Biodivers Conserv (2016) 25:261–273
DOI 10.1007/s10531-016-1045-6

ORIGINAL PAPER

Zostera marina meadows from the Gulf of California: conservation status

Jorge M. Lopez-Calderon[1] · Rafael Riosmena-Rodríguez[1] · Jorge Torre[2] · Alf Meling[3] · Xavier Basurto[4]

Received: 8 July 2015 / Revised: 24 December 2015 / Accepted: 9 January 2016 /
Published online: 20 January 2016

Abstract Eelgrass (*Zostera marina*) population estimates show a decreasing trend worldwide in the second half of the twentieth century. Mexico lacks long-term time series to determine trends for major eelgrass populations and has made no conservation efforts. Therefore, we present the first report on the historic presence of this annual coastal ecosystem in two wetlands of the Gulf of California (GC), the Infiernillo Channel (CIF, largest *Z. marina* population inside GC) and Concepcion Bay (BCP, the only eelgrass population along GC's west coast), combining field surveys (1999–2010), aerial photography (2000–2010), satellite imagery (1972–2005), and published reports (1994–2007). Three parameters were used as indicators of conservation status: shoot density, seed banks, and aerial coverage. Average shoot density in the CIF (741 shoots m^{-2}) was 3.8 times higher than in BCP (194 shoots m^{-2}), and average seed bank density was similar in both wetlands (17,442 seeds m^{-2} vs. 17,000 seeds m^{-2}). Opportunistic seagrass *Ruppia maritima* was observed in both wetlands, with higher abundance in summer when *Z. marina* disappears due to high water temperatures. Eelgrass coverage was three orders of magnitude greater in the CIF (9725 ha) than in BCP (3 ha). The striking difference between these wetlands is the lack of environmental protection for BCP and the protection of the CIF by the Seri indigenous community, which increases human pressure in the former, putting it at high risk of disappearing. Conservation of eelgrass meadows is not only necessary to preserve their ecosystem services but to insure the survival of migratory

Communicated by Dirk Sven Schmeller.

✉ Rafael Riosmena-Rodríguez
riosmena@uabcs.mx

[1] Programa de Investigación en Botánica Marina, Departamento Académico de Biología Marina, Universidad Autónoma de Baja California Sur, 23080 La Paz, BCS, Mexico

[2] Comunidad y Biodiversidad A.C., 85420 Guaymas, Son, Mexico

[3] Departamento de Investigaciones Científicas y Tecnológicas, Universidad de Sonora, Hermosillo, Son, Mexico

[4] Social Science and Policy, Duke University Marine Lab, Beaufort, NC 28516, USA

populations (Pacific brant goose, *Branta bernicla*), endangered species (Black turtle, *Chelonia mydas*), and fisheries-related species.

Keywords Seagrass meadows · Northwest Mexico · Thematic classification · Landsat images · Ecosystem services

Introduction

Seagrasses are key coastal ecosystems around the world (Short et al. 2007). They are highly productive and represent a major sink of atmospheric carbon dioxide (Nellemann et al. 2009). Unfortunately, there is evidence of worldwide decline at a rate higher than the deforestation of tropical rainforests (Orth et al. 2006; Waycott et al. 2009; Short et al. 2011). In Mexico, there are few efforts focused on determining the current status and medium-term trends of seagrasses, specifically for eelgrass populations (*Zostera marina*; Riosmena-Rodríguez et al. 2013).

Zostera marina meadows are critical habitats for conservation of biodiversity and of multiple ecosystem services (Riosmena-Rodríguez et al. 2013; Valle et al. 2013). Eelgrass is in danger of disappearing from the Gulf of California (GC) due its low populations number (five), global warming, and anthropogenic activity in the coastal zone. *Zostera marina* is a temperate species that has existed in the northeast Pacific since the Pliocene (five million years ago) (Domning 1976). Current distribution in North America extends from the Kotzebue Straight in Alaska to the GC in Mexico (Green and Short 2003). In northwest Mexico there are historic reports of *Z. marina* for 35 localities (Riosmena-Rodríguez et al. 2013), 23 of them in the GC; however, recent reports (after the year 2000) show a reduced presence of *Z. marina*, which is reported in only five localities (Table 1; Fig. 1a). Out of these, the Infiernillo Channel (CIF) and Concepcion Bay (BCP) are the most relevant; the former holds the largest annual population in northwest Mexico, and the latter is the only population occurring along the GC's western coast. Torre (2002) was the first to evaluate coverage of *Z. marina* meadows in the CIF, reporting over 6000 ha of continuous (3600 ha) and patchy (3000 ha) meadows. These meadows are the main biostructure in the CIF, providing fishing grounds and food for endangered (*Chelonia mydas*) and migratory species (*Branta bernicla*). Within BCP, eelgrass has only one population (located in the north), a small meadow (<10 ha) in a place called Arenas Point (Santamaría-Gallegos et al. 2000) (Fig. 1b). Unfortunately, this wetland lacks environmental protection, and human activities like fisheries have had detrimental consequences, collapsing invertebrate populations associated with *Z. marina* meadows in this area during the 1980s and 1990s (*Argopecten circularis*; Felix-Pico 1985; Tripp 1985; Gómez-del-Prado-Rosas et al. 1992; Villalejo-Fuerte and Ochoa-Báez 1993).

