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Environmental and Management Considerations for Adopting the Halophyte *Salicornia bigelovii* Torr. as a Sustainable Seawater-Irrigated Crop.

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Abstract: *Salicornia bigelovii* Torr. is a potential new crop for coastal and saline lands, because of the oil content of its seeds, its properties as fresh vegetable, forage, and other uses. As a true halophyte, it can grow with seawater irrigation. The aim of this study was to determine the phenology and water requirements of *Salicornia* as a new plant resource in growing areas for salt-tolerant crops in coastal and saline lands, and elucidate scenarios of sustainability about these issues. Water requirements were estimated in experimental plots on the coastal line and fulfilled with drip irrigation connected to seawater aquaculture discharge ponds, 30 m from the sea. The recorded phenological events were germination, flowering, fructification, maturation, and physiological death. Results reflect the difficulty to adopt it as a new crop because of its long-life cycle, around nine months, contrasting with the life cycle of common crops, from three to four months. Irrigation needs reached a depth of 240 cm, significantly exceeding those of conventional crops. Such limitations are highlighted, but also its potential use as a biofilter of coastal aquaculture effluents, being a productive target-biomass, feasible to be used as a dual-purpose use of water and energy required in aquaculture farms.

Keywords: *Salicornia*; sea asparagus; coastal agro-aquaculture; seawater irrigation; allometric equation

1. Introduction

1.1. Water Shortage Limitations for Conventional Agriculture in Arid Zones

At present and in the near future, agriculture will need to develop new sustainable schemes to feed future populations. It is clear that water use increases in a parallel rate to total production, and this is going to be a serious problem unless drastic measures are taken [1]. Freshwater limitations in some heavily irrigated regions could necessitate reversion of 20–60 Mha of cropland from irrigated to rainfed management or another source of water [2], as water is a critical resource for farmers, and ensuring access to water is quite important for reducing poverty in rural areas, because poverty reduction will lead to food security [3]. In this context, mankind will have to diversify production schemes, including the integration of livestock, aquaculture, or other, less fresh water-demanding activities; in this context, the proximity of aquaculture to and use of limited high-quality water resources gives a highly site-specific potential for minimizing environmental impact [4]. During the last decades, the use of plant resources of marine or coastal origin is gaining attention, but their use must be sustained on detailed studies, to face the freshwater scarcity and the lack of food [5,6]. Northwest México is an arid region where freshwater availability for agriculture is drastically decreasing, but on the other hand, it has a long coast sustaining a diversity of biota; the Mexican coastal ecosystems are located in the tropical and subtropical zones between 30° N 116° W and 15° N 90° W, with mild temperatures only on the north, neighboring with the USA border [7]. For the development of this area, regional policies based on the analysis and participatory use of water and natural resources are highly important for a rational planning approach [8]. The above is relevant to mitigate the overexploitation of water in this arid zone, whose main source is groundwater; this issue has become extremely crucial in the last decades, especially in similar arid and semi-arid regions, where the coastal aquifers are particularly at risk due to intrusion of seawater [9].

The shortage of high-quality water is an issue in arid and semi-arid regions. In consequence, the use of water resources of marginal quality is gaining important consideration, particularly in arid regions where large quantities of saline water are used for irrigation. Nevertheless, the use of these kinds of water in irrigated lands requires the control of soil salinity [10].

