INTRODUCTION

Globally, seagrasses are one of the most important coastal ecosystems, due to the high value of their ecosystem services, such as primary production, food supply, nutrient cycling, habitat formation, coastal protection, and carbon sequestration (Costanza *et al.* 1997; Ondiviela et al., 2014; Unsworth et al., 2019; UNEP, 2020). Despite their importance, seagrasses were until recently considered the perfect example of an ecosystem that is largely undocumented and understudied (Waycott, et al. 2009).

Recently, several authors have reported the global decline in seagrass meadows at unprecedented rates, due to global climate change, overfishing, even anthropogenic activities, mostly coastal modification, and water pollution (Orth et al., 2006; Duarte et al., 2009). The Gulf of California is one of the regions where this problem occurs (López-Calderón et al., 2010, Riosmena-Rodríguez et al., 2013; López-Calderón et al., 2016).

Nowadays, we know the Gulf of California is home to four species of seagrass: *Zostera marina* L. 1753, *Halodule wrightii* Ascherson 1868, *Halophila decipiens* Ostenfeld 1902 and *Ruppia maritima* L. 1753. According to the historical distribution, the seagrasses are mainly found in the Canal del Infiernillo in Sonora and the coastal lagoons in Sinaloa, while in the Baja California Peninsula, the most representative site is Bahía Concepción (Den-Hartog, 1970; Felger & Moser, 1973; McMillan, 1983; Aguilar-Rosas & López-Ruelas, 1985; Ortega et al., 1986; Ramírez-García & Lot, 1994; Riosmena-Rodríguez & Sánchez-Lizaso, 1996, Meling-López and Ibarra-Obando, 1999; Múñiz-Salazar et al., 2005; Orduña-Rojas & Riosmena-Rodríguez, 2008; Santamaría-Gallegos *et al.* 2006; López-Calderón et al., 2010).

This review focuses on the current state of knowledge of seagrasses in the Gulf of California. Based on the collected information, we made the first full assessment of the distribution, coverage and conservation status of the ecosystem, creating a threat index and provided a baseline to contribute to the study and conservation strategies of seagrass meadows.

MATERIAL & METHODS

STUDY SITE

El Golfo de California es un mar parcialmente cerrado ubicado entre la península de Baja California y la región noroeste de México. Tiene una extensión aproximada de 1600 km de longitud y 283,000 km2,en la que se encuentran alrededor de 900 islas e islotes. Es posible distinguir cuatro regiones oceanográficas: El Alto Golfo, El Golfo Norte, Región Central y El Golfo Sur (SEMARNAP 2000)

[…]

SYSTEMATIC REVIEW PROTOCOL

Three information sources were used for the database: specific literature, indirect literature and both national and international herbariums.

For this review, the keywords “Seagrasses”, “Gulf of California”, “*Zostera marina*”, “*Ruppia maritima*”, “*Halodule wrightii*” y “*Halophila decipiens*” were searched into Scholar (accessed 07/2019-01/2021). The selected information is made up of: scientific articles, bachelor, master's and doctorate theses; floristic inventories, book chapters and technical reports from academic and governmental institutions, which address the issue of seagrass in the Gulf of California from different perspectives. Also, despite not discussing seagrasses as central theme, some texts that could provide us some reference about distribution and / or extension were chosen.

Finally, the online collections of seven herbaria were reviewed: Herbarium of the University of Arizona (ARIZ), Herbarium of the Arizona State University (ASU), Herbarium of the Autonomous University of Baja California (BCMEX), Herbarium Nacional de Mexico (MEXU), Smithsonian National Museum of Natural History (SI NMNH), Herbarium Jesús González Ortega of the Autonomous University of Sinaloa (UAS), Herbarium of the University of Sonora (UNISON-USON).

From all information collected, four essential elements for the database were extracted: species, date, location and coordinates. With these data, maps of historical distribution of seagrass in the Gulf of California were made. Finally, the periods in which there was an increase in seagrass studies were identified and these were classified based on the topic they address.

Evaluation Criteria

For the evaluation criteria, the risk assessment model of the Red List of Ecosystems proposed by the IUCN (2016) was followed, which includes two non-threat categories: Least Concern (LC) and Near Threatened (NT), three threat categories: Critically Endangered (CR), Endangered (EN) and Vulnerable (V); and a collapsed ecosystem category (CO). In addition to a category that reflects the lack of information: Insufficient data (DD) and another for ecosystems that have not been even minimally evaluated: Not evaluated (NE).

