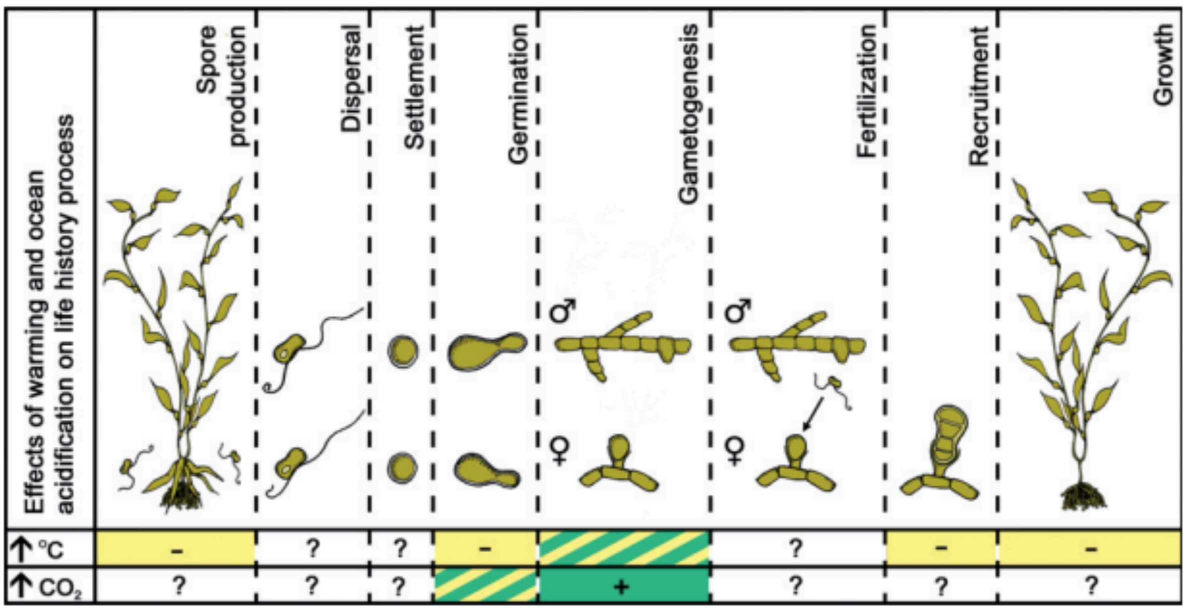

Figure 1. Effects of increasing temperature and CO2 on life history processes in *Macrocystis pyrifera*. Green boxes indicate experimental evidence of positive effects, yellow boxes indicate negative effects, hatched boxed indicate both positive and negative (i.e., context-specific) effects, and blank boxes represent unquantified responses owing to a lack of published information (Harley et al, 2012).

Remote Sensing

Long-term, large-scale ecological information is often required to understand how ecosystems respond and how it varies at different scales (Hughes et al., 2017). Unfortunately, these studies are rare and require a great amount of collaboration and cooperation among institutions to maintain them (Beas et al., 2020). Therefore, innovative tools such as remote sensing can contribute to fill information gaps for large scale, long terms estimation of kelp biomass.

Multispectral satellite images together with *in situ* data collection have been used to study past kelp forest biomass distribution (Cavanaugh *et al*., 2011). This was the first approach that represented the most spatially and temporally comprehensive analysis of historical trends for abundance and distribution of kelp forests along the California coast, in USA. This approach has now been extended to Alaska, Canada, Oregon and Northern California (Hamilton *et al,* 2020;Costa *et al*, 2020; Renshaw *et al*, 2017). Later in 2019, Cavanaugh and collaborators assessed the response kelp canopy biomass to a MHW in the Southern and Baja California (Cavanaugh *et al,* 2019). They found that when assessing regional responses on a 100 km coastline, local scale environmental and biotic processes played a larger role in determining the recovery of kelp from this extreme warming event. These results suggest that kelp beds have a different characteristic that allows them to be more resistant, persistent and resilient to MHW. These include nutrient availability, waves height, coast proximity, substrate composition, community composition, fishing pressure, and more. Therefore, the combined effects of multiple stressors of climate change and direct anthropogenic sources of variation can be ameliorated with the right combination of physical, chemical and biological characteristics. These areas have been previously proposed as microclimates or oceanographic refuge where local scale variability functions as a buffer for regional scale processes maintaining high diversity of species (Keppel, 2012; Woodson et al., 2018, Morgan *et al,* 2005).

Ensenada, Baja California, Mexico

The Ensenada Municipality is located near the southern distribution limit of *M. pyrifera* in the northern hemisphere, characterized by cold waters rich in nutrients, along with rocky reef substrate. Being closed to this range limit makes the kelp forests in this area an excellent case study to explore the combined effects of MHWs and other anthropogenic sources of variation. Ensenada is a city 130 km south of the U.S. border on the Pacific coast. It has more than half a million citizens and all the anthropogenic threats that present kelp forests could face in an urban environment. They also support some of the most economically important fisheries associated with kelp forests: lobster, sea urchins, sea cucumber and abalone (SEPESCA, 2018). But these sites differ in biophysical characteristics as well as direct anthropogenic influences. For example, some areas exposed to waves, whereas others are protected; some kelp patches are where cold water surges while others are exposed to direct urban runoffs; fishing of kelp-associated species happens and invasive algae compete for substrate. We chose Ensenada as a study site since it has great potential as a natural laboratory. Broadening the knowledge around local kelp forests dynamics and the bottom-down and down-up consequences of its loss on an environmental and economical level is key for its long-term management.

