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Time-space characterization of commercial seaweed species from the Gulf of California using a geographical information system

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Abstract

The Gulf of California, considered one of the most pristine areas of the world, hosts more than 50 seaweed species that have commercial applications. Only one species, however, is presently harvested commercially. In order to establish potential areas for seaweed use, a Geographical Information System (GIS) was used to determine areas for potential seaweed exploitation based on more than 9000 literature records. The system allows for the determination of sites, areas and times of the year when commercial species may be available. This information is being considered in a zoning program that would determine the areas of the Gulf sustainable for use or conservation. Temperature data were also included in order to determine potential areas for seaweed cultivation. GIS proves to be a powerful tool for large-scale management of seaweed resources.

Introduction

The Gulf of California, the youngest sea on Earth, is considered one of the most productive and pristine marine areas of the world (Alvarez-Borrego, 1983). It is responsible for 50% of the fisheries production in Mexico and 90% of the cultivated shrimp. It consists of a semi-enclosed basin of rectangular shape, approximately 1500 km long and 150 km wide, on average, with a mouth in the south connected to the Central Eastern Pacific. It covers an area of 260,000 km^2, comparable to the Red Sea, and encloses more than 900 islands and islets with many marine endemic species.

The Gulf of California is rich in all kinds of marine species including seaweeds. This has motivated many efforts by non-governmental organizations and government agencies to promote areas of the Gulf for conservation. At the same time, however, because it is one of the less developed areas in Mexico, the Gulf is currently being considered for many large-scale development projects including the construction of marinas, hotels and aquaculture farms.

The Gulf has also been recognized for its rich seaweed flora (Dawson, 1944; Norris, 1975). Of the 580 species mentioned by Espinoza-Avalos (1993) as reported for the Gulf, Pacheco-Ruíz and Zertuche-González (1996) have recognized at least 55 species that could have commercial applications, but only one is presently exploited (Pacheco Ruíz et al., 2003). Nevertheless, in the last decade, several of these species have been found to exist in sufficient amounts to be harvested commercially (Barilotti and Zertuche-González, 1990; Casas-Valdez et al., 1993; Hernández-Carmona et al., 1990; Pacheco-Ruíz & Zertuche-González, 1999; Pacheco-Ruíz et al., 1998, 2002).

The information currently available indicates that the Gulf of California may be an important source of commercial seaweed. This information, however, is not sufficient to define priority areas, their location and extent, which could be earmarked for seaweed harvesting or cultivation, nor the potential conflict with zones considered for conservation. A survey to determine the distribution of commercial species and the feasibility for exploitation in terms of abundance in space and

time would be costly and lengthy for an area the size of the Gulf of California.

In this study, we use a Geographical Information System (GIS) to characterize the Gulf of California in terms of the commercially valuable species reported in the literature. We test the possibility of defining areas of importance for commercial seaweeds by providing geographic references to all species reported in the literature and plotting the records on a map with the help of GIS. The records were superposed on a map of surface water temperature in order to define oceanographic regions of importance. Special attention was giving to those commercial species for which abundance data are reported in the literature.

With this study we expect to provide an inexpensive alternative for characterizing areas of importance for seaweed exploitation or cultivation, as well as to identify areas or species that require more studies, particularly in broad-scale regions. To our knowledge, this is the first study considering the use of GIS on the characterization of seaweed resources on broad areas.

Materials and methods

The extent of the Gulf of California varies depending on the criteria used to define its southern limit (Alvarez-Borrego, 1983). For the purpose of this work, the southern limit is established at 23°N latitude, which coincides with the southern end of the peninsula on the west coast and the southern limit of the state of Sonora on the east coast. Thus, four states border the Gulf of California: Baja California and Baja California Sur on the west coast, and Sonora and Sinaloa on the east coast (Figure1).