According to the Practical Guide for the Application of the IUCN Red List of Ecosystems Criteria (Rodríguez et al. 2015), to determine the risk of collapse, which is the most critical category, five criteria will be evaluated based on one or more proxies. It is important that the evaluation is made with existing data, otherwise, the ecosystem will be classified as DD (Data Deficient). The evaluation criteria includes:

* 1. Currently declining distribution
  2. Restricted distribution
  3. Degradation of the abiotic environment
  4. Altered biotic interactions
  5. Quantitative estimates of risk of ecosystem collapse

Once all the criteria have been evaluated, a final category, which summarizes all the results from the evaluation, is assigned. Based on the results and following the precautionary principle (Precautionary Principle Project 2005), the highest category obtained for any of the criteria will be considered as the general status of the ecosystem.

**Assessment variables**

To assess threat categories, we choose the following variables:

* Pollution
* Coastal modification
* Biological resources use
* Validation
* Protection level
* Marine Heatwaves

The information about the first three variables was obtained by information sheets on Ramsar Wetlands website ( https://www.ramsar.org/) and evaluation and characterization sheets by Comisión Nacional de Áreas Naturales Protegidas (). These variables were selected because all of them occurs un the study area and it is know some human activities such fisheries, aquaculture, livestock or even dredge and coastal modification, are threats highly related with loss and degradation of seagrasses ecosystems (Short et al. 2011). For each variable a score 0 to 1 was assigned, where 0 is absence, and 1 is presence of the threat.

For the validation process, the data base GC\_Seagrasses2021 was used to mapping the historical distribution of seagrasses in the Gulf of California. Later, satellite images were used to validate the presence or absences of seagrasses in the historical spots, in some cases, such La Paz bay, validation was carried out with drones. It was necessary to evaluate through two main approaches because the localities varied in their extension and in the access to the field. In this case, a score 0 to1 was also assigned, however, this was based at the threat of looses. Where 0 means the current present of seagrass in the spot, a score of 0.5 means that there is not information about the spot, therefore it was classified in DD and finally, a score of 1 means the loose of a seagrass spot

To assess the protection level, a Federal Natural Protected Areas (CONANP) shapefile was used. Due several authors have reported the effect of marine protected areas on the recovery and stability of threatened ecosystems (….), to identify how many records were included within on a protected polygon the merge between the NPA shapefile and the and the information of GC\_Seagrasses2021 shapefile was made.

For Marine Heatwaves, we retrieved Reynolds optimally interpolated sea surface temperature (OISST) data to calculate marine heatwaves events. Marine heatwaves are recognized threats to marine life with the potential to cause significant damage to natural communities (Beas‐Luna et al., 2020; Benedetti-Cecchi, 2021; Brown et al., 2020; Filbee-Dexter et al., 2020; Laufkötter et al., 2020; Suryan et al., 2021), are related to human induced climate change (Laufkötter et al., 2020), and can exacerbate other climate change effects (Cheung and Frölicher, 2020). We used the R package heatwaveR to identify heatwaves and calculate temporal trends from OISST data. The download and extraction process, as well as the analysis is fully reproducible using the R code provided at: GITUHUB LINK. The code was written in the R studio IDE (v.1.4.1103) working on R v.4.0.3.

Results and discussion

* DISTRIBUTION MAP: PRESENCE/ABSENCE. (1)

Summary of seagrass distribution in the Gulf of California.

According to our database, in the GC there are four species of seagrass: *Zostera marina, Ruppia maritima, Halodule wrightii and Halophila decipiens*. The specie most widely distributed is R. maritima, which is found Cienega de Santa Clara, in the Upper Gulf of California, to the Huizache-Caimanero Lagoon-Complex, Sinaloa (Figure 1). However, is not the most studied specie. *Zostera marina* has been recorded since 1645 in the east coast of the GC. It is mainly found in the Canal del Infiernillo, (CI) between Sonora and the Tiburon Island, although is possible to find it on the coast of Baja California Peninsula. For years it has been the subject of numerous researches, and so many efforts have been focused on its conservation (López calderón….). In contrast, *Halodule wrightii* and *Halophila decipiens*, they have fewer records and also a more limited distribution. H. wrightii, is found on both coasts of the GC, however, *Halophila decipiens* has a particular distribution, since it is the only specie restricted to the La Paz Bay.