Actual management techniques

In Mexico, many environmental and anthropogenic impacts are diminishing coastal ecosystems, creating a "*wicked*" issue that lack a simplistic or straightforward planning responses (Levin *et al.,* 2012). In 2012, a Management Plan for Macroalgae was published, including *Macrocystis pyrifera* (DOF, 2012). It recognizes kelp biomass variability due to environmental stressors like El Niño, but no specific techniques are exposed in order to assess this changes and sustainability of this ecosystem related to other economically important fisheries. These management efforts should consider the system complexity in its management techniques, where multidisciplinary data can help make climate smart decisions.

Importance of this study

Kelp forests provide a great diversity of ecosystem services to humans. One of the most important ecosystem services, that its also understudied is carbon capture and storage, which can help reduce climate change effects. Unfortunately, the combined effects of climate variability and direct anthropogenic agents of change threaten all ecosystem services. In order to sustain ecosystem services, there is a need to integrate interdisciplinary datasets to inform successful management actions. We propose a novel approach using remote sensing to estimate kelp biomass variability under different conditions and a MHW, however, this is only a first step. More information is needed and here, we discuss what and how the missing information could be integrated.

GENERAL QUESTIONS

- How do different kelp forests respond to The Blob and how this information can inform management?

Specific questions

- What is the temperature variability in the area?
- How kelp beds in the region are different?
- How did the different kelp patches respond?
- What information is missing?
- Which areas has potential to restore the ecosystem services of carbon capture?

METHOD

Study sites

The analysis for this study was focused on kelp beds with different biophysical and social ecological characteristics: Sauzal, Punta Banda, and Punta China. These sites have a similar coastal section of 9 km and a historical presence of kelp. These sites have historically varied in environmental variability and anthropogenic pressures. Sauzal is embedded in a growing urban coastal area, where vegetation is being removed to make space for housing and industrial development. With seasonal rains, many pollutants and sediments flow to the coast affecting substrate composition and water quality. Also with a lack of proper drainage, many black water discharges are illegally disposing into the ocean. Punta Banda, although not as fast as Sauzal, is also presenting vegetation removal for countryside housing purchasing, which also threatens with an increase in seasonal runoffs input to the ocean. Kelp forest dependent fisheries and tuna ranches are also pressuring this site. Finally, although not with an urban area, a limestone quarry has affected Punta China for more than 50 years. The limestone quarry has been discharging to ships on the coast for many decades in order to provide up to 80% of the material for the building industry for Baja California (El Vigía, 2010). The process of discharge is not efficient and a lot of the material escapes to the ocean and atmosphere, changing the ecological balance of this ecosystem and indirectly in human health, through the accumulation of heavy metals in economically important organisms (Torres-Moye and Escofet, 2014; Gutierrez-Galindo & Muñoz-Barbosa, 2003).

Temperature variability

Through the online tool developed by Schlegel (2020; http://www.marineheatwaves.org), based on Reynolds and collaborators data (2007), the warming event known as The Blob was identified. This website identifies temperature anomalies through remote sensing, making available data on their length, intensity and frequency along a chosen period of time and scale.

Canopy estimation and characterization

In order to identify areas historically occupied by kelp forests, multispectral satellite images from Landsat 5, 7, and 8 from 1982 to 2018 were utilized, with methodology from Cavanaugh and collaborators (2011). The images that capture Ensenada have coverage of 170-185 kilometers per side and a resolution 30 meters per side per pixel. The bands used for the analysis were green (500-590nm), red (610-680 nm), near infra-red (780-890 nm), and mid-infra-red (1580-1730 nm). To characterize *M. pyrifera* historical geographic variability along the study area, multispectral satellite images were used and translated into biomass from *in situ* measurements (kg of fresh kelp/pixel).

Biomass density maps were created with ArcMap 10.5, by dividing the pixel biomass means in 10 categories with the *Natural breaks* tool and coloring the biomass average per pixel with a color ramp. Also, persistence calculations and mapping were done based on the percentage of occupancy of a pixel, meaning: the proportion of all the historical multispectral satellite images where kelp biomass was detected by the satellite images. The persistence of each pixel was divided with the *Natural Breaks* tool in 6 categories of persistence and mapped and colored with a color ramp. Total pixel biomass variability was also calculated, using data from 2000 to 2018 due to images consistency in recent years.

Response to the Marine Heatwave The Blob

To estimate individual kelp forests response to MHW The Blob, total biomass average and persistence per site was calculated per time period. The time period chosen for this analysis accounted for interannual variability and recent canopy coverage before the event, where temperature conditions maintained under the temperature threshold from before the event, from 2011 to 2013; during, from 2014 to 2016; and after, from 2017 to 2018. Values were plotted in order to understand individual biomass and persistence responses and to evaluate local scale response from a regional water-heating event.

Existing information and data gaps

Analysis of existing information relevant to the management of kelp forests ecosystems was done. This included an evaluation per site of the state of the art on sustainability sectors that form an integrated ecosystem management: environmental, ecological, socio-economic, and governance.

Blue Carbon

With the software R, biomass was translated into an average of yearly carbon capture per site through a ratio of 1:0.026 of fresh kelp biomass to carbon (Mann, 1972: Wilmers *et al,* 2012).

RESULTS

The present work is one of the first approaches to a historical analysis of *M. pyrifera* small-scale distribution on the Mexican Pacific. Satellite images from 1982 to 2018 were analyzed for this purpose. It provided an insight for spatial variability and persistence of kelp forests in three sites of Ensenada. Kelp forests in the Ensenada region have shown a variety of responses in biomass facing the MHW known as The Blob, between 2014 and 2016. Our analysis suggests that this variety in responses is caused by synergy of environmental and anthropogenic pressures that work together on a smaller scale: runoffs input, fisheries, upwellings, and more.

Our study shows a high level of regional heterogeneity which points at a higher possibility of resilience after different disturbances. Although there is evidence of past conditions and recovery of different kelp patches, we analyzed the most recent responses on biomass of three sites in Ensenada to the MHW The Blob and how this information can point at research opportunities that recommend and promote an integrated ecosystem management.