There is a general lack of environmental protection for seagrasses in Mexico. This trend has been reported worldwide, that is, seagrasses are key coastal ecosystems as highly productive coastal ecosystems and fundamental carbon sinks, but historically have been overlooked by scientists and the media (Duarte et al. 2008; Nellemann et al. 2009). Seagrasses need to be listed in the Mexican conservation agenda, just as Australia and the United States did decades ago (Schemske et al. 1994; Fonseca et al. 1998; Lee-Long et al. 2000). Coastal management of Mexican seagrass meadows cannot be properly achieved, because current seagrass mapping is at an incipient stage, and existing marine protected areas (MPAs) do not adequately protect seagrasses. There is only one MPA in northwest Mexico that includes eelgrass populations (El Vizcaino Biosphere Reserve), but *Z. marina*

Table 1 Localities with reports for *Zostera marina* in the Gulf of California

Number	Locality	Reference
1	B. Concepción, El Requesón, B.C.S.	Riosmena-Rodríguez and Sánchez-Lizaso (1996)
2	B. Concepción, Isla Bargo, B.C.S.	Den-Hartog (1970)
3*	B. Concepción, Punta Arenas, B.C.S.	Ramírez-García and Lot (1994); Riosmena-Rodríguez and Sánchez-Lizaso (1996); Sánchez-Lizaso and Riosmena-Rodríguez (1997); Santamaría-Gallegos et al. (2000); Muñiz-Salazar et al. (2005)
4	Isla San Esteban, Son	Ramírez-García and Lot (1994)
5	Isla Turner, Son	Ramírez-García and Lot (1994)
6	Canal de Infiernillo, Punta Chueca, Son	McMillan (1983); Meling-López and Ibarra-Obando (1999)
7*	Canal de Infiernillo, Son	Ramírez-García and Lot (1994); Brusca et al. (2004)
8	El Desemboque, Son	Felger and Moser (1973)
9	Canal de Infiernillo, Bahía Sargento, Son	Ramírez-García and Lot (1994)
10	C. de Infiernillo, Punta Víboras, Son	Meling-López and Ibarra-Obando (1999)
11*	Canal de Infiernillo, Son	Muñiz-Salazar et al. (2005)
12	Isla Alcatraz, Son	Ramírez-García and Lot (1994)
13	Bahía Kino, Son	Ramírez-García and Lot (1994)
14	Estero Tastiota, Son	Den-Hartog (1970)
15	Bahía de San Carlos, Son	Den-Hartog (1970)
16	Guaymas, Son.	Den-Hartog (1970)
17	Agiabampo, Son	Ramírez-García and Lot (1994)
18	Agiabampo, Son	Ortega et al. (1986)
19*	Agiabampo, Son	Muñiz-Salazar et al. (2005)
20	Topolobampo, Sin	Aguilar-Rosas and López Ruelas (1985), Ramírez-García and Lot (1994)
21*	Bahía Navachiste—Isla El Metate, Sin	Orduña-Rojas and Riosmena-Rodríguez (2008)
22*	Bahía Santamaría, Sin	Muñiz-Salazar et al. (2005)
23	Altata, Sin	Den-Hartog (1970)

Numbers refer to the map in Fig. 1a. Recent reports (after the year 2000) are marked with an asterisk

is not listed as a target species in the MPA's management programme. Recent efforts have been made to include seagrass species in the Mexican list of endangered species (NOM-059-SEMARNAT-2010); hopefully this will be realised in the near future and a national programme for seagrass conservation will be outlined. Here we report on the conservation status for the most relevant populations of *Z. marina* in the GC (CIF, BCP) by comparing historic (1972–2005) and recent data (2008–2010), remotely acquired (aerial photography, satellite imagery) and in situ (field surveys).

Methods

Field surveys

The CIF has a length of 41 km with an average depth of 6 m and a width between 2 and 10 km, an approximate area of 30,900 ha. BCP has similar dimensions as the CIF, a length