Since 1645 to the present, there are 360 ​​records of seagrass distributed in 25 locations. Currently, there are seagrasses in only 12 of the 25 historical distribution sites, unfortunately at least 13 sites have lost seagrasses over the years. Generally, the absence of seagrass could be attributed to the seasonal dynamics of the ecosystem, but in some cases, the period of absence is too prolonged indicating their complete disappearance, for example, the last time seagrass was recorded in Los Cabos was in the late 1990s (Ramirez-Garcia & Lot; Leon de la Luz).

We identified four sites that currently do not have seagrasses (Guaymas, Navachiste La Paz and Los Cabos) and nine where it was impossible to validate them, these places are Bahía de los Angeles, El Desemboque, Mulege, Cienega de Santa Clara, El Tobari, the lagoons El Verde and Yavaros-Morancarit, and the Angel de la Guarda and Siari islands.

**Patterns of distribution per specie.**

*Zostera marina*

Historical distribution.

*Zostera marina* is distributed in 9 sites throughout the GC. The most important site is the Infiernillo Channel, as it has the largest and most stable meadows, in 2010 it had a cover up around 7,000 ha (López-Calderón et al, 2013). Over the years, several researchers focused on knowing the seasonal dynamics (Phillips and Backman, 1983; Mc Millan, 1983; Phillips et al. 1983; Santamaría-Gallegos, 1996 and Melling-López, 1999) and the genetic flow (Backman, 1991; Muñiz- Salazar 2005) in the region. Since 1970 CI was declared property of the Seri community, that is, they are the only people with permission to carry out fishing activities. Eventually, in 2009 the RAMSAR site #1891 was also declared. This indirect protection, could be explain the stability of seagrasses in the region.

A second important population of *Z. marina* is found in Bahía Concepción, BCS. There are two places where there is presence of seagrass: El Requeson beach and Punta Arenas, both share an area of ​​3 ha and it is the only place in the Baja California peninsula where *Z. marina* shares territory with two other species of seagrass. (López-Calderón et al 2013). Unlike the IC, Bahia Concepcion has a deficient type of protection since 1998 was declared a Priority Marine Area (CONABIO, USAID, WWF, FMCN, Fundación Packard).

Current distribution.

For this study, we validated the presence of Z. marina only at 9 sites. The Canal del Infiernillo continues to be the site with the largest extension, approximately xxxx ha, in second place is Bahia Concepcion. For the other seven sites, we were able to validate the presence of seagrass patches, but it was impossible to estimate the extent (Volver a pensar en la Tabla/Figura)

*Ruppia maritima.*

With the exception of Navachiste, *Ruppia maritima* is found in all historical distribution sites. Although it frequently shares space with the Zostera marina, in some places such as the Huizache-Caimanero lagoon, it is alone. This range is probably due to the fact that it is a species with high tolerance to salinity and temperature, which gives it advantages over other species. (Phillips 1960; Lazar and Dawes 1991; Cho et al. 2009; Cunha et al. 2013).

Although historically R. maritima has been present in the GC since 1921, recent records indicate that it is in places where it was not previously, such as Balandra, where it was first recorded in 2009. There are also other places where R. maritima showed an increase in abundance as Bahía Concepción of 2007 (Lopez-Calderon).

Current distribution.

During this study we can validate the presence of *Ruppia marina* in 10 sites, mainly in coastal lagoons with high anthropogenic activity. In *Huizache-Caimanero* lagoon R. maritima occurs alone, and it seems one of the most important sites for this species, due to its abundance, however it is also highly contaminated. CI and Bahía Concepción are also currently distribution sites, however, since R, maritima occurs in multispecific meadows, it is impossible to estimate their extent individually.

*Halodule wrightii*

Historical distribution.

Since it was first recorded, H. wright ii has been recorded at seven of the 25 sites, mainly at el Canal del Infiernillo, Bahia Concepción y El Soldado estuary. In all places, it has coincidences with Z. marina and *R. maritima* forming multispecific meadows (Lopez-Calderon...). It's common confused it with *Ruppia maritima*.

Current distribution.

It is only possible to confirm its presence in El Canal del Infiernillo, Estero El Soldado and Topolobampo.

*Halophila decipiens.*

Historical distribution.

It is the most geographically limited species. It was only recorded in La Paz, for the first time in 1999 at Punta Roca between El Caimancito and La Concha beaches. (Santamaria-Gallegos et al, 2006). The last documented record was in 2014 (García-Trasviña, 2017).

Current distribution.