From a data base containing 9481 records of seaweeds reported for the Gulf of California from 1911 to 2003 (58 papers), the information relating to 55 species regarded as commercially valuable by Pacheco-Ruíz & Zertuche-González (1996), was displayed on a map to characterize their distribution within the Gulf in time and space. From these species, we selected those for which biomass studies were available to be analyzed in terms of the geographical and seasonal presence. The information was displayed and analyzed using Arcview 3.2a GIS. The data base considers only records published in refereed journals. Herbarium records, varieties, or species reported as doubtful were not included. Taxonomic and geographic attributes were considered. Seasonality was included

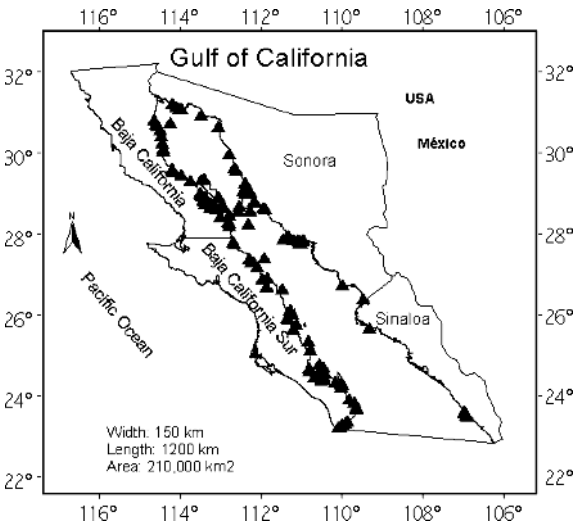

Figure 1. Sites with commercially valuable seaweed species reported from the Gulf of California.

when reported or when it was possible to deduce it from the manuscript. Most papers did not include geographic references. Therefore, based on the name of the localities, geographic coordinates were obtained from maps of the Mexican National Institute of Statistics, Geography and Informatics – INEGI – (Instituto Nacional de Estadística, Geografia e Informática). Records were grouped into "sites" when they were near an officially recognized map location. For instance, all records for a specific Bay or Point were grouped together.

Monthly mean surface temperatures were obtained from the PROMETEO data base (WWF, Program Mexico 2001). Seasonal temperature maps were derived from the average of three months. Data from January to March were used for winter, from April to June for spring, from July to September for summer and from October to December for fall. Site records for selected commercial species were superimposed on the temperature maps to determine their seasonal geographical distribution.

Results

Of the 160 sites recognized in the data base, 137 included commercially valuable seaweeds; commercial species occur throughout the Gulf of California, except for the southern east coast (state of Sinaloa), where the lack of studies was made evident by the low number of records (Figure 1).

Table 1. Seaweed biomass and number of sites evaluated versus the number of sites where these species have been reported

Species	Biomass (dry tons)	# of sites evaluated	# of sites present	References for biomass
Ulva lactuca	350	4	28	Pacheco-Ruíz et al. (2002)
Eucheuma uncinatum	165	1	27	Guzmán del Proo et al. (1986)
Chondracantus squarrulosus	160	1	19	Pacheco-Ruiz et al. (2000)
Gracilariopsis lemaneiformis	4060–5751	5	35	Pacheco-Ruiz et al. (1999)
Sargassum ssp	31,000	9	69	Pacheco-Ruíz et al. (1998)
Sargassum ssp	18,901(*)	1	69	Hernández-Carmona et al. (1993)
Sargassum ssp	7,250 (*)	1	69	Casas-Valez et al. (1993)

(*) Biomass reported as wet weight.

The species *Gracilariopsis lemaneiformis* (Bory de Saint-Vincent) E.Y. Dawson, Acleto & Foldvik (Pacheco-Ruíz & Zertuche-González, 1999) , *Ulva lactuca* Linnaeus (Pacheco-Ruíz et al., 2002), *Eucheuma uncinatum* Setchell & Gardner (Barilotti and Zertuche-González, 1990) and *Chondracantus squarrulosus* (Setchell & Gardner) Hughey, P.C. Silva & Hommersand (Pacheco-Ruíz et al., 2001), and the *Sargassum* species *Sargassum johnstonii* Setchell & Gardner, *Sargassum sinicola* Setchell & Gardner, *Sargassum herporhizum* Setchell & Gardner and *Sargassum lapazeanum* Setchell & Gardner were reported in the literature as present in large quantities (Hernández-Carmona et al., 1990; Casas-Valdez et al., 1993; Pacheco-Ruíz et al., 1998).