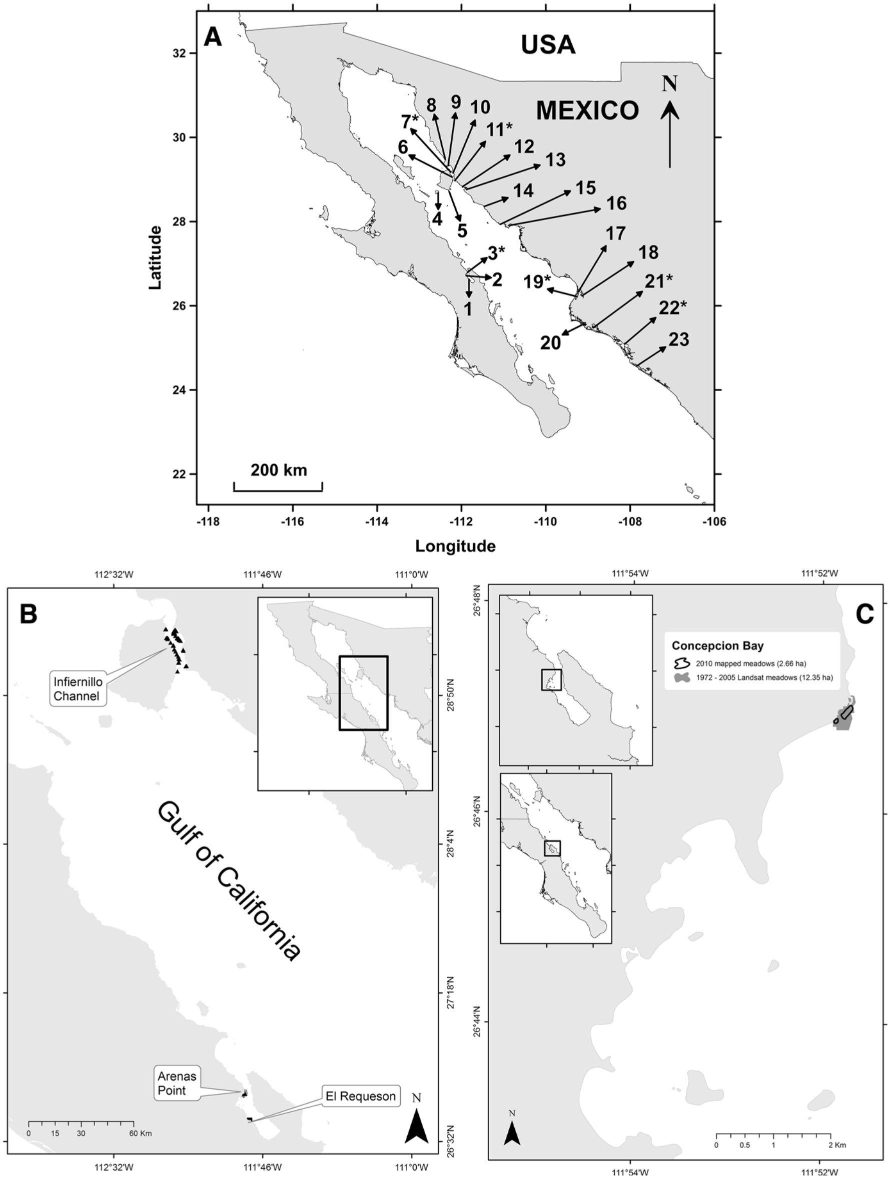

Fig. 1 **a** Historical reports for *Zostera marina* in the Gulf of California. Numbers correspond to localities listed in Table 1. **b** Eelgrass sampling locations at Concepcion Bay and Infiernillo Channel, *inset* shows location of both wetlands in the Gulf of California. **c** Eelgrass distribution mapped at Concepcion Bay with on-ground surveys (*black line*) and total presence area for years 1972, 1990, 2001, and 2005 with Landsat imagery (*gray polygon*)

of 41 km, a width between 4 and 11 km, an average depth of 17 m, and an approximate area of 28,600 ha. Given that eelgrass populations in the GC are annual, field surveys were performed on the dates that *Z. marina* meadows were present. In BCP there is only one eelgrass meadow located at Arenas Point, and it could only be observed on two occasions

(20–22 June 2009 and 1–5 May 2010). Meadows in the CIF are extremely abundant throughout the wetland and were sampled in three periods (27–31 March 2009, 9–16 March 2010, and 11–20 April 2010).

In order to describe the conservation status of *Z. marina*, we looked for meaningful population parameters. The NaGISA protocol outlined by Rigby et al. (2007) is a standardised method to sample coastal habitats worldwide (such as seagrass meadows) with the final purpose to describe biodiversity shifts for the next 50 years. This protocol highlights shoot density, seagrass coverage, and seed density as indicators for the conservation status of eelgrass and can be easily applied in developing countries like Mexico. Seagrass coverage was estimated visually from a boat, assisted by the traditional knowledge of local fishermen. The perimeter of each meadow was marked with a GPS Trimble Juno ST®. Coordinates for other substrates (sand, shell, algae, etc.) were also recorded to assist in the classification of satellite images. ArcGIS 9.3® was used to estimate the area of these polygons. Shoot density and seed banks were estimated as follows: for each sampled meadow, a 40 m transect was set, and four 25 × 25 cm quadrants were chosen randomly along this transect to quantify the shoots inside each quadrant. Three random points were also chosen to extract sediment cores using a 6″ PVC corer (López-Calderón and Riosmena-Rodríguez 2011). Each sediment core was sieved on the boat using seawater, with three sieves to collect different core fractions: 3360 μm (shoots), 840 μm (*Z. marina* seeds and invertebrates), and 420 μm (invertebrates). Each fraction was preserved using 70 % ethanol for later analysis. *Z. marina* samples were identified using specialised keys (Phillips and Menez 1988; Kuo and den Hartog 2001). The average number of seeds in the three replicate cores was used to estimate seed density. Statistical differences between localities and between samples were sought using parametric t-tests and one-way ANOVA with a significance level of 0.95.

Previous studies on both localities were used to compare eelgrass health statuses. For BCP, the only published reference is the work done by Santamaría-Gallegos et al. (2000), corresponding to the period from December 1994 to May 1995. For the CIF, Torre (2002) made a thorough evaluation of eelgrass meadows between 1999 and 2001, while Meling-López and Ibarra-Obando (1999) analysed the life cycle of this population. The CIF's *Z. marina* population has been the focus of research since the 1970s (Felger and McRoy 1975; Felger et al. 1980) as a potential food source.

Remote sensing

Aerial coverage was determined using recent and historic databases. Multispectral Landsat imagery was used at the following dates: BCP (2 November 1972, 4 May 1990, 17 October 2001, 12 October 2005) and the CIF (3 November 1972, 19 March 1976, 9 April 1990, 4 November 2005). Thematic classification of these images (Song et al. 2001) was done with validation data collected at the CIF and BCP on the dates mentioned at the beginning of the Methods section and also using data collected by Torre (2002) for the CIF. In the CIF, we were able to complement this information with aerial photography acquired in 2000 (Torre 2002) and 2010 (this study). All flights were in a Cessna 182 plane at an altitude of 2700 m. First flights coincided with periods of maximum eelgrass biomass (April 2000) and accelerated eelgrass growth (November 2000). In 2010, two flights were made over the CIF (March and April) in order to compare *Z. marina* coverage with data collected a decade ago (April 2000). Flights followed the protocol outlined by Torre (2002), flying at an altitude of 2700 m, with each photograph including a portion of land in order to georeference each one and calculate the area of each meadow. Photographs were taken flying sideways at right angles with the ocean surface and the camera lens in order to minimise optical deformation. Photographs were taken using a Nikon D3® camera with a polarised filter to enhance contrast between the sand and seagrass.

Results

Field surveys

Table 2 shows mean values for indicators shoot and seed density in both wetlands; high variability was observed for both of them through time, with significant differences (one-way ANOVA, $p < 0.05$) for all except in March 2010 versus March 1997, 1998 (shoot density) (Meling-López and Ibarra-Obando 1999). The CIF values for both indicators were higher than those at BCP. Minimum and maximum mean values for shoot density were 78 shoots m^{-2} (Palo Fierro Point) and 1488 shoots m^{-2} (Bajo Callero). The mean shoot density for the whole area was 741 shoots m^{-2}. The mean canopy height was 52 cm, with minimum and maximum values of 15 cm (Xpanams Point and Tormenta Point) and 100 cm (Arenas Point and Bajo Callero), respectively. Seed density was measured in 14 meadows inside and outside the CIF, with values from 208 seeds m^{-2} (Ensenada Tiburon) to 71,605 seeds m^{-2} (El Almo) and a mean value for the area of 17,442 seeds m^{-2}.

