

Outstanding appearance of *Ruppia maritima* along Baja California Sur, México and its influence in trophic networks

Jorge Lopez-Calderon · Rafael Riosmena-Rodríguez · Juan M. Rodríguez-Baron · Javier Carrión-Cortez · Jorge Torre · Alf Meling-López · Gustavo Hinojosa-Arango · Gustavo Hernández-Carmona · Jaqueline García-Hernández

Received: 4 March 2010 / Revised: 17 June 2010 / Accepted: 22 June 2010 / Published online: 13 July 2010
© Senckenberg, Gesellschaft für Naturforschung and Springer 2010

Abstract Human impact and global warming are driving major modifications to the world's ecosystems, the coastal zone being one of the most damaged. Seagrass meadows constitute coastal communities that have experienced great losses worldwide. The dominant seagrass in the meadows of the Pacific coast of North America is *Zostera marina*. There is evidence that *Z. marina* has been replaced in some places by the opportunistic seagrass *Ruppia maritima* with important implications for the trophic connections of local ecosystems. In México, there are few reports on the distribution and loss of seagrass meadows. Here, we report on the importance that *R. maritima* has gained in three wetlands of northwest México, replacing *Z. marina* and modifying local trophic networks. We made extensive samplings on *Z. marina* and *R. maritima* meadows, recording shoot density and marking their spatial distribution with GPS. We included information on the presence of *R. maritima* at other wetlands of northwest México from historical reviews and current sampling. *R. maritima* was

recorded in 29 localities, 3 of which are new records. Their shoot density and spatial coverage were highest in late fall and decreased in late spring, while *Z. marina* meadows increased after the reduction of *R. maritima* meadows. *R. maritima* now constitutes a primary food source for green turtles in the sampled wetlands, something unprecedented a few years ago. Improvement of wetland management plans is needed to stop environmental degradation, *R. maritima* invasion, and the loss of ecosystem functions.

Keywords Invasive species · Aquatic plants · Sea turtles · Wigeongrass · Eelgrass · Marine protected areas

Introduction

The genus *Ruppia* (L. 1737) (family *Ruppiaceae*) belongs to a taxonomic group of aquatic vascular plants that lives in poikilosaline environments, which means that it tolerates

J. Lopez-Calderon (✉) · R. Riosmena-Rodríguez · J. Carrión-Cortez
Programa de Botánica Marina, Departamento de Biología Marina,
Universidad Autónoma de Baja California Sur,
Apdo. Postal 19-B,
La Paz, Baja California Sur 23080, México
e-mail: jlopez@uabcs.mx

J. M. Rodríguez-Baron · G. Hernández-Carmona
Centro Interdisciplinario de Ciencias Marinas,
Av. Instituto Politécnico Nacional s/n,
Playa Palo de Santa Rita,
La Paz, Baja California Sur 23096, México

J. Torre
Comunidad y Biodiversidad A.C.,
Blvd. Agua Marina 297 entre Jaiba y Tiburón, Col. Delicias,
Guaymas, Sonora 85420, México

A. Meling-López
Departamento de Investigaciones Científicas y Tecnológicas,
Universidad de Sonora,
Blvd. Luis Donaldo Colosio entre Reforma y Sahuaripa,
Edificio 7G,
83000 Hermosillo, Sonora, México

G. Hinojosa-Arango
The School for Field Studies,
Puerto Acapulco s/n,
Puerto San Carlos, Baja California Sur 23740, México

J. García-Hernández
Centro de Investigación en Alimentación y Desarrollo A.C.
(CIAD),
Carretera al Varadero Nacional km. 6.6, Col. Las Playitas,
Guaymas, Sonora 85480, México

hypersaline, brackish, and freshwater conditions (Setchell 1924; Kuo and den Hartog 2001; Den Hartog and Kuo 2006). There has been some taxonomic disagreement among specialists concerning the number of species within this genus, which has resulted in many proposed species, most of them being morphotypes of *Ruppia maritima* L. (1753) (Setchell 1946; Phillips 1958; Richardson 1980; Den Hartog 1981; Kantrud 1991; Zhao and Wu 2008). *Ruppia maritima* (also known as wigeongrass) is the most representative species of the genus because of its wide distribution in temperate and tropical latitudes in both hemispheres (Oliveira et al. 1983; Orth and Moore 1988; Reyes and Merino 1991; Malea et al. 2004; Keates and Osher 2007). It is a narrow-leaved species, characterized by a fast growing rate and low underground and aboveground biomasses. These characteristics give *R. maritima* the possibility to be an excellent competitor, able to colonize large areas in short periods of time after a disturbance or when unfavorable environmental conditions for climax seagrass species occur (temperature, light, salinity). Sea temperature fluctuations produced by global warming or El Niño Southern Oscillations (ENSO) are responsible for major reductions of seagrass populations around the world (Johnson et al. 2003; Ehlers et al. 2008). In these conditions, it is possible that climax seagrass species, like *Thalassia testudinum* (Koenig) (Robblee et al. 1991) or *Zostera marina* (L.) (Orth and Moore 1988), could be partially or completely replaced by opportunistic species (i.e., seaweeds or *R. maritima*), producing a radical change in the trophic structure of the community (Cho et al. 2009).