Seaweed biomass data is only available for species on the west coast and for few sites from the many that are present (Table 1). *Sargassum* species are by far the most abundant flora. These studies, however, do not always differentiate among the different species of *Sargassum*. Pacheco-Ruíz et al. (1998) reports *S. johnstonii* as the most abundant.

Species reported to occur in large quantities showed a strong seasonal variation. They all showed a maximum distribution in winter-spring and minimum in the summer-fall, except for *Sargassum lapazeanum,* with maximum distribution in spring-summer. However, their maximum distribution varies geographically.

Surface water temperature in the Gulf ranges from 15 to 30 °C throughout the year. The largest distribution

Table 2. Number of sites (#s), temperature range (T °C) and latitude range (°) of commercial species per season

	Spring			Summer			Fall			Winter			
Species	# s	T °	L.	# s	T °	L.	# s	T °	L.	# s	T °	L.	Lat
Ulva lactuca	16	18	23	7	26	23	2	25	23	11	15	23	23–29
		25	29		30	29		26	24		22	29	
Eucheuma uncinatum	18	18	27	4	26	27	2	21	27	9	15	27	27–31
		24	31		30	29		24	28		18	30	
Chondracantus squarrulosus	13	18	27	2	26	28	3	21	28	6	15	27	27–31
		24	31		30	31		25	31		18	31	
Gracilariopsis lemaneiformis	21	18	24	6	26	27	11	21	24	14	15	24	24–31
		24	31		30	30		26	31		21	31	
Sargassum johnstonii	19	18	24	5	26	27	5	21	28	12	15	25	24–31
		23	31		30	31		24	31		20	31	
Sargassum lapazeanum	10	18	22	10	28	24	6	21	24	3	16	24	22–30
		24	28		30	28		26	29		21	30	
Sargassum sinicola	23	18	22	23	26	23	20	21	23	25	15	23	22–31
		25	31		30	31		26	31		22	31	

Lat is the latitudinal distribution throughout the year.