In June 2009 the *Z. marina* shoot density was 147 shoots m^{-2}, while in May 2010 it was 240 shoots m^{-2} (Table 2). Canopy height was higher in May (36 cm) than in June (25 cm); however, this reduction was not statistically significant (*t* test, $p > 0.05$). Seed density for this meadow was estimated at 17,000 seeds m^{-2} in May 2010. Sea surface temperature was higher in June (29 °C) than in May (25 °C). The presence of *R. maritima* was observed in both wetlands, in four localities in the CIF (San Miguel Estuary, Ohna Point, Tormenta Point, Santa Rosa Estuary) and two localities in BCP (Arenas Point and El Requeson). The mean shoot density for *R. maritima* in the CIF was 732 shoots m^{-2}, with minimum and maximum values of 328 shoots m^{-2} (October 2009) and 1368 shoots m^{-2} (August 2010). For BCP, there are no precedent records of *R. maritima*; its mean shoot density was higher at Arenas Point (984 shoots m^{-2}, May 2010) than at El Requeson (630 shoots m^{-2}, May 2010).

Table 2 Shoot density and seed density for *Zostera marina* at Concepcion Bay and the Infiernillo Channel measured in this study and previous reports

Wetland	Date	Shoot density (m^{-2})	Seed density (m^{-2})
Infiernillo Channel	March 2009	616.5 ± 287.4[a]	6210.9 ± 1312.9[a]
Infiernillo Channel	March 2010	998.7 ± 134.8[c]	25,333.5 ± 8231.8[c]
Infiernillo Channel	April 2010	780.7 ± 104.2[b]	20,054.9 ± 9341.0[b]
Infiernillo Channel[a]	March 1999, 2000	2055.0 ± 584.0[d]	–
Infiernillo Channel[b]	March 1997, 1998	1049.0 ± 300.0[c]	71,187.0 ± 12,992.0[d]
Concepcion Bay	June 2009	146.7 ± 13.3[e]	–
Concepcion Bay	May 2010	240.0 ± 59.4[f]	17,000.0 ± 0.0[e]
Concepcion Bay[c]	May 1995	664.0[g]	30,000.0[f]

[a] Torre (2002)

[b] Meling-López and Ibarra-Obando (1999)

[c] Santamaría-Gallegos et al. (2000)

Remote sensing

Combining data from samplings made in 1999–2001 and 2009–2010 (Fig. 2b), eelgrass coverage was similar to the coverage determined with Landsat imagery for November 2005 (Table 3; Fig. 2a). Change in seagrass coverage, combining satellite information from 1972, 1976, 1990, and 2005, shows a permanently vegetated area of 7200 ha (Table 3; Fig. 2b), representing 21 % of the whole area covered by eelgrass at some time since 1972. On average, 37 % of this whole covered area represents non-vegetated sites that were vegetated in the previous year (decolonised), and 42 % were non-vegetated sites occupied by *Z. marina* in the next year (colonised, Table 3).

At Arenas Point, seagrass coverage is minimum compared to the CIF; in the latter eelgrass covers 23 % of the wetland, while the former was historically covered by only 0.04 % (12 ha). Thematic classification for BCP was less extensive than the CIF because *Z. marina* is confined to Arenas Point and only the west coast was surveyed for types of substrate. The extension of the meadow in the image from October 2005 was 3 ha; however, for the image from May 1990 the size of the meadow was almost twice as much (5 ha). Considering the whole area covered by eelgrass at some time since 1970 at BCP, a maximum extension of 12 ha was reached (Fig. 1c). Within this polygon, on average, 41 % of eelgrass coverage persisted between 1970 and 2005 (Table 3, stable), while 39 % of the area covered was decolonised at some time (decolonised); the remaining 20 % corresponded to areas that shifted from non-vegetated to vegetated at some point (colonised).

Discussion

Seagrass density in the CIF was three times more than what was observed for BCP. Canopy height values from 2009 to 2010 were significantly higher (*t* test, $p < 0.05$) than the measurements taken more than a decade ago (52 vs. 34 cm, Meling-López and Ibarra-Obando 1999). There was high variability in seed bank density (four-fold variation between meadows), with the highest values similar to those reported by Meling-López and Ibarra-Obando (1999) for meadows located in Punta Chueca and Viboras Point (Table 2). Maximum observed abundance of *R. maritima* in CIF corresponded to the season when *Z. marina* was absent (summer), and thus it had the chance to occupy more substrate; other primary producers showed the same pattern, like the native algae *Caulerpa sertularioides*.

Comparison of aerial photographs between 2000 and 2010 lead us to state that seagrass meadows have remained without significant spatial variation during the last decade (Fig. 2c, d), with the exception of the northern section of the CIF, where two meadows (Sargento Estuary and north of El Alamo) appeared less extensive (data not shown). Possible reasons for this reduction are sediment runoff, herbivory, or local shifts in circulation. Photographical estimations are confirmed by Landsat imagery; that is, a permanent seagrass coverage at the CIF between 1972 and 2005 of 7200 ha (Fig. 2b). Surveys based on field (Fig. 2b, 9725 ha) and satellite data (Fig. 2a, 8221 ha) show seagrass coverage above this value.