There are few studies that focus on the distribution or abundance of *R. maritima* along the littoral zone of México. One possible reason for this is the common knowledge that this species thrive in brackish–freshwater habitats (Oliveira et al. 1983; Kuo and den Hartog 2001). Therefore, botanists tend to overlook this species in the marine environment, perhaps misidentifying *Ruppia* sp. as *Halodule* sp. Wigeongrass is distributed along the Pacific and Atlantic coasts of México (Dawson 1962; Felger et al. 1980; Flores-Verdugo et al. 1988; Reyes and Merino 1991). At the Gulf of California and the west coast of the Baja California peninsula, *R. maritima* has been documented as a component of the seagrass community in some wetlands (Meling-López and Ibarra-Obando 1999; Santamaría-Gallegos et al. 2001, 2007; Riosmena-Rodríguez et al. 2010). However, information regarding *R. maritima* is not complete as records referring its presence do not give any information on its geographic location within these wetlands or its abundance. This fact could indicate that the presence of *R. maritima* was too low compared to the presence of the seagrasses *Z. marina* (also known as eelgrass), *Phyllospadix torreyi* (S. Watson,) and *Phyllospadix scouleri* (Hooker) at the time of the surveys.

Dawson (1962) was one of the first to report *R. maritima* in northwest México, specifically at Bahía San Quintín (Fig. 1). Oliva-Martínez and Ortega (1983) studied the submerged vegetation in two wetlands in the state of Sinaloa and found that *R. maritima* was the only vascular plant present. This is one of the few works that illustrates the spatial location of *R. maritima* and includes a qualitative estimation of its spatial and temporal distribution. Felger et al. (1980) and Felger and Moser (1985) reported the presence of *R. maritima* at the Gulf of California, in the water body between Tiburon Island and the state of Sonora, a region known as Canal de Infiernillo (Fig. 1, site 18). Ramírez-García and Lot (1994) published the most extensive description of *R. maritima* for the Gulf of California; they report its presence at 11 sites, ranging from Angel de La Guarda Island in the north, to Cabo San Lucas at the southern end of Baja California Sur (Fig. 1, sites 16 and 7, respectively). In the present study, we include data from recent surveys made at the northern end of the Gulf of California, Canal de Infiernillo, and along both coasts of the southern Baja California peninsula (Fig. 1, underlined localities), expanding our knowledge on the variability of *R. maritima* meadows.

Recently, studies have been done on the vascular vegetation in three major coastal lagoons on the Pacific side of Baja California Sur: Laguna Ojo de Liebre (Scammon's Lagoon), Laguna San Ignacio, and Bahía Magdalena (Fig. 1). Santamaría-Gallegos et al. (2001) studied Laguna San Ignacio and Laguna Ojo de Liebre during February and June 1998 and reported the presence of *R. maritima* and *Z. marina* for both lagoons in February and the absence of intertidal meadows in June. Santamaría-Gallegos et al. (2007) focused on the ecology of *Z. marina* at Bahía Magdalena; they mentioned the presence of *P. scouleri* and *P. torreyi* in the high-energy outer shore of the bay, and that *R. maritima* was found with relatively low abundance inside the bay (the authors did not mention specific geographic coordinates). Bizarro (2008) published a review of the physical and biological characteristics at Bahía Magdalena but the only vascular plants he refers to as present in the bay are three species of mangrove (*Avicenia germinans* L.; *Laguncularia racemosa* L.; *Rhizophora mangle* L.) and two species of seagrass (*Z. marina* and *P. torreyi*).

The purpose of this study was to document the increasing importance of the presence of *R. maritima* in three wetlands of Baja California Sur México (Punta Abrejos, Laguna San Ignacio, and Bahía Magdalena), based on three main aspects: the increase of its biomass, the increase of its spatial distribution, and its key trophic role in some of these wetlands. We discuss the implications of this increase for the seagrass management strategies of marine protected and non-protected areas.