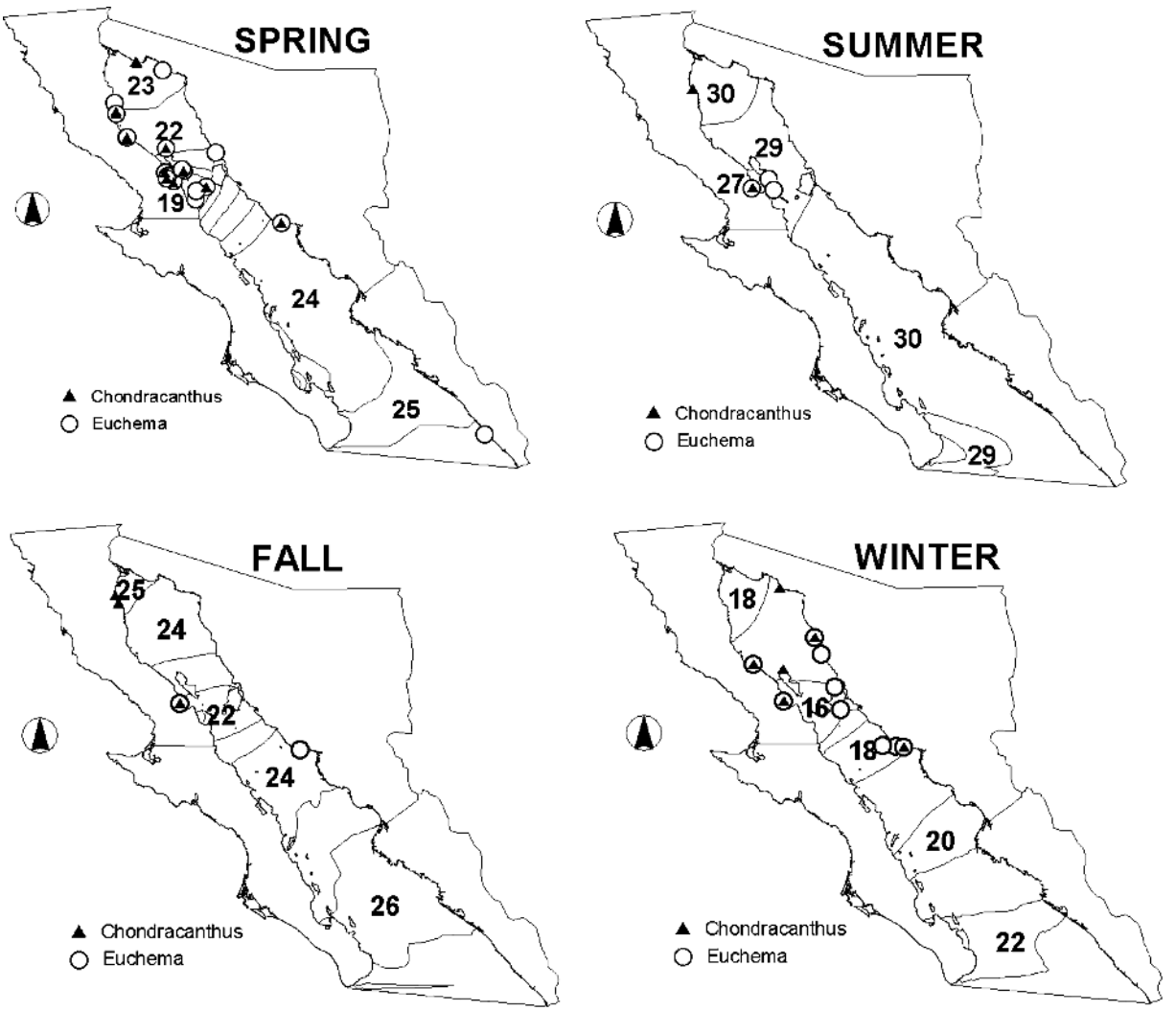

Figure 2. Seasonal distribution of sites of the carrageenophytes *Eucheuma uncinatum* and *Chondracantus squarrulosus* in the Gulf of California.

of commercial species is limited to areas and times when water temperature varies between 16 and 24 °C. The large temperature gradient in the Gulf of California makes it a sea of extreme climates when compared with the Pacific Ocean at similar latitudes (Table 2). An important anomaly is the fact that the coolest area is not the northern-most but the region of the large islands (28 to 30 °N), and that the largest annual temperature gradient is present in this region and to the north. Most of the seaweed records are, in fact, between 28–30 °N. Thus, while the annual temperature range at the mouth is 7 °C (from 22 to 29 °C), the gradient in the large islands region is 11 °C (from 16 to 27 °C) and in the north region 14 °C (from 18 to 30 °C). Surface temperatures showed strong seasonal variation in the Gulf, ranging from 18 to 25 °C in spring, from 26 to 30 °C in summer, from 20 to 27 °C in fall and from 15 to 23 °C in winter. Minimum temperatures, however, are present in the north-central region, from 28 to 30 °N, increasing to the north and south (Table 2).

The distribution of the carrageenophytes *E. uncinatum* and *C. scuarrulosus* is limited to the north of 28 °N, approximately. Both species tend to disappear in fall. Large beds are reported only in the north central region (between 28 °N and 29 °N) of the west coast of the Gulf (Figure 2).