For BCP, Hinojosa-Arango et al. (2014) did an evaluation of the benthic habitats in April 2011 in combination with satellite data (May and June 2011). They reported a seagrass coverage of 33.74 ha for the bay; however, these authors did not specify whether the seagrass coverage was *Z. marina* or *R. maritima*, the latter being an opportunistic

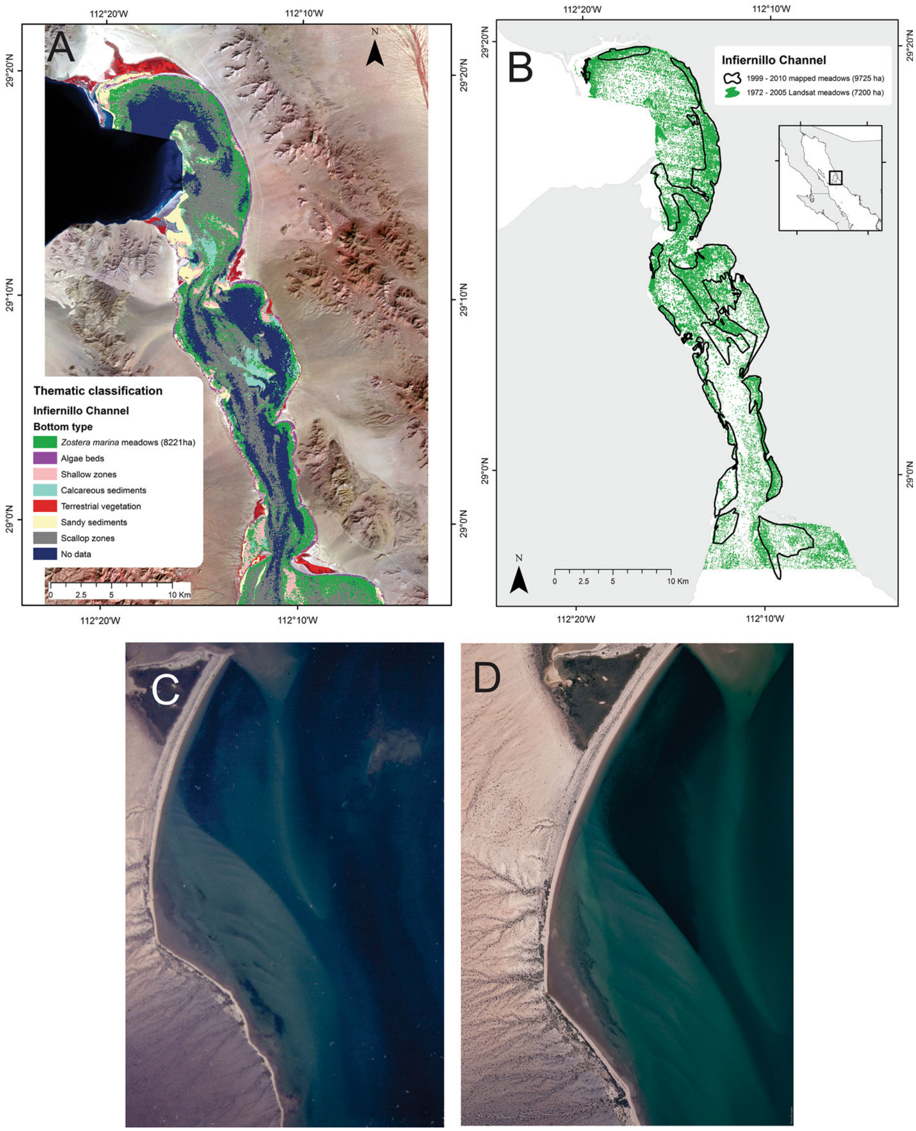

Fig. 2 **a** Thematic classification of Infiernillo Channel Landsat image (4 November 2005) showing different types of bottom. **b** Eelgrass distribution mapped at Infiernillo Channel with on-ground surveys (*black line*) and total presence area for years 1972, 1976, 1990, and 2005 with Landsat imagery (*green polygons*). **c** Aerial photographs of *Zostera marina* meadow at Coniic Point (Infiernillo Channel) showing stability of the meadow between April 2000 and April 2010 (**d**)

species that has expanded recently in the bay (Arenas Point and El Requeson). This coverage could be an overestimation of *Z. marina's* presence in BCP or a tremendous sign of recovery for this population. In either case, detailed information on the location of the field surveys is needed. Sampling periods for BCP were restricted to months when eelgrass shoots could be observed (May and June), which is a sign of stress for this population. In

Table 3 Change in seagrass coverage for *Zostera marina* at Concepcion Bay (BCP) and the Infiernillo Channel (CIF) measured with Landsat imagery, aerial photography, and previous reports

Wetland	Date	Stable	Colonised	Decolonised	Coverage
BCP	Nov 1972–May 1990	3.21	1.47	6.35	
BCP	May 1990–Oct 2001	3.91	1.36	0.93	
BCP	Oct 2001–Oct 2005	2.18	1.74	3.3	
BCP (total presence area)	Nov 1972–Oct 2005				12.35
BCP	Oct 2005				3.0
BCP (field survey)	May 2010				2.66
CIF	Nov 1972–Mar 1976	2135	5863	3893	
CIF	Mar 1976–Apr 1990	3584	7341	4547	
CIF	Apr 1990–Nov 2005	3443	4662	7609	
CIF (total presence area)	Nov 1972–Nov 2005				7200
CIF	Nov 2005				8221
CIF (aerial photographs)	Mar 1999, 2010				9725
CIF Torre (2002)	Mar 1999, 2000				6687

contrast, CIF observations could be made for more months (March, April, October). Given that the CIF is home to the world's largest annual *Z. marina* population, we made an additional sampling in August to assess the period when eelgrass meadows are absent and other submerged aquatic vegetation (*C. sertularioides* and *R. maritima*) covers portions of their territory.