Temperature Variability

The Blob effect was registered in sea surface temperature for the Ensenada Region between 2014 and 2016, with various heat peaks during those dates. In Figure 2, historical daily mean can be appreciated in blue dotted line; historical upper 90 percentile with a red dotted line; yellow and orange areas represent moderate and strong marine heatwaves. In Figure 3, marine heatwaves are identified and isolated with the degrees of surpassing. Higher peaks that characterize The Blob can be appreciated between 2014 and 2016.

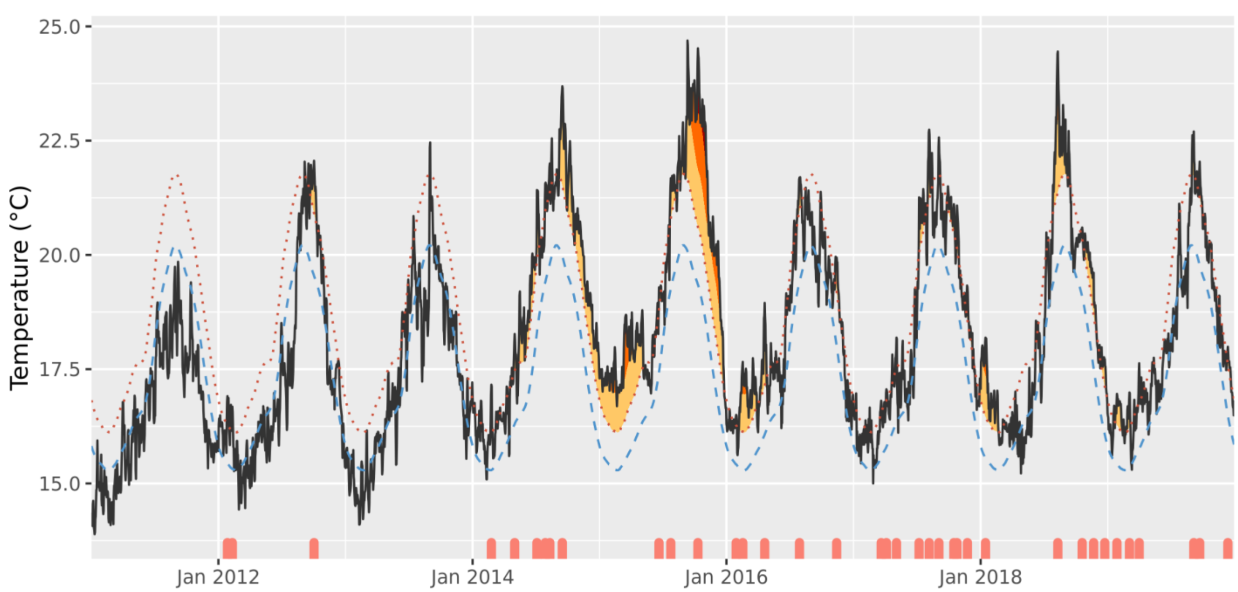

Figure 2. Sea surface temperature of the Ensenada Region where threshold surpassing can be appreciated from 2012 to 2020 (Schlegel, 2020):

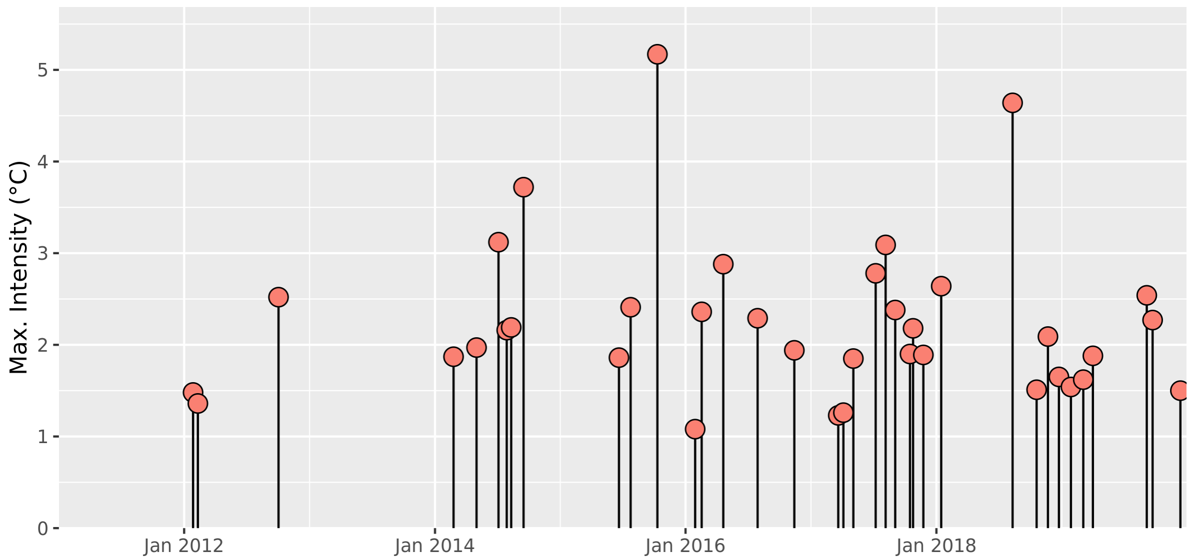

Figure 3. Lolli plot of Marine Heatwaves identified in the Ensenada Region from 2012 to 2020 (Schlegel, 2020):

Sites characterization

Time series

Data shows an interanual biomass variability per site, where biomass fluctuates naturally, but differs in dynamics. A recent increase in variability can be seen in recent years for the study sites, but all differ in peaks and lows along the years. A regional tendency cannot be pointed out from the biomass fluctuations along the biomass variability time series, but the contrary: sites differ on a small scale.