We carry out drone and satellite validations, but we can't find seagrass in the locality. However, in 2021 our team found Halophila decipiens in the Pichilingue Research Unit of the Autonomous University of Baja California Sur (com. Pers. Salgado-Castrejon & Guerrero-Martínez). …

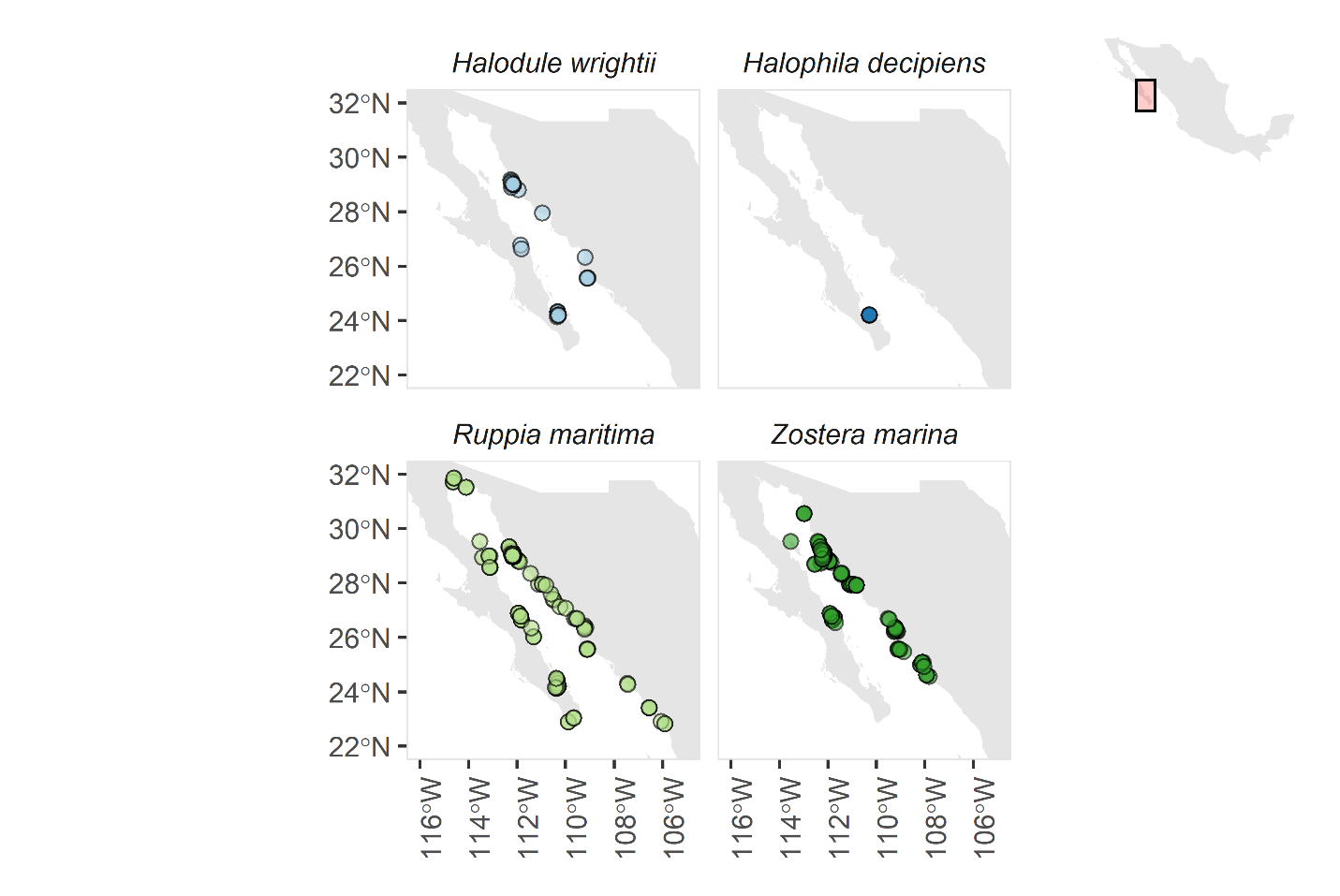


Figure 1. Historical distribution of the four species of seagrass in the Gulf of California.