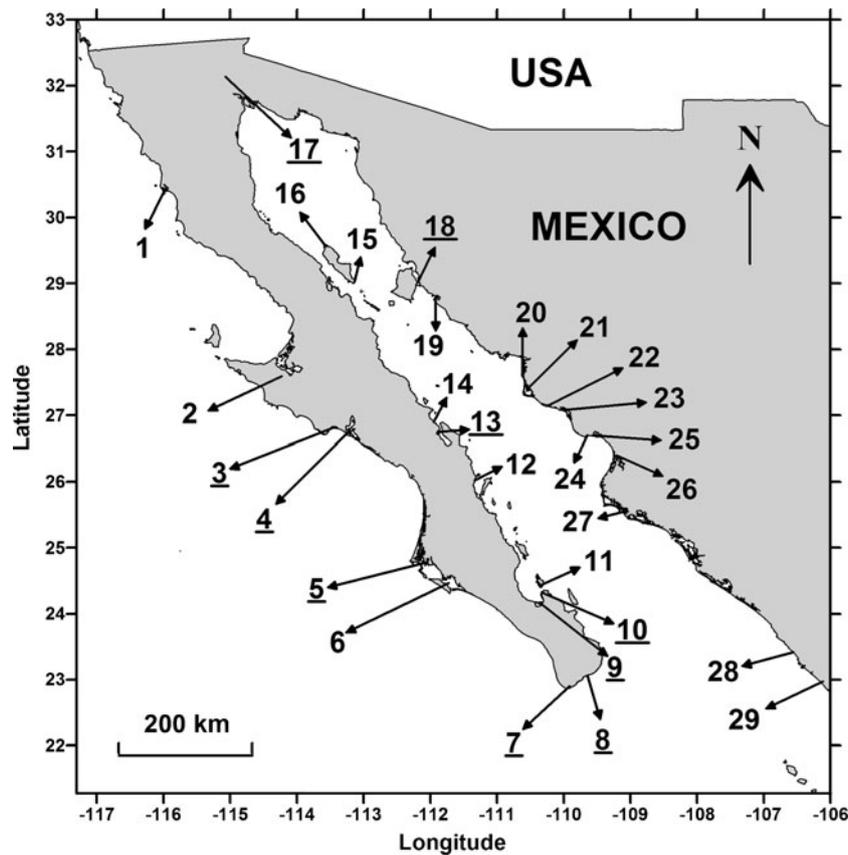


Fig. 1 Location sites for *Ruppia maritima* in northwest México. *Underlined numbers* are localities sampled for this work. 1 Bahía San Quintín (Dawson 1962; Ward et al. 2004); 2 Scammon's Lagoon (Santamaría-Gallegos et al. 2001); 3 Punta Abreojos; 4 Laguna San Ignacio (Santamaría-Gallegos et al. 2001); 5 Bahía Magdalena (Santamaría-Gallegos et al. 2007; Riosmena-Rodríguez et al. 2010); 6 Bahía Almejas (Santamaría-Gallegos et al. 2007); 7 Cabo San Lucas (Ramírez-García and Lot 1994); 8 Bahía San José del Cabo (Ramírez-García and Lot 1994); 9 Bahía de La Paz (Ramírez-García and Lot 1994); 10 Bahía Balandra; 11 Bahía San Gabriel at Espiritu Santo Island (Ramírez-García and Lot 1994); 12 Loreto (Ramírez-García and Lot 1994); 13 Bahía Concepción (Ramírez-García and Lot 1994); 14

Mulege (Ramírez-García and Lot 1994); 15–16 Angel de La Guarda Island (Ramírez-García and Lot 1994); 17 Hardy River and Santa Clara Wetland; 18 Canal de Infiernillo (Felger et al. 1980; Ramírez-García and Lot 1994; Torre 2002); 19 Bahía Kino (Meling-López, unpublished data); 20 El Siuti (Meling-López, unpublished data); 21 Bahía Lobos (Meling-López, unpublished data); 22 El Tobarí (Meling-López, unpublished data); 23 Isla Siari (Meling-López, unpublished data); 24 Santa Barbara (Meling-López, unpublished data); 25 Yavaros-Moroncarit (Meling-López, unpublished data); 26 Agiabampo (Meling-López, unpublished data); 27 Bahía Topolobampo (Ramírez-García and Lot 1994); 28 Laguna El Verde (Flores-Verdugo et al. 1988); 29 Laguna Caimanero-Huizache (Oliva-Martínez and Ortega 1983)

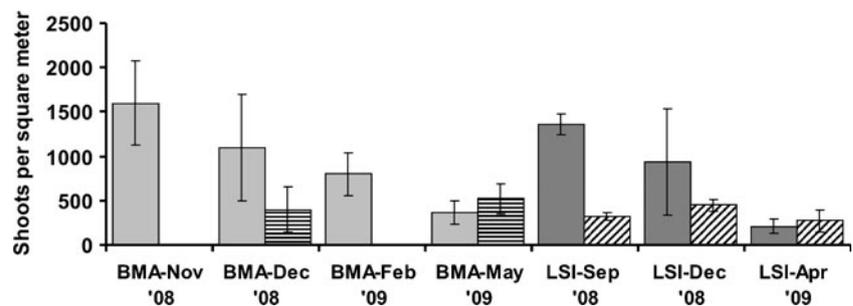
Materials and methods

During the course of extensive evaluations of seagrass populations (Fig. 1, sites 3, 4, 5, 7, 8, 9, 10, 13, 17, 18) and feeding habits of the east Pacific green turtle (also known as black turtle, *Chelonia mydas agassizii* Cornelius) in northwest México, we have found noticeable amounts of *Ruppia maritima* growing close to *Z. marina* meadows in areas and densities unknown for the northwest of México (Fig. 1; sites 3, 4, 5, 9, 10, 13, 17, 18), and in other areas we noted the absence of this species (Fig. 1, sites 7 and 8). At Laguna San Ignacio, we extensively sampled the bed size and shoot density and collected specimens from the subtidal zone (1–3 m depth) in a locality known as El Mapache (26° 50'8.88"N, 113°15'30.3"W; site 4, Fig. 1) in September

2008, December 2008, and April 2009 (Fig. 2; Table 1). We obtained several samples of stomach contents from dead green turtles found along the shore, as a result of incidental bycatch during June 2008 (Table 2); during May 2009, we collected oesophagic contents from nine live turtles at a locality called La Piedrita (26°56'15.71"N, 113°9'34.51"W).

At Bahía Magdalena, we extensively sampled the bed size and shoot density and collected specimens from the subtidal zone (1–3 m depth) in a locality adjacent to the Comisión Federal de Electricidad (24°48'44.88"N, 112°5'58.85"W; site CFE, Table 1) in November 2008, December 2008, February 2009, and May 2009 (Table 1). All bed-size estimations were done following the meadows' outer contour from a 7-m-long outboard motorboat using a GPS unit (Trimble Juno ST[®]). We also sampled oesophagic contents from several live green

Fig. 2 Shoot density for *Ruppia maritima* (solid bars) and *Zostera marina* (dashed bars) at two sites: Bahía Magdalena (solid light-gray and horizontally-dashed bars) (BMA; site CFE) and Laguna San Ignacio (solid dark-gray and diagonally-dashed bars) (LSI; site El Mapache)



turtles inside Estero Banderitas (24°54'53.01"N, 112°7'4.03"W), Estero San Buto (24°49'55.39"N, 112°2'51.93"W) during August 2008 (both estuaries are part of Bahía Magdalena), and Punta Abreojos (26°49'10.05"N, 113°27'17.41"W) during March 2009 (Fig. 1, sites 5 and 3). Oesophagic contents of green turtles were sampled and analyzed as described by Forbes and Limpus (1993). We present the percentage of consumption of *R. maritima* (Table 2) by captured green turtles in relation to the main constituents of their diet (*Z. marina* and seaweed).