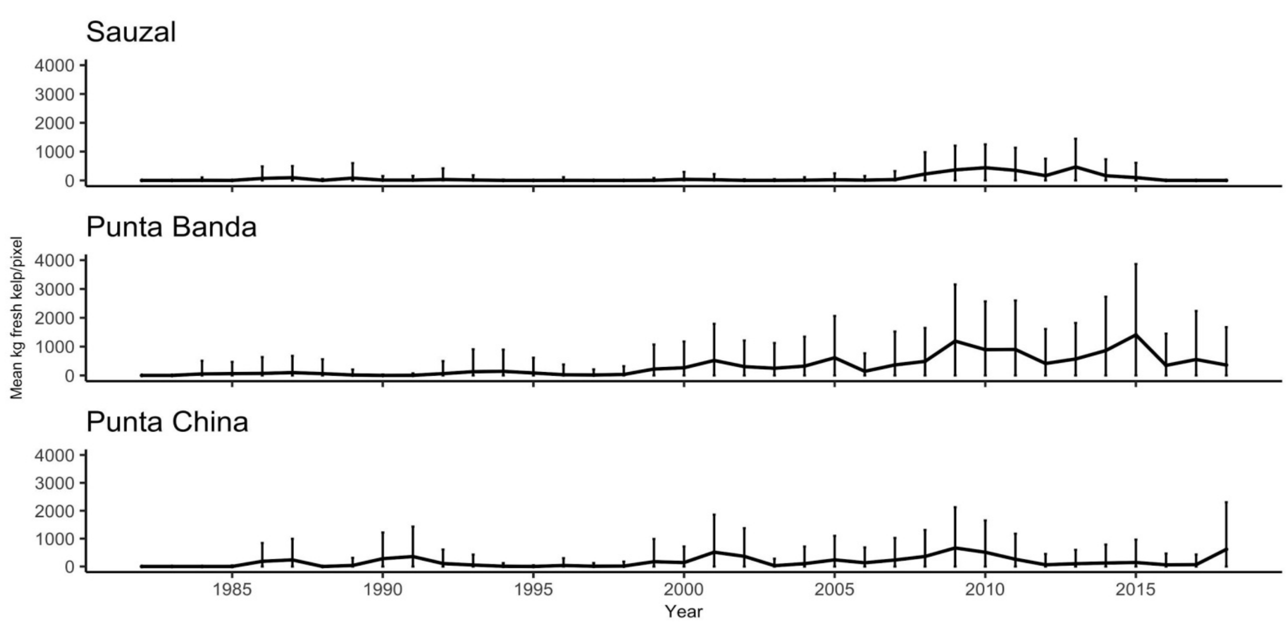

Figure 4. Sites yearly mean biomass of kelp forest dominated by *Macrocystis pyrifera*.

Pixel variance

Figure 5, shows a pixel biomass variability scatter plot. Colored ellipses differentiate most dense areas per site. Sauzal distribution shows a great variance of biomass occupancy, but with low mean biomass values, whereas Punta China shows a less variable, higher biomass pixel distribution. Finally, Punta Banda shows a great variety of mean biomass variability. Highly persistent and dense sites would be expected to have a distribution like the one present in Punta China.

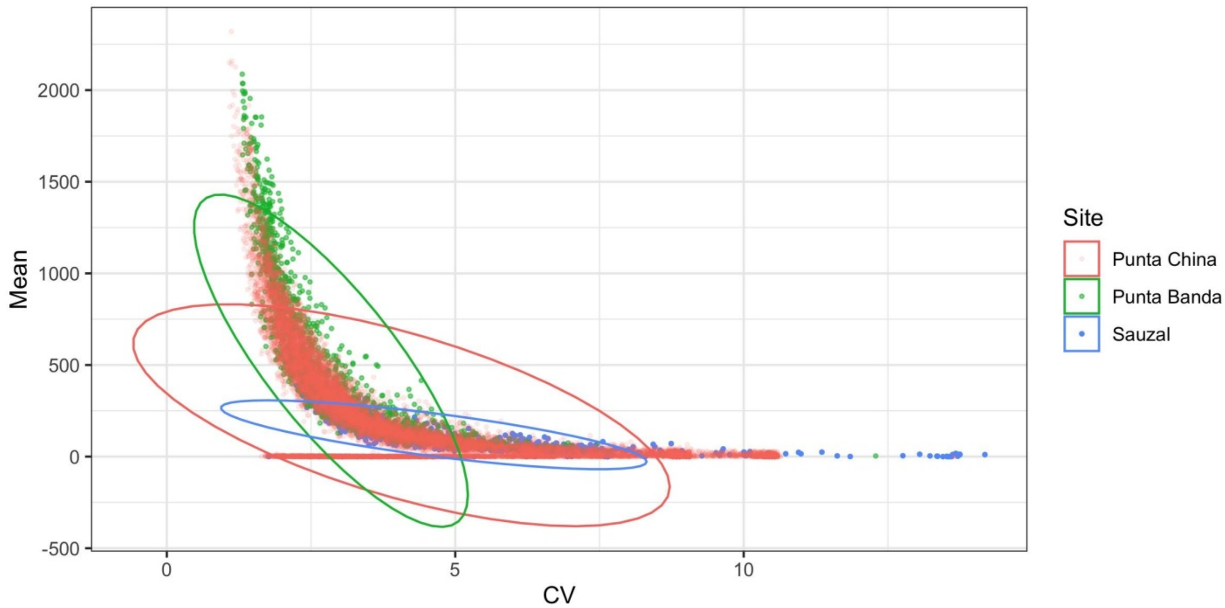

Figure 5. Scatter plot of biomass per pixel variance by site, from 2000 to 2018.

Kelp biomass and persistence

Regional heterogeneity was also found when mapping historical biomass and persistence. All three sites with kelp canopy were found no more than 1.5 kilometers of the coast, and showed near-concentric distribution, like a nucleus, of biomass and persistence with higher values on the inside of the different kelp patches, and the most ephemeral and less dense on the edges. We attribute this distribution of biomass and persistence to a more direct exposure to wave intensity on the exposed edge, and a higher exposure to breakwater on the protected edge. This type of distribution can be clearly seen in the biggest patch of Punta China.