1.2. The Cultivation of Halophytes as an Option to Reduce the Demand for Fresh Water in Agriculture

As an alternative option for coastal development where shortage of freshwater prevails, several species of wild halophyte vegetation are used seasonally for human consumption and grazing [11]. In México, halophytes are distributed along the Pacific Ocean coast and the Gulf of México and grow on saline soils, which are particularly frequent in places close to the coast, as many of them are permanently wet. Under these conditions, true halophyte species are plants that grow in saline environments, with the capacity to develop true tolerance to salts. The importance of the world's halophyte resources is shown for obtaining fodder, grass forage, and medicinal and oil raw materials, as well as biological agents for reclaiming degraded lands, especially in arid regions, where dire shortages of food are observable [12]. These communities include genera and species with wide distribution [13]. In coastal plant communities in northwestern México, two of the most common plant families are Gramineae and Chenopodiaceae, with several halophytic species [14]. Among the attributes of halophytes, succulence is a common feature in different families, and their tolerance to high osmotic pressure caused by salinity [15]. The annual halophyte *Salicornia bigelovii* Torr., also known as *'sea asparagus'* or *'Salicornia'*, of the family Chenopodiaceae, is an annual plant with succulent stems; the whole plant is divided into branches and leaves that are not apparent; groups of plants form compact and frequently extensive colonies. Representative plants reach a height up to 50 cm height, with stems articulated, crass and fleshy, of bright green color; the flowers are inconspicuous and of reduced size [16]. They usually inhabit saline terrains (inland or coastal) such as salt marshes. It is found in flood-prone salt marshes along the northern coast of the Mexican Pacific Ocean, on plains and alkaline coastal plains of the Baja California Peninsula, and on the islands Tiburón and Angel de la Guarda [14,17]. The differences in growth between halophyte plants as *Salicornia* and glycophytes such as tomato or lettuce, when subjected to salinity conditions require, for the former, salts for their proper development, while glycophytes reduce their growth and productivity, even with minimum increases in salinity [11,18].

The promising importance of *Salicornia* not only lies in the oil content of its seeds, or its potential use as fresh vegetables with high mineral content of their forage, but also because its response to watering, it is suitable candidate as a biofilter to recycle water and nutrients contained in effluents from marine aquaculture [19,20]. *Salicornia* has been studied by several researchers, studying its ecology, physiological responses to salinity changes, agricultural management, and utilization [18,20,21], also the phenology of related species with an emphasis on floristic aspects, the nutrient content [22,23], and other issues. On the coast of the Bay of La Paz BCS, México, it is possible to find *Salicornia* associated to halophytic vegetation and with diversified soil microbiota, both in winter and in spring, which decreases in summer and autumn due to a change in seasonal climate [24].

Even when a productive potential of *Salicornia* is perceived, taking advantage of seawater from aquaculture effluents and reducing the demand for fresh water required by agriculture, various management-related difficulties in the soil-agroecosystem relationship hinder its adoption. Among other aspects, the duration of the life cycle, the obvious low inclusion in traditional foods, its management at different scales, and the real availability of land compatible with aquaculture are important issues to investigate in greater detail. Accordingly, the purpose of the present study is to corroborate the viability of the halophyte *Salicornia bigelovii* Torr. as a new crop irrigated with seawater and verify the cultivation period for further adjustments in the design of coastal farms.

2. Materials and Methods

2.1. Study Area

The study was conducted in El Comitán, a coastal town at La Paz Bay and Lagoon, in the southern portion of the Baja California Peninsula, focused on the phenological monitoring and watering of a *Salicornia bigelovii* plot, developed from seeds harvested from a natural population during 2016–2018, which was the establishment and observational period. The experimental plots were established at a stripe adjacent to aquaculture ponds and on a flooded marsh on the coastal line at the Center for Biological Research of Northwest México (CIBNOR), 17 km west of La Paz City, BCS, Mexico. The coastal area of the *Salicornia* natural population and plot are located at coordinates 24°10′ N and 110°20′ W (Figure 1).