We were able to perform additional seagrass surveys at Bahía Balandra (site 10; Fig. 1) and at Bahía de La Paz (site 9) in May 2009. We surveyed El Requeson beach at Bahía Concepción (26°38'23.53"N, 111°49'56.12"W; Fig. 1, site 13) in December 2008 and June 2009. Visits to Bahía San Jose del Cabo and Cabo San Lucas (Fig. 1, sites 8 and 7) were done in December 2008 and March 2009. In the case of Canal de Infiernillo (Fig. 1, site 18), we visited the area in March 2009, October 2009, March 2010, and April 2010, and found populations of *R. maritima* in the last three samplings. At the northern end of the Gulf of California, near the Colorado River Delta (Fig. 1, site 17), we found specimens of *R. maritima* growing abundantly in two habitats: the agricultural drains near the Hardy River (32°13'57.24"N, 115°18'22.07"W; 32°9'3.70"N, 115°16'53.11"W) and at the border of the Santa Clara Wetland (32°2'0.39"N, 114°51'22.27"W); during February, May, June, and October 2005.

Extensive collections of *R. maritima* specimens were done in both described sites (El Mapache and CFE). Detailed morphological evaluations of the sampled populations at Laguna San Ignacio and Bahía Magdalena were done using all the plants collected in 3 replicate sediment cores (around 100 plants per core).

Results

Based on the literature survey and our sampling efforts, we found 29 sites with records for *Ruppia maritima* (Fig. 1). Out of the total, in five we were able to confirm the presence of the species (sites 4, 5, 9, 13, and 18), three were new records (sites 3, 10, and 17) and in two, we were not able to find the species again and the record remains unconfirmed (sites 7 and 8). Shoot densities were high in autumn (1,600 shoots m⁻²) with constant decrements in both localities (Laguna San Ignacio and Bahía Magdalena), down to a minimum of 200 shoots m⁻² in spring (Fig. 2). At Bahía Concepción (site 13), shoot densities were higher in June 2009 (1,900±100 shoots m⁻²) than in December 2008 (1,500±50 shoots m⁻²) (± 1SD). At Bahía Concepción, we have been performing periodic botanical surveys since 1989, and before 2006 we have not found evidence of *R. maritima* shoots. Something similar occurred for other wetlands from Baja California Sur. We have visited Bahía Balandra (site 10) at least twice a year since 1986, and it was not until 2009 that we found the first specimens of *R. maritima*. At Laguna San Ignacio, members of the Programa de Botánica Marina made surveys in the months of January and June 1997, 1998, 2000, 2001, 2003, and 2004 without any report of *R. maritima*; it was not until September 2008 that we made the first observations for the species. Non-systematic visits to Bahía Magdalena were done from 1989 to 1995 and then again from 2004 to 2007; nevertheless, the first reports of *R. maritima* for this lagoon came from 2006 and then again in 2008.

We found significant seasonal differences ($p < 0.05$) but no significant spatial differences for *R. maritima* shoot densities between Laguna San Ignacio (site El Mapache)

Table 1 Size (in ha) of meadows of *Ruppia maritima* and *Zostera marina* (in parenthesis) in two localities: Bahía Magdalena (site CFE) and Laguna San Ignacio (site El Mapache), in winter 2008 and spring 2009

	Nov 2008	Dec 2008	Feb 2009	Apr 2009	May 2009
Bahía Magdalena	3.7 (0.0)	3.4 (0.24)	0.60 (0.0)	ND	0.01 (1.5)
Laguna San Ignacio	ND	6.7 (17.49)	ND	0.08 (0.89)	ND

ND No data available

Table 2 Percentages of primary food sources for green turtle (*Chelonia mydas agassizii*) of Laguna San Ignacio (LSI; sites NID and La Piedrita), Bahía Magdalena (BMA; site Estero San Buto), and Punta Abreojos (PAO; site Estero El Coyote) in summer 2008 and spring 2009

	LSI June 2008 NID	LSI May 2009 La Piedrita	BMA August 2008 Estero San Buto	PAO March 2009 Estero El Coyote
<i>Zostera marina</i>	16.95	44.21	0	3.33
<i>Ruppia maritima</i>	14.94	0.39	7.92	24.33
<i>Gracilaria</i>	1.7	1.3	57.92	12
<i>Gracilaria vermiculophylla</i>	42.73	0	11.15	0
Other spp. ^a	23.68	54.1	23.01	60.34

NID No identified site (samples from June 2008 came from dead turtles found stranded along the beach due to incidental bycatch)