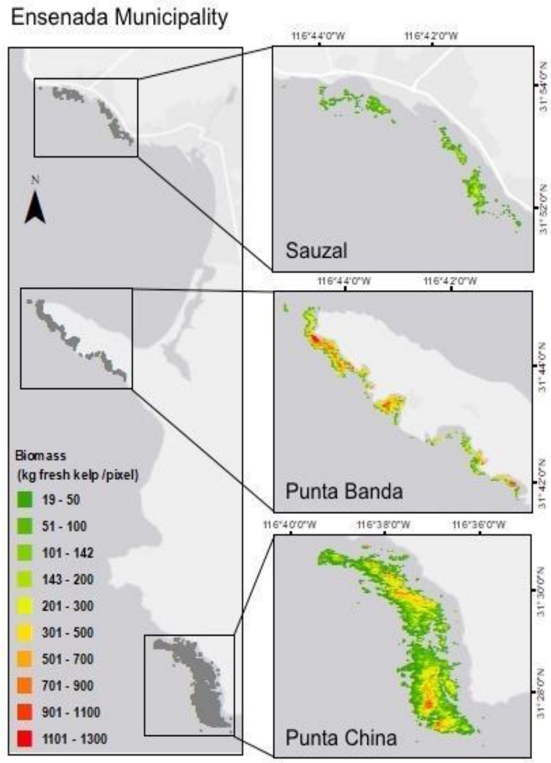

Figure 7. Historical kelp biomass per site

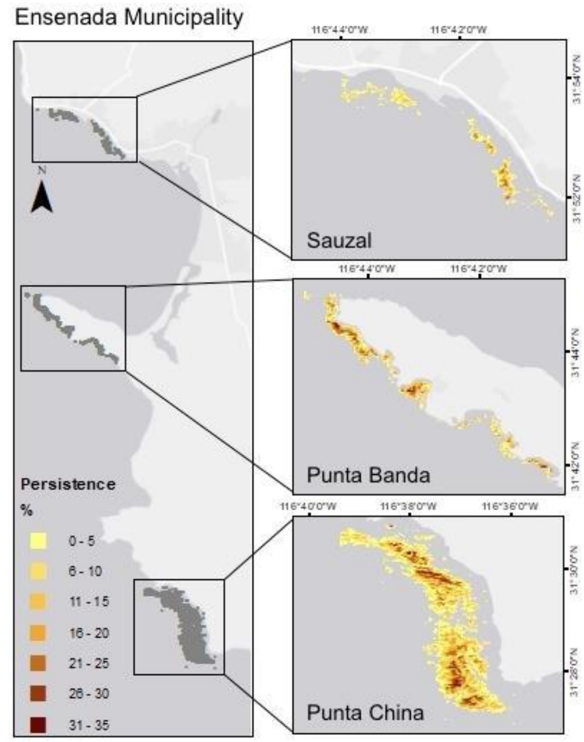

Figure 6. Historical persistence per site

Data integration

On a local scale, comparison indicates that variable anthropogenic pressures, geomorphology and oceanographic regime are reflected in historical biomass distribution and persistence on a small scale along Ensenada. Although Punta Banda is still heavily fished from different fishermen cooperatives and it´s geomorphology protects tuna growing ranches, Table 1 shows that is the most productive kelp forest in the region described, with an average of 347.8 kg of fresh kelp/pixel. We attribute this to a more complex geomorphology and higher exposure to cold-water surges rich in nutrients that promote algae growth and persistence.

Although all sites were taken from a 9 km coastal section, the highest canopy cover and persistence was calculated for Punta China, with maximum biomass values close to Punta Banda, but with canopy surface almost five times grater. This can also be explained from a geomorphological level, since this site is also well protected from wave exposure and with a probable surge regime similar to Punta Banda, what in combination with nutrients inputs from the limestone quarry up the basin, creates a highly productive canopy, and potentially a highly productive ecosystem.

In comparison, Sauzal presents the lowest historical values of all biomass, persistence and cover. Sauzal is exposed to common wave action from the north and under the Bahía Todos Santos bay dynamics. In consequence, kelp forest canopy has almost disappeared. Field observations have shown that Sauzal presents a high input of sediments due to vegetation removal up the basin, where urbanization is rapidly spreading (Image 1). Urban pollution and sediment runoff to coastal areas may haves surpassed the natural capacity of the seasonal sediment migration to expose rocky substrate for organisms to settle. In consequence, a small overall canopy and biomass.

Table 1. Data comparison per site

	Historical						
Site	**Área** (ha)	**Biomass**	(kg fresh kelp/pixel)		**Persistence**	(%)	
	Total	*Mean*	*Max*	*Min*	*Mean*	*Max*	*Min*
Sauzal	87.21	77.6	267.1	8.9	7.4	25	0.5
Punta Banda	141.03	347.8	1252.7	19	11.7	32.9	0.9
Punta China	721.89	169.7	1212.4	1.8	10.1	34.7	0.2

Image 1. Drone footage of the coast of Sauzal after a night of heavy rains on 27/03/2020.

Biomass and persistence response to The Blob

Three time periods were chosen in order to evaluate kelp forests responses against the MHW The Blob on a local scale: before (2011-2013), during (2014-2016) and after (2017-2018). Mean values per site per period of time were calculated and plotted. According to theoretical biomass response of kelp forests to MHW the only site that presented this behavior was Sauzal, with a descending biomass average and persistence per period of time. In comparison, Punta Banda and Punta China showed different behaviors than expected (Table 2).