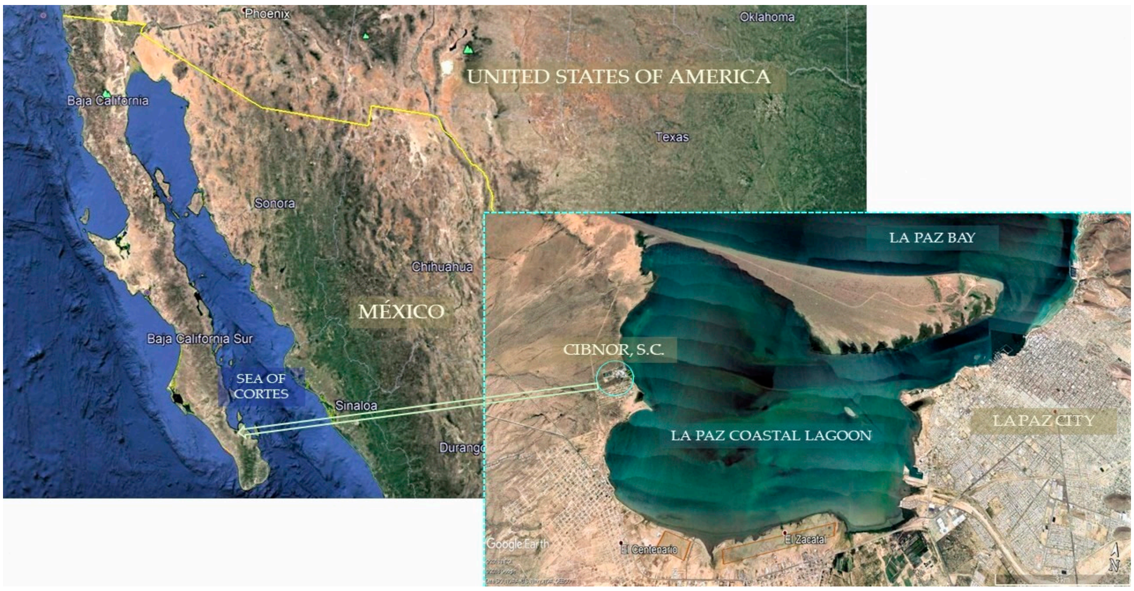

Figure 1. Geographic location of the 'Center for Biological Research of Northwest México' (CIBNOR, S.C.), 17 km west La Paz City at the southern tip of the Baja California Peninsula, northwest México.

2.2. Experimental Site

Irrigations of *Salicornia* plots were applied using effluent waters from seawater aquaculture ponds, being a way to promote their reuse (Figure 2). The southwest portion of Ensenada de La Paz, known as Chametla–El Centenario salt marsh, in its natural environment is a floodplain influenced by tides, with more than 1000 linear meters of wetlands. The soil of the experimental site was a sand type, with granular structure, high permeability, and efficient drainage; however, it contrasts with the soil/sediment that sustains the natural populations of *Salicornia*, which is a medium sand type, similar to the beach [25]. The region's climate is arid with an historical annual rainfall of 180 mm, constantly outpaced by evaporation; the hottest months are July–September, reaching a mean temperature of 30 °C; annual rainfall for the study period was lower than the historical mean (Figure 3).

Figure 2. Seawater aquaculture ponds and *Salicornia bigelovii* irrigated plots established at CIBNOR, S.C., 17 km west La Paz City, México.

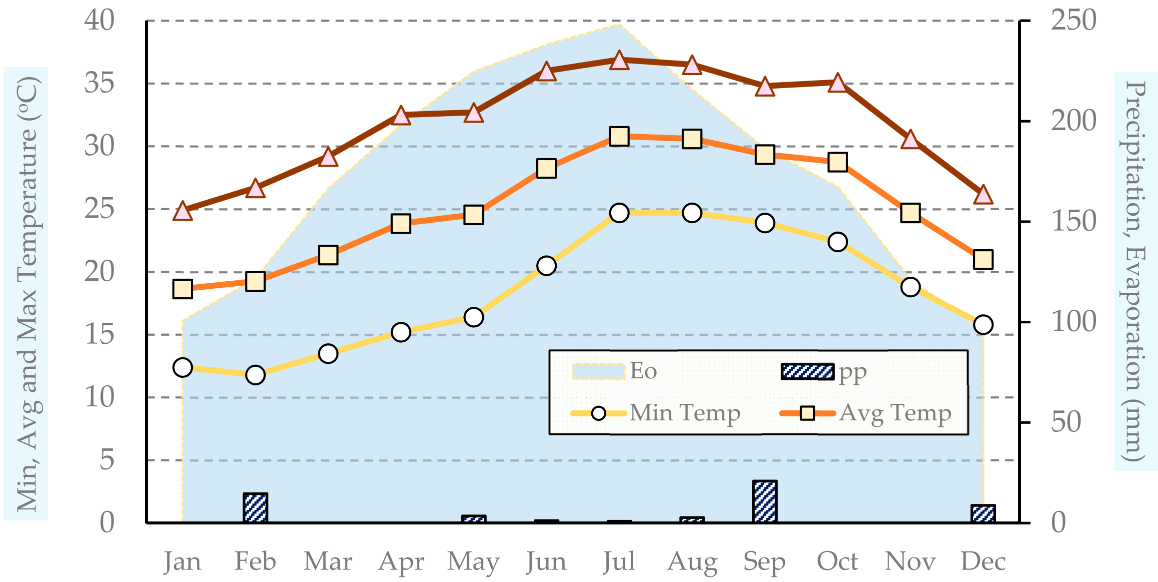

Figure 3. Main climatic variables for the study period (1916–1918) in the coastal area of CIBNOR's Research Station, 17 km west La Paz City, México. (Eo: evaporation; pp: precipitation).