^a Other spp. accounts for non-identified animal matter and seaweed species of insignificant abundance

and Bahía Magdalena (site CFE), with the highest variability in December 2008 for both lagoons (Fig. 2). A similar trend was observed for the seasonality of bed size at both lagoons (Table 1). *R. maritima* bed size at Bahía Magdalena was high in late fall and early winter (Table 1) with lowest values in late winter (February 2009) and spring (May 2009); likewise at Laguna San Ignacio, *R. maritima* bed size was highest in December 2008 (6.70 ha) and lowest in April 2009 (0.08 ha). Presence of *Zostera marina* for both sites was low. At Bahía Magdalena, patches of *Z. marina* were absent in November 2008, appeared in December with an average shoot density of only 400 shoots m⁻² and disappeared again in February 2009 (Fig. 2; Table 1). Eelgrass meadow appeared again at the CFE site in May with its maximum bed size and shoot density (1.5 ha; 520 shoots m⁻²), while wigeongrass had almost disappeared (0.01 ha; 368 shoots m⁻²). At Laguna San Ignacio, *R. maritima* winter bed size was twice as large (6.7 ha) as at Bahía Magdalena (3.4 ha); likewise, winter eelgrass bed size was larger at Laguna San Ignacio (17.49 ha) than at Bahía Magdalena (0.24 ha), significantly decreasing from December (17.49 ha) to April (0.89 ha).

Six morphological vegetative characteristics for the collected *R. maritima* specimens were compared: distance between rhizome nodes, leaf length, leaf width, sheath length, leaf apex, and presence of a central vein in the leaf. All leaves showed serrated leaf apexes and uninervated leaves. There were no significant differences ($p > 0.05$) between sites (CFE and El Mapache) in the distance between rhizome nodes (0.82±0.28 cm; 0.40±0.20 cm), leaf length (4.50±1.42 cm; 3.41±0.74 cm), leaf width (0.55±0.17 mm; 0.40±0.08 mm), and sheath length (1.18±0.22 cm; 1.31±0.51 cm).

According to oesophagic contents, the largest constituent of green turtle diet was between *Gracilaria textorii* (43%, Laguna San Ignacio), *Z. marina* (44%, Laguna San Ignacio), *Gracilaria vermiculophylla* (58%, Bahía Magdalena), and *R. maritima* (24%, Punta Abreojos). Wigeongrass constituted between 0.40 and 24.33% of the diet of

green turtles at these three sites, while eelgrass values were between 3.33 and 44.21% (Table 2).

Discussion

There is an outstanding expansion of *Ruppia maritima*'s distribution in northwest México compared to its historical known distribution, based on our current sampling efforts and the periodic measurements performed for over 20 years (since 1986) as part of the research conducted by the Programa de Botánica Marina in several wetlands of northwest México (Riosmena-Rodríguez and Sánchez-Lizaso 1996; Sánchez-Lizaso and Riosmena-Rodríguez 1997; Meling-López and Ibarra-Obando 1999; Santamaria-Gallegos et al. 2001, 2007; Riosmena-Rodríguez et al. 2010; Rodríguez-Salinas et al. 2010). In 4 of the 10 sampled sites for this work (Bahía Magdalena, Bahía Balandra, Laguna San Ignacio, Bahía Concepción), it seems that the appearance or greater abundance of *R. maritima* begun around 2007.

Morphological measurements of our specimens (apex serrated, leaf uninervated, leaf width and sheath length) did not show significant differences ($p > 0.05$) with reported measurements (Oliveira et al. 1983), with the exception of leaf length and distance between rhizome nodes that were significantly smaller (at both sites). These differences could be a phenotypic response of *R. maritima* to environmental conditions. Sampled sites at Laguna San Ignacio (El Mapache) and Bahía Magdalena (CFE) are low energy subtidal environments with an average depth of 2 m; sediment texture was a mixture of fine-sand and silt, and sediment color was black just a few millimeters below the surface indicating an important content of organic matter (sediment odor was also indicative of this). Temperature during sampling was around 20°C (December 2008). Thus, seagrasses at both sites experience roughly the same temperature, light availability and sediment characteristics, all of them contributing to the observed phenotype.

Wigeongrass meadows of these bed sizes and densities were not observed a few years ago in northwest México. First reports available on the presence of *R. maritima* from the 1980s and 1990s (Ramírez-García and Lot 1994; Santamaría-Gallegos et al. 2001) perhaps correspond to small populations inhabiting protected shallow-muddy areas inside some estuaries. So, the large populations currently located at Laguna San Ignacio (El Mapache) and Bahía Magdalena (CFE) could have two origins (or a combination of both). They could come from local *R. maritima* populations which experienced an anomalous expansion triggered by a change in environmental conditions (global warming, ENSO, eutrophication) or from alloctonous populations brought by migratory species (waterfowl) traveling each year to northwest México which transport wigeongrass seeds or shoots attached to their bodies or within their digestive tracts (Charalambidou et al. 2003), and ship traffic coming from around the world to the Baja California peninsula, bringing material attached to the ship's hull or trapped in the bilge water. A phylogenetic analysis of these invasive populations will be an excellent method to determine their biogeographic origin.