Sargassum spp are distributed throughout the Gulf. The records for *S. johnstonii*, the only species reported to be present in large quantities, are concentrated in the central and northern region (north of 28 °N), while the

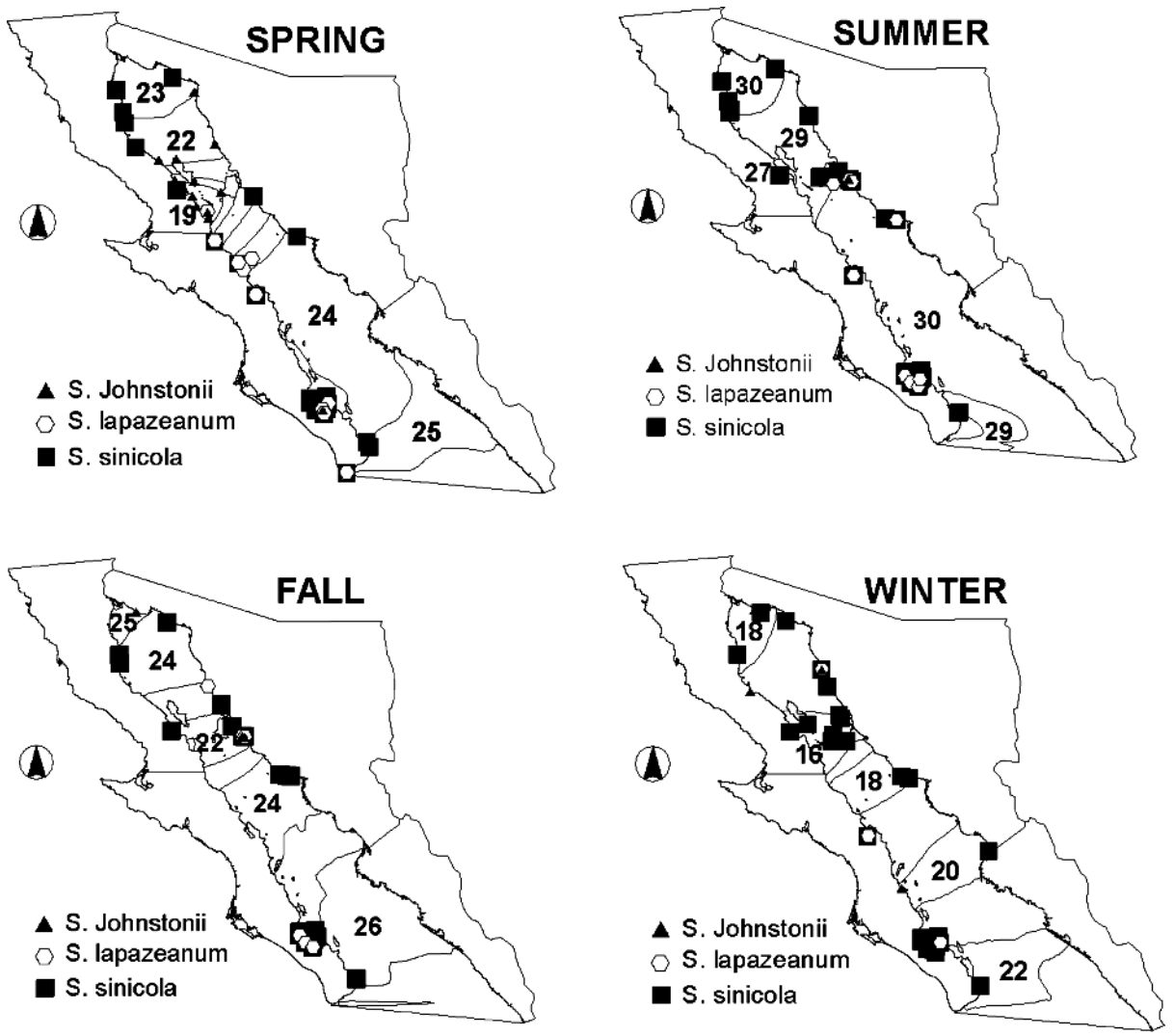

Figure 3. Seasonal distribution of sites of *Sargassum johnstonii, Sargassum lapazeanum* and *Sargassum herporizum* in the Gulf of California.

records for *S. lapazeanum* are restricted to the southern region (south of 28 °N) on the west coast. *S. sinicola* is reported throughout the Gulf, with the exception of the southern east coast (south of 27 °N), for which there are no records of *Sargassum* species (Figure 3).