Punta Banda, with the highest values of the study sites showed max biomass and persistence during the event, but with a drop of biomass after the event and lower visible drop of persistence. Both biomass and persistence presented minimum values after the event. In comparison, Punta China showed a different behavior. The highest values of biomass were shown after the event. Persistence had not a similar tendency than other sites, highly related to biomass (coef. corr. = 0.83-0.89). Instead, max values of persistence were shown during the event, although biomass values were the lowest of the analyzed time series.

Table 2. Data integration per site per time period: before, during and after The Blob.

	Marine Heatwave		
Site	**Biomass** (kg fresh kelp/pixel)		
	Before	*During*	*After*
Sauzal	326.7	87.5	0.5
Punta Banda	628.3	872.2	456.7
Punta China	297.2	109.4	340.1

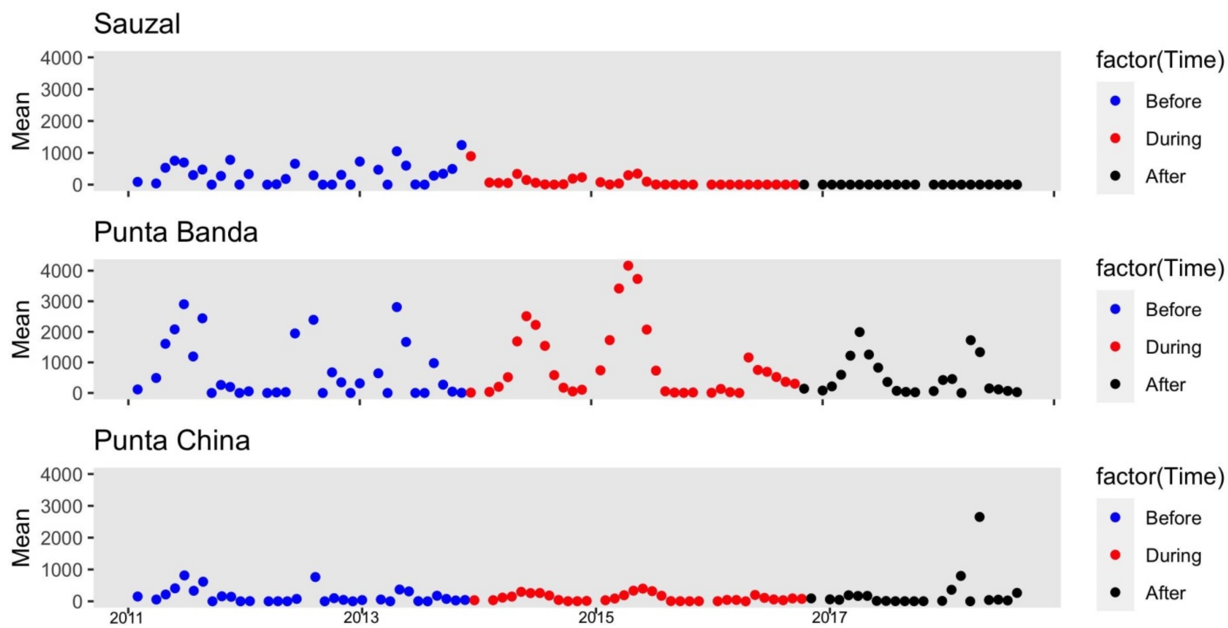

Figure 8. Biomass plot per site per time period.

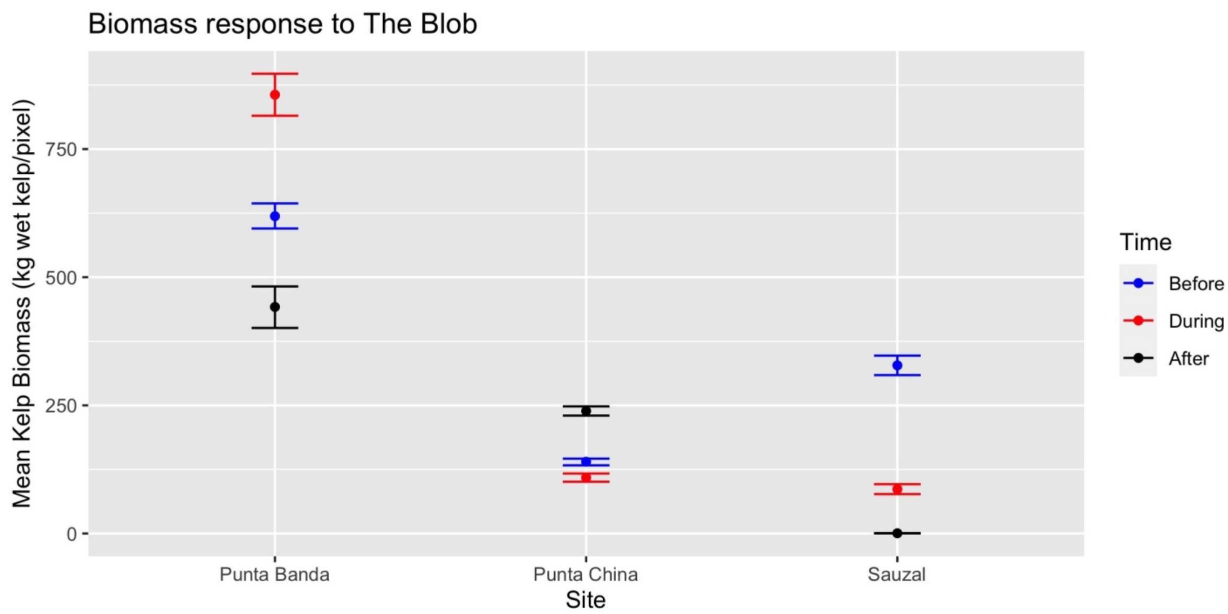

Figure 9. Biomass per site per time period.