There is ongoing competition for substrate between *R. maritima* and *Z. marina* at Laguna San Ignacio and Bahía Magdalena. Former monospecific eelgrass populations at El Mapache and CFE now show, during autumn and winter, a dominant or large component of wigeongrass (Table 1, Fig. 2) while eelgrass now seems to occupy the space during winter and spring. This is more clearly observed at CFE site where a larger and denser eelgrass meadow occurred during May, when the wigeongrass meadow was at its minimum. An eelgrass population was not present at the CFE site during November and February (Table 1), possibly because of inadequate environmental conditions or competition for space with the *R. maritima* population. The increasing abundance of wigeongrass in habitats previously restricted to eelgrass or other climax species has been reported elsewhere (Cho et al. 2009) and is partially a consequence of global warming and ENSO phenomena. Temperature is a fundamental factor for the survival of seagrasses. It has been reported that *R. maritima* is a species with high tolerance to temperature (10–30°C) and salinity (0–35) variations (Phillips 1960; Lazar and Dawes 1991; Cho et al. 2009) and that the thermal (10–20°C) and saline (10–25) tolerances for *Z. marina* are narrower (Nejrup and Pedersen 2008). Therefore, *R. maritima* has an advantage over *Z. marina* to occupy shallow areas that experience temperature or salinity increases. Water temperature inside Bahía Magdalena is highly dominated by temperature variability of the neighboring ocean; moreover, the impact of interannual phenomena like El Niño/La Niña tends to be equal or larger inside than outside the lagoon (Lluch-Belda et al. 2000). It has been reported that the anomaly of sea-surface temperature in this

area has been increasing since the first half of the twentieth century and that the increase is steeper since the middle 1970s (Lluch-Belda et al. 2000). So, the declining of *Z. marina* meadows from El Mapache and CFE sites could be a consequence of this ocean warming. It is possible that something similar is happening at Laguna San Ignacio. It is worth mentioning that Bahía Magdalena is the southern limit for *Z. marina* in the eastern North Pacific (Riosmena-Rodríguez and Sánchez-Lizaso 1996).

The loss of eelgrass meadows in recent years at the lagoons of northwest México already has consequences on the biodiversity and trophic structure of these wetlands. The Pacific black brant (*Branta bernicla nigricans* Lawrence) is a goose that migrates each winter from Alaska and Canada to the wetlands of southern California and northwest México to feed on eelgrass meadows (Ward et al. 2005). The *B. bernicla* population has been steadily declining since 1990 (Sedinger et al. 2007) and is changing its wintering grounds from Baja California peninsula to more northward regions (California, Washington, Oregon) due to less availability and abundance of *Z. marina* in México (Ward et al. 2005, 2009). Although there are some studies that report wigeongrass as part of *B. bernicla*'s diet (Ward 1983; Lindberg et al. 2007), most published works agree that eelgrass is the preferred food source for the Pacific black brant population (Nienhuis and Ierland 1978; Ganter 2000; Ward et al. 2005).

R. maritima and its ecological role in the wetlands of northwest México have increased. It is known that *Z. marina* constitutes the main seagrass food source in the diet of immature green turtles (*Chelonia mydas*) that use several northwest Mexican wetlands as nurseries (Lopez-Mendilaharsu et al. 2002, 2005, 2008). We were able to confirm this for two of our sampled wetlands: Laguna San Ignacio and Bahía Magdalena. However, at Punta Abreojos, this did not hold true: *Z. marina* was replaced by *R. maritima* as the major seagrass food source for this species. Even more, wigeongrass was the largest food source for the juveniles of *C. mydas* living at Punta Abreojos and the third largest food source at Laguna San Ignacio and Bahía Magdalena (Table 2). At Bahía Magdalena, we also sampled in the locality Estero Banderitas and found *R. maritima*; however, it did not appear in the oesophagic contents of the turtles captured in this estuary. Nevertheless, Talavera-Saenz et al. (2007) found that wigeongrass can constitute 43% of the stomach contents for immature green turtles at Estero Banderitas. Punta Abreojos is an outstanding record, first because there are no previous reports of wigeongrass for this lagoon and second because, at least during spring, wigeongrass is displacing eelgrass as the primary food source for immature green turtles (Table 2). This fact has important management implications, considering that *C. mydas* is an endangered species included in the IUCN Red

List (International Union for Conservation of Nature 2009) and that Punta Abreojos is an important feeding ground for juvenile turtles (López-Castro et al. 2010). Therefore, feeding grounds for immature individuals of this species must be considered as high priority areas for conservation: *Z. marina* meadows in Laguna San Ignacio and Bahía Magdalena and, in the case of Punta Abreojos, *R. maritima* meadows.

Mexican environmental legislation and management plans for marine protected areas must include seagrass communities as a key coastal ecosystem in order to secure marine biodiversity. Special areas must be designated where no fishing or urban activity is allowed, and fishing regulation should encourage the use of fishing gear and techniques non-destructive of the ocean floor and its inhabitants. In wetlands like Bahía Magdalena located outside a marine protected area, more caution should be taken, otherwise the environmental degradation could be severe in the upcoming years. This work intends to be a baseline for the urgent need of awareness and conservation efforts of one of the key coastal ecosystems along the northwest coast of México such as seagrasses, outlining new challenges spawned by the outstanding expansion of *R. maritima* meadows. Wigeongrass now represents a key species for the region because its spatial and temporal evolution can be used as an indirect measurement of the effects of global warming at a regional scale.

Acknowledgements The authors gratefully acknowledge the key financial and logistical support provided by The School for Field Studies (SFS) Center for Coastal Studies. We wish to thank to the ‘Laguna San Ignacio Ecosystem Science Program’ (Dr J Urban and Dr S Swartz) for their support. R.R.R. thanks the ‘Project CONACYT-SEMARNAT’ for the support throughout this research. A.M.L. thanks to the Project CONACYT-SEMARNAT-C01-1434 for the field-work funding. G.H.C. expresses his thanks to ‘Comisión de Operación y Fomento de Actividades Académicas del IPN (COFAA)’ and to the program ‘Estímulo al Desempeño de los Investigadores del IPN (EDI)’ for the fellowship granted. J.M.R.B. thanks to the people from LSI, BMA, and PAO who participate with Grupo Tortuguero de las Californias A.C. Thanks to Elena Holguin for her valuable help with the sampling at Santa Clara Wetland. We thank the comments of three anonymous reviewers who helped to improve this article. J.L.C. was supported by CONACYT grant 41393.