As for shoot density, Santamaría-Gallegos et al. (2000) reported a fluctuation between 2334 shoots m^{-2} (January 1995) and 664 shoots m^{-2} (May 1995) for BCP. Shoot density quantified in this study is 36 % lower than that reported 20 years ago. Likewise, seed banks in May 2010 were 53 % lower than in May 1995. An increase in seawater temperature as a consequence of global warming could be a reason for the reduction observed in shoot density and seed banks. Unfortunately, there are no time series reports for seawater temperature for this locality. Temperature is a limiting factor for *Z. marina*. Nejrup and Pedersen (2008) reported that between 25 and 30 °C this species shows an increase in mortality and a reduction of its photosynthetic and growth rates. On the contrary, this temperature range represents no threat to *R. maritima*, whose temperature tolerance (10–30 °C) is greater than that of *Z. marina* and other seagrass species (Lazar and Dawes 1991). Another factor affecting *Z. marina* is human settlements located about 50 m away from the meadow, consisting of a group of 25 cabins, some of which are utilised seasonally by vacationers. It is clear that during the last 15 years there has been an alteration to the structure of the submerged aquatic vegetation. Evidence of this is the presence of a second seagrass species (*R. maritima*) which has not been reported for this locality or for the rest of BCP.

Despite its aesthetic value and richness of flora and fauna, BCP is not within an MPA; it only holds one governmental award as a Priority Marine Area granted in 1998 (CONABIO, USAID, WWF, FMCN, Packard Foundation). This increases the vulnerability of this wetland, because fragile ecosystems like *Z. marina* meadows lack environmental protection to warrant their endurance. Thus, human activities in Arenas Point like fishing or sewage discharges can increase without proper management, jeopardising the permanence of *Z. marina* in BCP in the mid-term. Seed densities observed in the CIF and BCP were within the values reported for other annual meadows (Santamaría-Gallegos 1996; Olesen 1999); however, the small size of the meadow in BCP results in a higher degree of vulnerability for this population. Muñiz-Salazar et al. (2005) reported the existence of genetic flux between populations of these two wetlands; therefore, there is a possibility of a natural repopulation from the CIF to BCP. Mesoscale circulation in the GC (Pegau et al. 2002; Lopez-Calderon et al. 2008) shows evidence of a rapid (weeks) exchange of water masses between both coasts. It is important to highlight that seagrass transport towards BCP will be unfruitful if the habitat quality keeps deteriorating. A further reduction in light availability coupled with an increase in nutrient input (eutrophication) will prevent the development of *Z. marina* shoots.

Eelgrass meadows are threatened throughout the GC, and their reduction has been documented previously (Riosmena-Rodríguez et al. 2013). As noted in Table 1 and Fig. 1a, *Z. marina* was historically present in 23 localities of the GC, with BCP being the only locality on the western coast of the gulf with eelgrass populations, the rest being on the eastern coast, from El Desemboque, Sonora (locality 8) to Altata, Sinaloa (locality 23) (Table 1; Fig. 1a). This is no longer the scenario for *Z. marina*. After the year 2000 there have only been reports for this seagrass species in five localities: BCP, CIF, Agiabampo, Bahia Navachiste, and Bahia Santamaría (Table 1). BCP is one of the worst scenarios for *Z. marina*, and the only eelgrass bed is on the western side of the GC. On the other hand, the CIF is the best preserved population in the whole GC. An example of this is in Fig. 2c, d. Whereas the CIF had almost the same amount of disappeared and colonised areas, BCP had almost twice as many disappeared areas in relation to colonised areas (Table 3). Thus, the CIF has a stable eelgrass interannual coverage, while BCP has been constantly declining. Healthy seagrass populations should have a difference between disappeared and colonised areas that is positive or close to zero. Positive balance in the CIF is a result of protection from overfishing, anthropogenic runoff, and land use change by the Seri indigenous community. Conversely, BCP shows a negative balance, because it lacks any source of environmental protection and has been stressed by factors like overexploitation in the 1980s by the scallop fishery (Gómez-del-Prado-Rosas et al. 1992; Villalejo-Fuerte and Ochoa-Báez 1993). The remaining *Z. marina* meadows in the GC are jeopardised by natural factors (ocean warming, hurricane intensification) but mostly by anthropogenic factors (agriculture, urban and industrial runoff, land use change, overfishing, and oyster and shrimp farms). Eutrophication has serious consequences that intensify the effect of other disturbances like ocean warming (increasing plants' metabolism), and more available nutrients could also trigger excessive growth of macroalgae above the meadow, hampering the light field and eventually suffocating the shoots. Seagrasses can tolerate this stress, but at a high cost. In the worst case, chronic damage is capable of obliterating an entire population, even after eutrophication has diminished (Van Katwijk et al. 2010).

Valle et al. (2013) demonstrated that eelgrass meadows are dynamic entities, meaning that not all habitable areas are colonised each year. It is important to acknowledge this trait when creating seagrass conservation areas. Spatial distribution models are useful tools to identify suitable habitats and to delimitate conservation areas. In their study, Valle et al. (2013) showed that few environmental variables are needed to predict eelgrass' total presence and conservative presence areas, and that 4 years of data (remotely sensed and ground surveyed) are enough to establish a representative spatial distribution model for a population (significantly reducing costs). To preserve a seagrass meadow not only means to preserve its ecosystem services such as fisheries species or blue carbon capture; it also means the survival of the migratory Pacific brant goose or black brant (*Branta bernicla nigricans*), whose habitat (from Alaska to Baja California peninsula) strongly depends on tidal and shallow subtidal eelgrass beds, the main food source for this species during its winter migration (Moore et al. 2004). According to Valle et al. (2013), geographically isolated bays (1×10^2 km apart) with abundant eelgrass beds are key points to black brant's annual flyway, like Humboldt Bay. In addition to the brant goose, the black turtle (*Chelonia mydas*) uses seagrass as a feeding habitat, and changes in the available species will be clearly reflected in the diet (Lopez-Calderon et al. 2010). In the southern portion of the Baja California peninsula there are three key zones with such characteristics: one in the GC (CIF, largest annual eelgrass population in the world) and two in the Pacific (Magdalena Bay and San Ignacio—Ojo de Liebre lagoons). These three zones are major and fundamental feeding areas for the Pacific brant goose (Ward et al. 2005, 2009).