The distribution of *Ulva lactuca* is limited to the central and southern region, below 30 °N. The records showed two distinctive distributions, one between 28 °N and 29 °N, which is absent in fall, and another in the southern region, concentrated between 23 °N and 26 °N, present all year around (Figure 4).

Gracilariopsis lemaneiformis occurs in practically all of the Gulf but in greater abundance during spring and winter. In fall, it is absent from most of the west coast, except in the northern and southern regions, where temperatures are warmer than the region of the islands; however, this pattern of distribution does not replicate on the east coast (Figure 5). *Gracilariopsis lemaneiformis* is the only species currently harvested in the Gulf of California (Pacheco-Ruíz et al., 2003). Commercial harvesting occurs between 28 °N and 29 °N, where Pacheco-Ruiz et al. (1999) estimated more than 4000 harvestable dry tons. This study shows many others sites where this species is present, particularly around 28° and 29 °N on the east coast of the Gulf and 24 °S on the west coast (Figure 5).

In the case of *Sargassum,* distinct areas were defined for *S. johnstonii* and *S. lapazeanum*, the former being

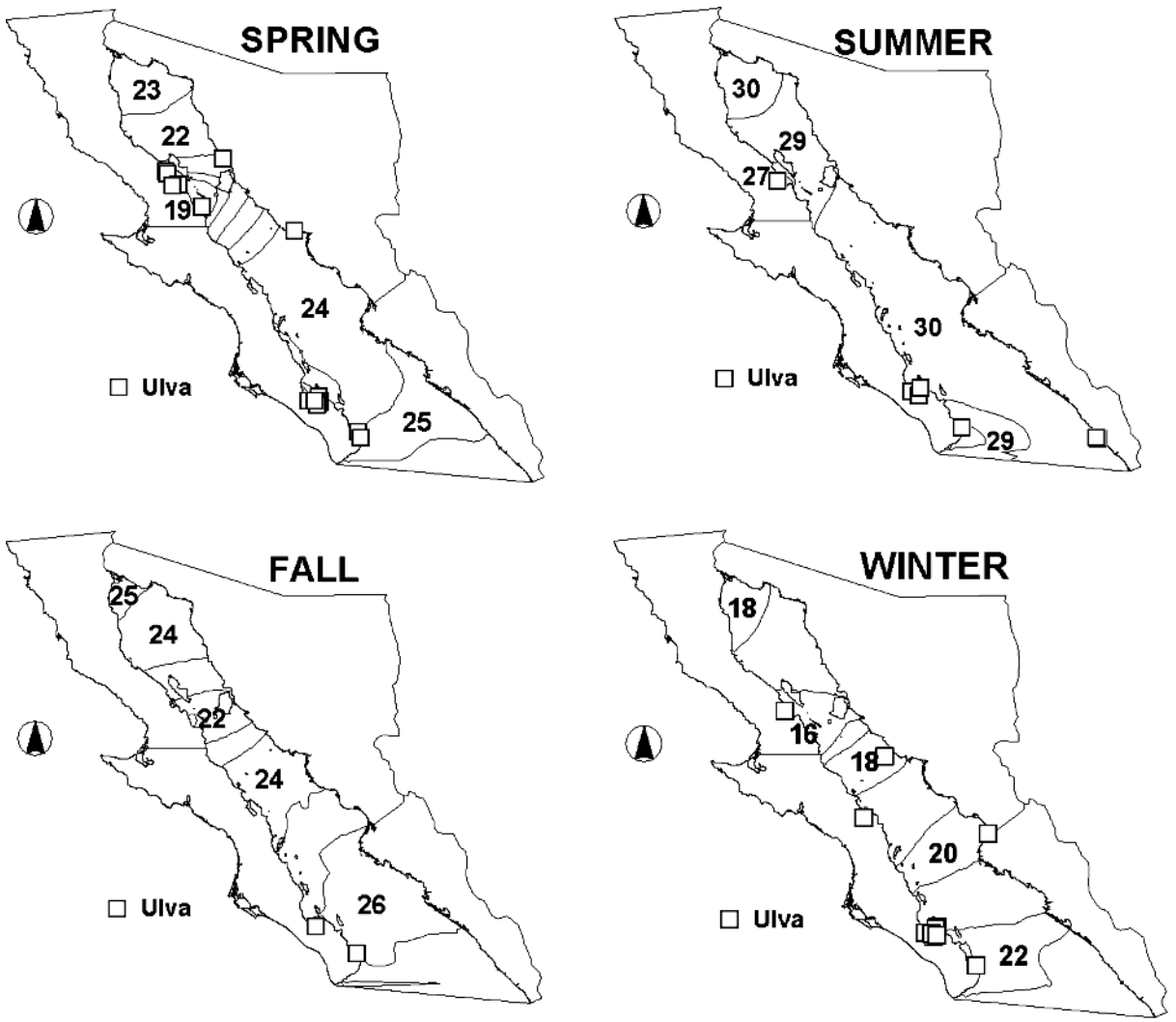

Figure 4. Seasonal distribution of sites of *Ulva lactuca* in the Gulf of California.

more abundant to the north of 27 °N and the latter to the south of 26 °S (Figure 3, Table 2). Similarly, large beds of *U. lactuca* do not occur north of 29 °30′N, but distinct populations are present (Figure 4). This distribution suggests a greater resistance for the southern population to warm temperatures, which may translate into longer harvesting periods.

Of the seven species with commercial application analyzed in this study, three are considered endemic: *E. uncinatum*, *C. squarrulosus* and *S. johnstonii*.

Discussion

Most of the few pristine coastal environments in the world are located in developing countries, where social pressure for development is challenging the conservation of marine resources. Governments are faced with the difficult task of designating areas for conservation or exploitation, and there is usually insufficient information on which to base their decision. The characterization of marine environments on a meso-scale represents a major challenge. GIS can be a powerful tool for analyzing databases of biological species and other information useful for management. However, its use as a tool to analyze information depends on the reliability of the database. Wrong interpretations may be made if insufficient data are available. On the other hand, GIS is a useful tool to identify geographical areas where there have been few or no studies. It is obvious from the data used in this study, taken from more than