Ethical standards All the samplings and analysis performed during this research comply with the current environmental laws of México.

Conflict of interest We the authors declare that we have no conflict of interest.

References

- Bizarro J (2008) A review of the physical and biological characteristics of the Bahía Magdalena Lagoon complex (Baja California Sur, México). Bull S C Acad Sci 107:1–24
- Charalambidou I, Santamaria L, Langevoord O (2003) Effect of ingestion by five avian dispersers on the retention time, retrieval and germination of *Ruppia maritima* seeds. Funct Ecol 17:747–753
- Cho HJ, Biber P, Nica C (2009) The rise of *Ruppia* in seagrass beds: changes in coastal environment and research needs. In: Drury EK, Pridgen TS (eds) Handbook on environmental quality. Nova Science, New York, pp 1–15
- Dawson EY (1962) Marine and marsh vegetation of Bahia San Quintin, Baja California. Pac Nat 3:275–280
- Den Hartog C (1981) Aquatic plant communities of poikilosaline waters. Hydrobiologia 81:15–22
- Den Hartog C, Kuo J (2006) Taxonomy and biogeography of seagrasses. In: Larkum AWD, Orth RJ, Duarte CM (eds) Seagrasses: biology ecology and conservation. Springer, Dordrecht, pp 1–23
- Ehlers A, Worm B, Reusch TBH (2008) Importance of genetic diversity in eelgrass *Zostera marina* for its resilience to global warming. Mar Ecol Prog Ser 355:1–7
- Felger RS, Moser MB (1985) People of the desert and sea: Ethnobotany of the Seri Indians. The University of Arizona Press, Arizona
- 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, New York, pp 260–276
- Flores-Verdugo FJ, Day JW Jr, Mee L, Briseño-Dueñas R (1988) Phytoplankton production and seasonal biomass variation of seagrass, *Ruppia maritima* L., in a tropical Mexican lagoon with an ephemeral inlet. Estuaries 11:51–56
- Forbes G, Limpus C (1993) A non-lethal method for retrieving stomach contents from sea turtles. Wildl Res 20:339–343
- Ganter B (2000) Seagrass (*Zostera* spp.) as food for Brent geese (*Branta bernicla*): an overview. Helgoland Mar Res 54:63–70
- International Union for Conservation of Nature (2009) IUCN Red list of threatened species. Version 2009.1 <<http://www.iucnredlist.org>>
- Johnson MR, Williams SL, Lieberman CH, Solbak A (2003) Changes in the abundance of the seagrasses *Zostera marina* L. (eelgrass) and *Ruppia maritima* L. (widgeongrass) in San Diego, California, following an El Niño event. Estuaries 26:106–115
- Kantrud HA (1991) Widgeongrass (*Ruppia maritima* L.): a literature review. Fish Wildl Res 10:1–58
- Keates RA, Osher LJ (2007) The macroinvertebrates of *Ruppia* (Widgeongrass) beds in a small Maine estuary. Northeastern Nat 14(3):481–491
- Kuo J, den Hartog C (2001) Seagrass taxonomy and identification key. In: Short FS, 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
- Lindberg MS, Ward DH, Tibbitts TL, Roser J (2007) Winter movement dynamics of black brant. J Wildlife Manage 71:534–540
- Lluch-Belda D, Hernández-Rivas ME, Saldierna-Martínez R, Guerrero-Caballero R (2000) Variabilidad de la temperatura superficial en Bahía Magdalena, México, B.C.S. Oceanides 15:1–23
- López-Castro MC, Koch V, Mariscal-Loza A, Nichols WJ (2010) Long-term monitoring of black turtles *Chelonia mydas* at coastal foraging areas off the Baja California peninsula. Endang Species Res 11:35–45
- Lopez-Mendilaharsu M, Gardner SC, Seminoff JA, Riosmena-Rodríguez R (2002) Feeding ecology of the East Pacific green turtle (*Chelonia mydas agassizii*) in Bahía Magdalena, B.C.S. México. 22nd Annual Symposium on Sea Turtle Biology and Conservation, Miami, Florida, pp 219–220