It has been forecasted that by the year 2044 25 % of the 250,000 known species of vascular plants in the world will be extinct (Schemske et al. 1994). *Z. marina* will not be on that list, but its populations at the southern limit of its distribution in the Pacific are at a higher risk for disappearing. Actions must be taken in all parts of society (government, academia, media, and community) to ensure its long-term conservation (monitoring, restoration, and legal protection).

Ruppia maritima has gained relevance in northwest Mexico in the last decade as an opportunist species colonising several localities, sometimes displacing *Z. marina*, especially in muddy zones of the intertidal (Lopez-Calderon et al. 2010).

Acknowledgments We wish to thank pilot Sandy Lanham for her support during the CIF aerial surveys in 1999 and 2010 and the Christensen Fund for funding the flights. We also thank the Comcáac community, especially Alfredo López, elder of the Comcáac council. Additionally, we thank Thor Morales for the photographs taken during aerial surveys in 2010, as well as Rafael Segovia, Cathy Marlett, and Steve Marlett for sharing their knowledge on the CIF. JMLC is grateful for support by CONACYT Grant #19923, and Rafael Riosmena-Rodríguez acknowledges the support of CONACYT SEMARNAT Grant #2345.

References

Aguilar-Rosas R, López-Ruelas J (1985) *Halodule wrightii* Aschers (Potamogetonales: Cymodoceae) in Topolobampo Bay, Sinaloa, Mexico. Cienc Mar 11:87–91

Brusca RC, Kimrey E, Moore W (2004) A seashore guide to the northern Gulf of California. Arizona-Sonora Desert Museum, Tucson

Den-Hartog C (1970) The seagrasses of the world. North Holland Publishing, Amsterdam

Domning DP (1976) An ecological model for late tertiary sirenian evolution in the North Pacific Ocean. Syst Zool 25:352–362

Duarte CM, Dennison WC, Orth RJ, Carruthers TJB (2008) The charisma of coastal ecosystems: addressing the imbalance. Estuaries Coasts J CERF 31:233–238. doi:10.1007/s12237-008-9038-7

Felger RS, McRoy CP (1975) Seagrass as potential food plants. In: Somers GF (ed) Seedbearing halophytes as food plants. University of Delaware, Newark, pp 62–74

Felger R, Moser MB (1973) Eelgrass (*Zostera marina* L.) in the Gulf of California: discovery of its nutritional value by the Seri Indians. Science 181:355–356

Felger RS, Moser MB, Moser EW (1980) Seagrasses in Seri Indian culture. In: Phillips RC, McRoy CP (eds) Handbook of seagrass biology: an ecosystem perspective. Garland STPM Press, New York, pp 260–276

Felix-Pico EF (1985) %Cultivo de *Argopecten circularis* en Baja California Sur, México. 5th International Pectinid Workshop. España, p 12

Fonseca MS, Kenworthy WJ, Thayer GW (1998) Guidelines for the conservation and restoration of seagrasses in the United States and adjacent Waters. In: NsCO Program (Ed.) Decision analysis series no. 12. U.S. Department of Commerce—NOAA, Maryland

Gómez-del-Prado-Rosas MdC, Álvarez-Torres S, Perez-Urbiola JC (1992) Algunos parásitos de almeja "catarina", *Argopecten circularis*, en Bahía Concepción, B.C.S., México. Anales del Instituto de Biología Universidad Nacional Autónoma de México Serie Zoología 63:265–271

Green EP, Short FT (2003) World atlas of seagrasses. University of California Press, Berkley

Hinojosa-Arango G, Rioja-Nieto R, Suárez-Castillo AN, Riosmena-Rodríguez R (2014) Using GIS methods to evaluate rhodolith and *Sargassum* beds as critical habitats for commercially important marine species in Bahía Concepción, B.C.S., México. Cryptogam Algol 35:49–65

Kuo J, den-Hartog C (2001) Seagrass taxonomy and identification key. In: Short FT, Coles RG (eds) Global seagrass research methods. Elsevier, Amsterdam, pp 31–58

Lazar AC, Dawes CJ (1991) A seasonal study of the seagrass *Ruppia maritima* L. in Tampa Bay, Florida: organic constituents and tolerances to salinity and temperature. Bot Mar 34:265–269

Lee-Long WJ, Coles RG, McKenzie LJ (2000) Issues for seagrass conservation management in Queensland. Pac Conserv Biol 5:321–328

López-Calderón J, Riosmena-Rodríguez R (2011) Nucleador para praderas de pastos marinos. Ondas Internas 15:30–32

Lopez-Calderon J, Martinez A, Gonzalez-Silvera A, Santamaria-del-Angel E, Millan-Nuñez E (2008) Mesoscale eddies and wind variability in the northern Gulf of California. J Geophys Res. doi:10.1029/2007JC004630

Lopez-Calderon J, Riosmena-Rodríguez R, Rodríguez-Baron JM, Carrión-Cortez J, Torre J, Meling-López A, Hinojosa-Arango G, Hernández-Carmona G, García-Hernández J (2010) Outstanding appearance of *Ruppia maritima* along Baja California Sur, México, and its influence in trophic networks. Mar Biodivers 40:293–300

McMillan C (1983) Seed germination for an annual form of *Zostera marina* from the Sea of Cortez, Mexico. Aquat Bot 16:105–110

Meling-López AE, Ibarra-Obando SE (1999) Annual life cycles of two *Zostera marina* L. populations in the Gulf of California: contrasts in seasonality and reproductive effort. Aquat Bot 65:59–69

Moore JE, Colwell A, Mathis RL, Black JM (2004) Staging of Pacific flyway brant in relation to eelgrass abundance and site isolation, with special consideration of Humboldt Bay, California. Biol Conserv 115:475–486

Muñiz-Salazar R, Talbot SL, Sage GK, Ward DH, Cabello-Pasini A (2005) Population genetic structure of annual and perennial populations of *Zostera marina* L. along the Pacific coast of Baja California and the Gulf of California. Mol Ecol 14:711–722