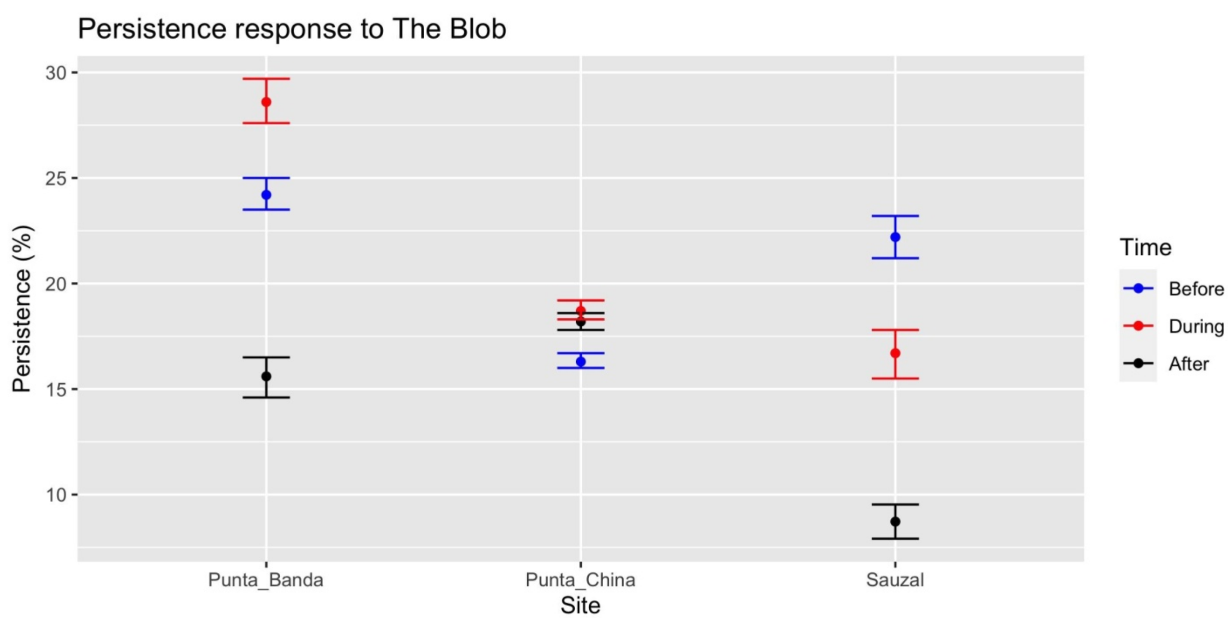

Figure 10. Persistence per site per time period.

Information and data gaps

Different responses were found when analyzing kelp forest biomass during, before and after the MHW The Blob. This is associated with a variety of anthropogenic impacts, geomorphology, oceanographic regime, and others (Cavanaugh *et al,* 2019), all which can modify the natural dynamics of local kelp forests through multiple scales of time and space. Here, general and specific recommendations are made based on the existing information and data gaps of sectors that affect kelp forests on a local scale: environmental, ecological, socio-economic, and governance. These should be understood in order to make informed management recommendations.

For all localities, environmental variables that have shown to affect kelp forest dynamics should be monitored *in situ*: temperature, light, turbidity and currents. Environmental variability like sea surface temperature, wave height and tides could be monitored through remote sensing (US National Oceanic and Atmospheric Administration; https://psl.noaa.gov/data/gridded/tables/sst.html) Also, the increasing input of runoffs should be accounted for: in Sauzal caused by urbanization runoffs (Gudino-Elizondo *et al.*, 2018), Punta Banda due to land use change and Punta China based in the limestone quarry (Torres-Moye and Escofet, 2014).

On an ecological aspect, although monitoring efforts are being done by the academic consortium MexCal (Management of Ecosystems Across the Californias; www.mex-cal.org), seasonal ecological monitoring of fish, algae, invertebrates and substrate, description should be done in order to understand the community dynamics and stability of each site, including invasive species monitoring (Rodriguez-Bravo, *in prep*). Also, updated biomass and persistence of kelp canopy should be seasonally assessed through remote sensing like shown in this study. The increasing sediment input effect on *M. pyrifera* settlement should be understood for Sauzal and Punta China, as well as the effect of existing purple urchin barrens on local kelp forests productivity in Punta Banda (Edwards *et al*, 2020).

On the socio-economical side of the ecosystem assessment, information of fished species and areas, as well as communities and industries involved in direct exploitation can be found through local governmental institutions and international organizations, like the National Institute of Fisheries (from the spanish *Instituto Nacional de Pesca*) and the Food and Agriculture Organization. Urbanization rate of these coastal areas and land use change should also be assessed with the National Institute of Statistics and Information (from the spanish *Instituto Nacional de Estadística y Geografía)*. This, in order to evaluate pressure on the marine ecosystems and a pressure increase in coastal ecosystems due to vegetation removal up the basins, urban sediments and contaminants runoffs to coastal substrate and water column.

As explored before, local kelp forest species management in Ensenada is not being carried out on an ecosystem level, but through quotas rights of specific marine resources and areas. A recommendation to address this issue is to integrate all knowledge and key actors involved for decision making through a marine management council (Zepeda-Dominguez 2016). This council should aim for an integration of regional, state and federal recognition of this ecosystem complexity on an environmental, cultural and economical level, and that it needs to be managed like that.

Blue carbon

Associated to the biomass-carbon proportion (1:0.026), biomass maps point directly to carbon sink and potential carbon sequestration areas, where more historically dense areas have capture the most carbon. The analysis shows that carbon capture estimations differed per site as well. A yearly average of carbon capture for Punta China, had the highest values, with 12,928.18 ton C/year but with a 4.9 gr m^2/day. Punta Banda with 5,178.32 ton C/year had the highest daily average with 9.9 gr m^2/ day, and finally Sauzal with 713.72 ton C /year and 2.2 gr m^2/ day. Although variable, these values are comparable with carbon on standing crops of tropical forests with 1,750 gr C m^2 /year (Whitaker, 1975).