- Lopez-Mendilaharsu M, Gardner SC, Riosmena-Rodríguez R, Seminoff J (2005) Identifying critical foraging habitats of the green turtle (*Chelonia mydas*) along the Pacific Coast of the Baja California Peninsula, México. *Aquat Conserv* 15:259–269
- Lopez-Mendilaharsu M, Gardner SC, Riosmena-Rodríguez R, Seminoff JA (2008) Diet selection by immature green turtles (*Chelonia mydas*) at a coastal foraging ground along the Pacific Coast of the Baja California Peninsula, México. *J Mar Biol Assoc UK*. doi:10.1017/S0025315408001057
- Malea P, Kevrekidis T, Mogias A (2004) Annual versus perennial growth cycle in *Ruppia maritima* L.: temporal variation in population characteristics in Mediterranean lagoons (Monolimni and Drana Lagoons, Northern Aegean Sea). *Bot Mar* 47(5):357–366
- 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
- Nejrup LB, Pedersen MF (2008) Effects of salinity and water temperature on the ecological performance of *Zostera marina*. *Aquat Bot* 88:239–246
- Nienhuis PH, Ierland ETV (1978) Consumption of eelgrass, *Zostera marina*, by birds and invertebrates during the growing season in Lake Grevelingen (SW Netherlands). *Neth J Sea Res* 12:180–194
- Oliva-Martínez MG, Ortega MM (1983) Estudio preliminar de la vegetación sumergida en la Laguna Caimanero y Marisma de Huizache, Sinaloa. *An Inst Biol Univ Nal Autón México Ser Bot* 54:113–152
- Oliveira FEC, Pirani JR, Giulietti AM (1983) The Brazilian seagrasses. *Aquat Bot* 16:251–267
- Orth RJ, Moore KA (1988) Distribution of *Zostera marina* L. and *Ruppia maritima* L. sensu lato along depth gradients in the lower Chesapeake Bay, U.S.A. *Aquat Bot* 32:291–305
- Phillips RC (1958) Extension of distribution of *Ruppia maritima* var. *obliqua* (Schur.) Aschers. and Graebn. *Q J Florida Acad Sci* 21:185–186
- Phillips RC (1960) Observations on the ecology and distribution of the Florida seagrasses. Prof Pap Ser No 2 Fla St Bd Conserv Mar Lab, St Petersburg
- 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
- Reyes E, Merino M (1991) Diel dissolved oxygen dynamics and eutrophication in a shallow, well-mixed tropical lagoon (Cancun, México). *Estuaries* 14(4):372–381
- Richardson FD (1980) Ecology of *Ruppia maritima* L. in New Hampshire (U.S.A.) tidal marshes. *Rhodora* 82:403–439
- Riosmena-Rodríguez R, Sánchez-Lizaso JL (1996) El límite sur de distribución de *Zostera marina* L. y *Phyllospadix torreyi* Watson para el noroeste mexicano. *Océanides* 11:45–48
- Riosmena-Rodríguez R, Talavera-Sáenz A, Acosta-Vargas B, Gardner SC (2010) Heavy metal dynamics in seaweeds and seagrasses in Bahía Magdalena, B.C.S., México. *J Appl Phycol* 22:283–291
- Robblee MB, Barber TR, Carlson PR, Durako MJ, Fourqurean JW, Muehlstein LK, Porter D, Yarbro LA, Ziemann RT, Ziemann JC (1991) Mass mortality of the tropical seagrass *Thalassia testudinum* in Florida Bay (USA). *Mar Ecol Prog Ser* 71:297–299
- Rodríguez-Salinas P, Riosmena-Rodríguez R, Hinojosa-Arango G, Muñoz-Salazar R (2010) Restoration experiment of *Zostera marina* L. in a subtropical coastal lagoon. *Ecol Eng* 36:12–18
- Sánchez-Lizaso JL, Riosmena-Rodríguez R (1997) Macroalgas epífitas de *Zostera marina* L. en Bahía Concepción, B.C.S., México. *Océanides* 12:55–59
- Santamaría-Gallegos NA, Riosmena-Rodríguez R, Sánchez-Lizaso JL (2001) Las praderas de *Zostera marina* L. en la Reserva de la Biosfera El Vizcaíno, México. *Actas de la I Jornada sobre Reservas Marinas, Murcia, España, Ministerio de Agricultura, Pesca y Alimentación* 135–146
- Santamaría-Gallegos NA, Félix-Pico EF, Sánchez-Lizaso JL, Riosmena-Rodríguez R (2007) Ecología de la fanerógama *Zostera marina* en el sistema lagunar Bahía Magdalena–Bahía Almejas. In: Funes-Rodríguez R, Gómez-Gutiérrez J, Palomares-García R (eds) *Estudios ecológicos en Bahía Magdalena*. CICIMAR-IPN, La Paz, pp 101–112
- Sedinger JS, Nicolai CA, Lensink CJ, Wentworth C, Conant B (2007) Black brant harvest, density dependence, and survival: a record of population dynamics. *J Wildlife Manage* 71:496–506
- Setchell WA (1924) *Ruppia* and its environmental factors. *Proc Natl Acad Sci USA* 10(6):286–288
- Setchell WA (1946) The genus *Ruppia* L. *Proc Calif Acad Sci* 25 (18):469–478
- Talavera-Saenz A, Gardner SC, Riosmena-Rodríguez R, Acosta-Vargas B (2007) Metal profiles used as environmental markers of Green Turtle (*Chelonia mydas*) foraging resources. *Sci Total Environ* 373:94–102
- Torre J (2002) Inventory, monitoring and impact assessment of marine biodiversity in the Seri Indian territory, Gulf of California. Dissertation, University of Arizona, México
- Ward DH (1983) The relationship of two seagrasses: *Zostera marina* and *Ruppia maritima* to the black brant, *Branta bernicla nigricans*, San Ignacio Lagoon, Baja California. Dissertation, University of Oregon, México
- Ward DH, Tibbitts TL, Morton A, Carrera-González E, Kempka R (2004) Use of digital multispectral videography to assess seagrass distribution in San Quintín Bay, Baja California, México. *Cienc Mar* 30:47–60
- 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* 62:301–311
- Zhao LC, Wu ZY (2008) A review of the taxonomy and evolution of *Ruppia*. *J Syst Evol* 46(4):467–478