Nejrup LB, Pedersen MF (2008) Effects of salinity and water temperature on the ecological performance of *Zostera marina*. Aquat Bot 88:239–246

Nellemann C, Corcoran E, Duarte CM, Valdés L, de Young C, Fonseca L, Grimsditch G (2009) Blue carbon: a rapid response assessment. United Nations Environment Programme. Grid-Arendal. www.grida.no

Olesen B (1999) Reproduction in Danish eelgrass (*Zostera marina* L.) stands: size-dependence and biomass partitioning. Aquat Bot 65:209–219

Orduña-Rojas J, Riosmena-Rodríguez R (2008) Inventario de la macrofauna marina de interés económico de las islas del norte de Sinaloa, México (Ed.) Sinaloa PFC-. CIDIR Unidad Sinaloa, Guasave, pp 1–36

Ortega MM, Ruiz-Cárdenas J, Oliva-Martínez MG (1986) La vegetación sumergida en la Laguna Agiabampo, Sonora-Sinaloa. An Inst Biol Univ Nal Autón México Ser Bot 57:59–108

Orth RJ, Carruthers TJ, Dennison WC, Duarte CM, Fourqurean JW, Heck KL (2006) A global crisis for seagrass ecosystems. Bioscience 56(12):987–996

Pegau WS, Boss E, Martínez A (2002) Ocean color observations of eddies during the summer in the Gulf of California. Geophys Res Lett. doi:10.1029/2001GL014076

Phillips RC, Menez EG (1988) Seagrasses. Smithson Contrib Mar Sci 34:1–104

Ramírez-García P, Lot A (1994) La distribución del manglar y de los "pastos marinos" en el Golfo de California, México. An Inst Biol Univ Nal Autón México Ser Bot 65:63–72

Rigby PR, Kato T, Riosmena-Rodríguez R (2007) NaGISA seagrass protocol. In: Rigby PR, Iken K, Shirayama Y (eds) Sampling biodiversity in coastal communities: a NaGISA handbook. Kyoto University Press, Kyoto, pp 25–30

Riosmena-Rodríguez R, Sánchez-Lizaso JL (1996) El límite sur de distribución de *Zostera marina* L. y *Phyllospadix torreyi* Watson para el noroeste mexicano. Oceánides 11:45–48

Riosmena-Rodríguez R, Muñiz-Salazar R, López-Calderón J, Torre-Cosio J, Meling A, Talbo SL (2013) Conservation status of *Zostera marina* populations at Mexican Pacific. In: Daniels JA (ed) Advances in environmental research, vol 27. Nova Science Publishers, New York, pp 35–63

Sánchez-Lizaso JL, Riosmena-Rodríguez R (1997) Macroalgas epífitas de *Zostera marina* L. en Bahía Concepción, B.C.S, México. Oceánides 12:55–59

Santamaría-Gallegos NA (1996) Ciclo de crecimiento y fenología de la fanerógama *Zostera marina* L. en Punta Arena, Bahía Concepción, B.C.S., México, p 97. Unpublished Master Thesis, Centro Interdisciplinario de Ciencias Marinas, La Paz

Santamaría-Gallegos NA, Sánchez-Lizaso JL, Félix-Pico EF (2000) Phenology and growth cycle of annual subtidal eelgrass in a subtropical locality. Aquat Bot 66:329–339

Schemske DW, Husband BC, Ruckelshaus MH, Goodwillie C, Parker IM, Bishop JG (1994) Evaluating approaches to the conservation of rare and endangered plants. Ecology 75(3):584–606

Short FT, Carruthers TJ, Dennison WC, Waycott M (2007) Global seagrass distribution and diversity: a bioregional model. J Exp Mar Biol Ecol 350:3–20

Short FT, Polidoro B, Livingstone SR, Carpenter KE, Bandeira S, Bujang JS (2011) Extinction risk assessment of the world's seagrass species. Biol Conserv 144:1961–1971

Song C, Woodcock CE, Seto KC, Lenney MP, Macomber SA (2001) Classification and change detection using Landsat TM data: when and how to correct atmospheric effects? Remote Sens Environ 75:230–244

Torre J (2002) Inventory, monitoring and impact assessment of marine biodiversity in the Seri Indian territory, Gulf of California, Mexico. School of renewable natural resources. The University of Arizona, PhD dissertation, Tucson, p 196

Tripp QA (1985) Explotación y cultivo de la almeja catarina *Argopecten circularis* en Baja California Sur. Unpublished Master in Science Thesis, CICIMAR, IPN, p 267

Valle M, van Katwijk MM, de Jong DJ, Bouma TJ, Schipper AM, Chust G, Benito BM, Garmendia JM, Borja Á (2013) Comparing the performance of species distribution models of *Zostera marina*: implications for conservation. J Sea Res 83:56–64

Van Katwijk MM, Bos AR, Kennis P, de Vries R (2010) Vulnerability to eutrophication of a semi-annual life history: a lesson learnt from and extinct eelgrass (*Zostera marina*) population. Biol Conserv 143(1):248–254

Villalejo-Fuerte M, Ochoa-Báez RI (1993) The reproductive cycle of the scallop *Argopecten circularis* (Sowerby, 1835) in relation to temperature and photoperiod, in Bahia Concepcion, B.C.S., Mexico. Cien Mar 19:181–202

Ward DH, Reed A, Sedinger JS, Black JM, Derksen DV, Castelli PM (2005) North American Brant: effects of changes in habitat and climate on population dynamics. Glob Chang Biol 11:869–880

Ward DH, Dau CP, Tibbitts TL, Sedinger JS, Anderson BA, Hines JE (2009) Change in abundance of Pacific Brant wintering in Alaska: evidence of a climate warming effect? Arctic 62(3):301–311

Waycott M, Duarte CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proc Natl Acad Sci 106(30):12377–12381