DISCUSSIONS

Analyzed data indicates that scale matters: multiple stressors interact to create synergy, transforming kelp forest response against a MHW into a complex phenomenon to be measured. Therefore, kelp forest in Ensenada should be studied on a local scale. For this to be achieved, the recommendations should be addressed, due to the importance that this biogenic species have as a provider of multiple environmental services. But first, data gaps need to be filled for an integrated management of the kelp forest ecosystem proposal to be taken into action.

Punta Banda's main challenge is based on how a local threat of land use change can potentially increase runoff inputs to coastal substrate where productive kelp forests settle, and how to minimize this effect. For Sauzal, with urbanization already occupying those coastal areas, its challenge lies mainly in first: the research of mitigations of urban runoffs; and later reforestation viability for those areas where kelp forests used to thrive. Finally, Punta China's response although with a decrease in biomass after the event of The Blob, can be associated with a better resistance of this ecosystem facing environmental variability, and a capacity to respond after a MHW. Even with this local characteristic response, research should be first focused in understanding local dynamic that provoke this behavior with a limestone quarry actively working up the basin for over 50 years, and how it has affected community structure and its fishing potential.

Carbon capture data still does not translate as a carbon sink per se, but this analysis could take on step further to understand how carbon flows through kelp forests systems; from carbon that is stored as food for grazers and other fish, to carbon released back to the atmosphere and stored in deep waters. These results could highlight the role and importance of coastal marine ecosystems in Ensenada, especially Punta China, which shows that although it's substrate and water column have been heavily impacted by the limestone quarry, this patch has shown to be resilient in response to a recent MHW, a great carbon captor and with persistent canopy. Further knowledge generation in this area can support management strategies, such as the international market of Carbon and networks of climate change refuges.

According to the Chapter 17 section E of the Agenda 21 (UNCED, 1992) "Addressing critical uncertainties for the management of the marine environment and climate change", states that the high degree of uncertainty in present information inhibits effective management and limits the ability to make predictions and assess environmental change. As reviewed before, and after more than 25 years of this agreement was signed, kelp forest in the Ensenada region and its southern limit distribution have not been researched enough in order to understand the variation drivers on their biomass and productivity and to implement an integrated sustainable management of this resource. Plans and management programs should be updated with the recommendations and more than will come along the way.

Research of ecosystem modeling and how fisheries can affect the ecosystem is being done (Vilalta-Navas *et al,* 2018). This is another type of tool that integrated with the proper basis of anthropogenic impact and environmental variability effects on kelp, will help to predict the best practices that can assure ecosystem sustainability against a changing world.

Sites like Isla Todos Santos and Punta San Miguel (Paz-Lacavex, 2018) are recognized as the most productive kelp forests of the region, with a high economical importance for local fisheries. We consider that these sites have been able to thrive despite anthropogenic pressures due to their geographical distribution; frequency of surges with cold waters rich in nutrients, coastal structures that have acted as refuges for storms and their distance from urban areas. Facing climate change, these sites could act as climate shelters or refuges, allowing kelp forests dispersal and recovery when environmental conditions are optimal. But coastal areas, with anthropogenic impacts, like those explored in this study, are as relevant due to the ecosystem services they provide.

CONCLUSIONS

Through this study, evidence was found that the Ensenada´s kelp forest biomass variability response facing a MHW indicates that local differences are significant. Punta China showed to be the most resistant site, together with Punta Banda, whereas Sauzal showed no signal of significant recovery after the MHW. We attribute these differences to local characteristics, greater than environmental variability. Therefore, we recommend that further information is gathered on a local scale in order to understand cumulative effects that cause variability and to inform better management of this ecosystem dominated by *M. pyrifera*.

This example is one of the first approaches that through tools like remote sensing, data of historical biomass and persistence of kelp forests is shown in the Northern Mexican Pacific, specifically the Ensenada region. Like biomass and persistence maps, this display can be used as a tool for outreach, providing decision makers with comprehensive graphical data and promoting its use for an integrated coastal management when assessing this ecosystem on multiple scales. With this remote sensing technology and the integration of available data, it is possible to generate relevant information that allows the update of existing management strategies of the Ensenada region's kelp forests.

This analysis can be replicated in the Baja California Peninsula, in the southern distribution limit of kelp forests, to be used as a first approach to analyze other local dynamics and to promote a future network of Marine Reserves (Arafeh-Dalmau *et al,* 2017). The management of these selected sites can help avoid or slow down and resist regime shifts through tipping points surpassing, like tropicalization of temperate ecosystems, due mainly by Climate Change, promoting its resilience and resistance against environmental variability and anthropogenic impacts. In addition, stakeholders' alliance (government, fisheries, NGOs, research institutes, industry and local communities) is recommended to form through a key actors council, to promote and achieve an integrated kelp forest ecosystem management.

Given the amount of data handled for this study, limitations need to be considered. For example, results shown do not consider oceanographic variables like water turbidity, substrate types, depth, wave height, and others. In addition, recent satellite images contain data on a smaller scale, which could lead to past omission of smaller scale variability. Therefore, we consider this data as an underestimation of total biomass production along the years. Smaller scale analysis (>30x30m pixel), like images taken from drones, can help us understand on a finer scale local natural and anthropogenic drivers.

Effective adaptation and mitigation efforts by marine managers can benefit from improved knowledge on kelp forests response against local stressors, which at present is not accounted for as part of *Macrocystis pyrifera*s management in the Ensenada region. There is an imminent need for an updated Integrated Ecosystem Management. Through the use of innovative tools like the one presented in this study, and through the study of environmental variability responses, anthropogenic impacts and a multisectorial assessment, a sustainable usage of kelp forest ecosystem could help seek coastal solutions for today's issues.

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