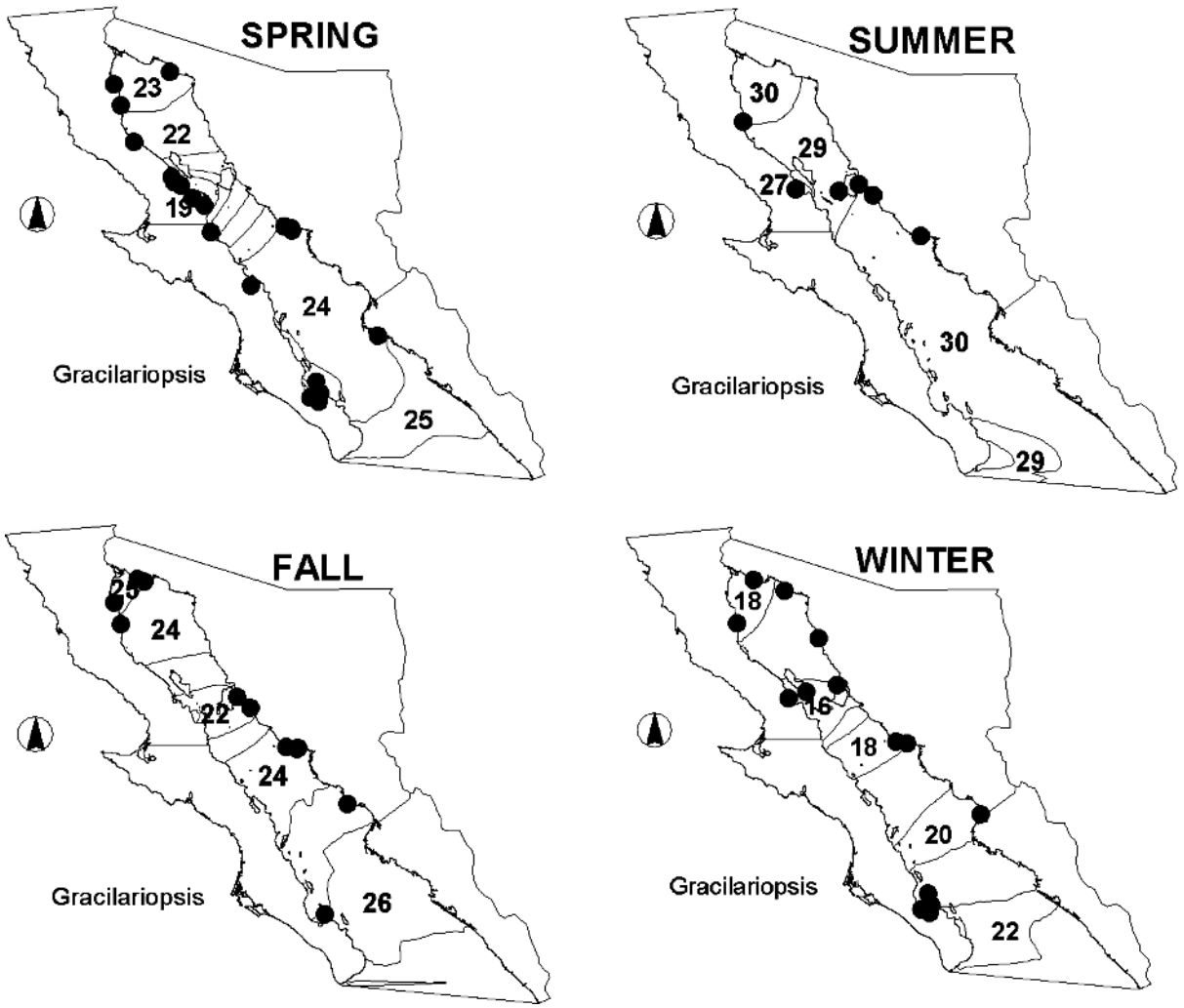

Figure 5. Seasonal distribution of sites of *Gracilariopsis lemaneiformis* in the Gulf of California.

fifty papers published between 1911 to 2003 on the flora of the Gulf of California, that studies are lacking for the southeast coast (state of Sonora); however, sufficient data seem to be available for the rest of the Gulf to be able to define important regions of different commercial seaweed. This study gives an example of the utility of the use of a GIS as a tool for the preliminary assessment for a broad area of the potential of seaweeds as a resource. The study identifies the location of the species in time and if there are biomass estimates or not. Furthermore, by comparing the number of sites in which the biomass has been determined against the number of sites where the seaweed is present, a potential for future surveys can be obtained. This analysis could be obtained for any species present in the region and can provide useful information to support policies for management and conservation.

This study indicates that the definition of areas for seaweed exploitation would depend on the species considered. It would seem that the southern region of the Gulf would be more suitable for tropical species suited to grow in warmer and relatively stable temperatures, while the islands region would be favorable for temperate species, although for just part of the year when relatively low temperatures prevail (winter and spring, 16 to 23 °C). This characteristic would be fundamental for establishing different zones in the Gulf for seaweed exploitation or cultivation.

Based on the fact that 85% of the sites studied in this region contain valuable species and that at least

seven of them are reported to exist in large quantities even though few sites biomass has been evaluated, the Gulf of California could be an important source of seaweeds with commercial applications. The unique oceanographic conditions define different regions in the Gulf where different species predominate. Nevertheless, as a whole, seaweed availability shows a strong seasonality that would limit the possibility of seaweed utilization to only three to six months of the year. It is clear from this study that studies are lacking on the southeast coast of the Gulf.

Conclusions

GIS can be a powerful tool to support research, management or planning programs where special analysis of broad areas is necessary. In this study, the application of the use of a GIS to determine the potential availability of commercial seaweeds from the Gulf of California proved useful to identify valuable species, their location in time and space and the degree of knowledge about their biomass estimates. This approach can be used as an example to be applied in other areas of the world for the characterization of seaweed resources.

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