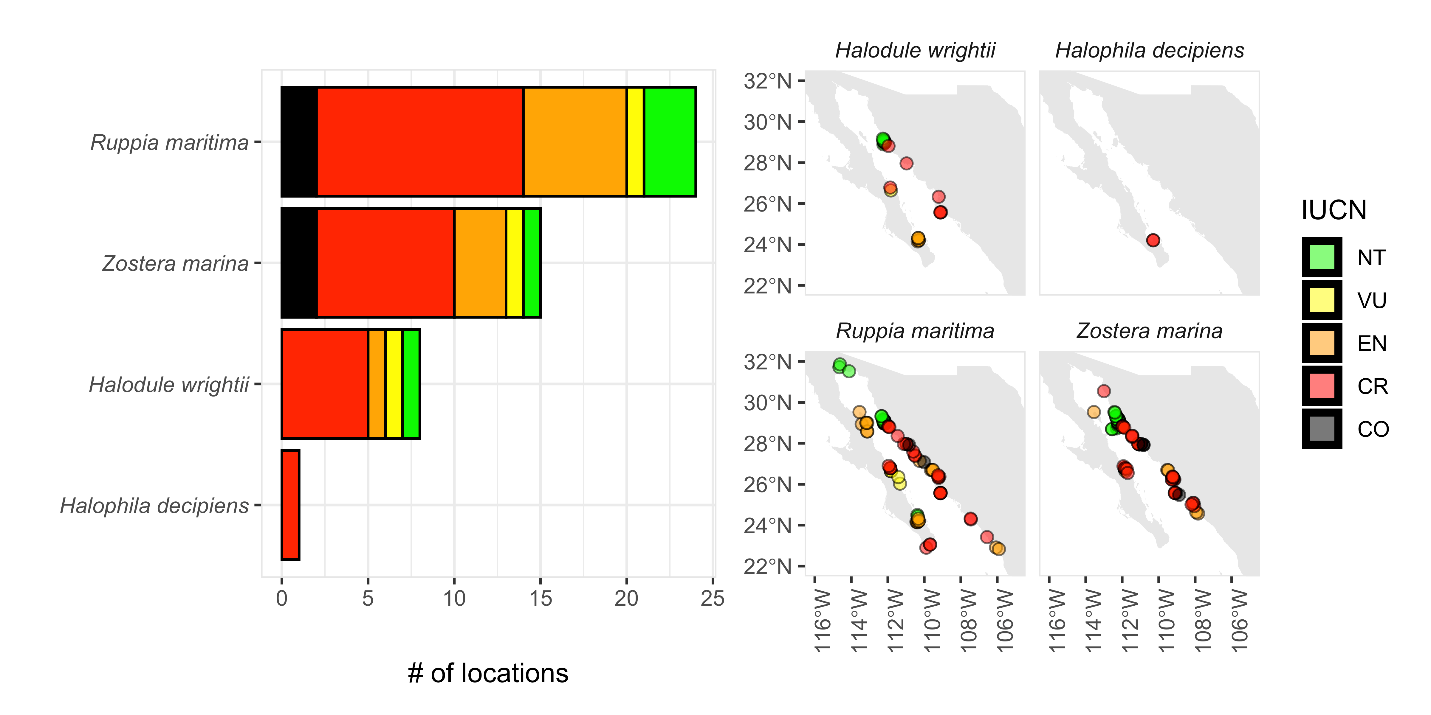
**Knowledge and information**

We compilated 78 publications about seagrasses of the GC, which include herbarium collections, public outreach articles and scientific papers, however, ​information is mostly available in gray literature. In the GC, interest in seagrass started in 1645 with the first records and their uses in the Seri territory (Felger & Moser, 1973). Research on cultural and ethnobotanical uses was conducted by missionaries, however, scientific research on biology and ecology started in the late 1970s. Since the 2000s, we observe an increase in the number of publications with a peak in the last decade, and a small change in the topic of interest, since conservation is the priority (Figure 2)

Chart

Description automatically generated

Figure 2. Seagrass research in the Gul of California.



* DECADE (PLOT) (2)

DISCUSSION

* HISTORICAL DISTRIBUTION VS CURRENT DISTRIBUTION SITE (1)
* WHAT WE KNOW TODAY?(2&3)BY
* TAXONOMY DISCREPANCY
* WHY SEAGRASSES ARE IN THE CURRENT SITES?(1&3)
* BIOTIC & ABIOTIC FACTORS(1&3)
* INVASIVE?/TROPICALIZATION (1&3)
* CONSERVATION STATUS (4)

\*\*\* FUTURE CHALLENGE

* NECESSARY ACTIONS AND PROPOSALS

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