2.3. Water Quality

Irrigation water quality was a water-dependent factor of aquaculture ponds, in this sense, the water source originated from white shrimp and yellow snapper farming ponds. Water analysis was performed according to the standards and procedures of the water quality laboratory. pH was measured with an Orion® 620 pH meter (Beverly, MA, USA), and salinity were measured according to the Mexican Norm NMX-AA-034-SCFI-2015 (Water analysis: Measurement of salts and solids dissolved in natural water, wastewaters and treated wastewaters—Test method) [26].

2.4. Plant Materials and Irrigation Methods

Salicornia seeds were collected from natural populations established on the coast of La Paz, BCS. The phenological events perceivable in the field were recorded, including germination, flowering, fructification, lignification, maturation, and physiological death; also, its growth throughout the life cycle, including the variables height above ground, the number of internodes and ramifications. *Salicornia* was established in the period 2016–2018; four measurements were made per month, from 25 January to 30 October 2017, for eight sub-populations chosen previously at random. A flexible metric tape and millimeter 'vernier' were used. The water requirement was estimated in experimental plots established in CIBNOR's coastal line and fulfilled with drip irrigation connected to the aquaculture discharge ponds, 30 m from the sea; arrays were established by the design of borders and furrows with a spacing of 70 cm; borders were 2 m wide by 4 m long. A 10 m × 7 m plot with drip irrigation connected to the aquaculture ponds. The optimal irrigation was applied to simulate moisture caused by tides in the natural environment of *Salicornia*, trying to maintain a humidity similar to that of the floodable salt-marshes. Irrigation water was pumped from an open-air aquaculture pond, 5 m high, located 150 m from the coastal line of CIBNOR. Water flow for irrigation was measured with in-line hose meters NDJ Model BH (diameter 12.7 mm). Irrigation was applied daily, at an estimated rate of 2 cm during 120 days.

2.5. Statistical Analysis

The data obtained were captured and processed with an Excel spreadsheet; for growth monitoring, we measured 8 groups of plants, with n: 6 and N: 48. The statistical analyzes were performed in triplicate for the variables of seawater quality and in quadruplicate for plant growth. The mean values obtained were compared according to the Tukey procedure; statistical procedures were carried out using the SAS software (Statistical Analysis System) with an institutional license [27].

3. Results and Discussion

3.1. Water Quality

Analysis of the seawater quality parameters were carried out in the laboratories of CIBNOR, showing means of pH = 7.82 and salinity = 37.6 ppt; maximum values of 45 ppt were recorded in the summer of 2017, due to the effect of higher temperatures and evaporation rate in the aquaponic ponds. The main aquaculture species cultivated in CIBNOR's ponds were White shrimp (*Litopenaeus vannamei*) and Yellow snapper (*Lutjanus argentiventris, L. peru*). For pH and salinity (ppt) of the irrigation water, no significant differences were observed among the years of the study period. By applying analysis of variance, for pH, an observed value of F = 0.53 (p = 0.62 ns) was calculated, and for salinity F = 0.84 (p = 0.48 ns). According to Tukey's comparison test, the widest difference was detected for the years 2017 and 2016 (39.5 and 37.0 ppt), when an average increase of 2.8 ppt was reflected, compared to 2015 (36.3 ppt) (Table 1, Figure 4); however, this difference was statistically non-significant.

Table 1. pH and salinity of seawater obtained from aquaculture ponds with cultivated species.

Period	Aquacultured Species		Water Variables	
	Common Name	Scientific Name	pH	ppt (*o/oo*)
2015–2016	White shrimp, Yellow snapper	*Litopenaeus vannamei, Lutjanus argentiventris*	7.7	36.3
2016–2017	White shrimp, Yellow snapper	*Litopenaeus vannamei, Lutjanus peru*	7.9	37.0
2017–2018	White shrimp	*Litopenaeus vannamei*	7.8	39.5

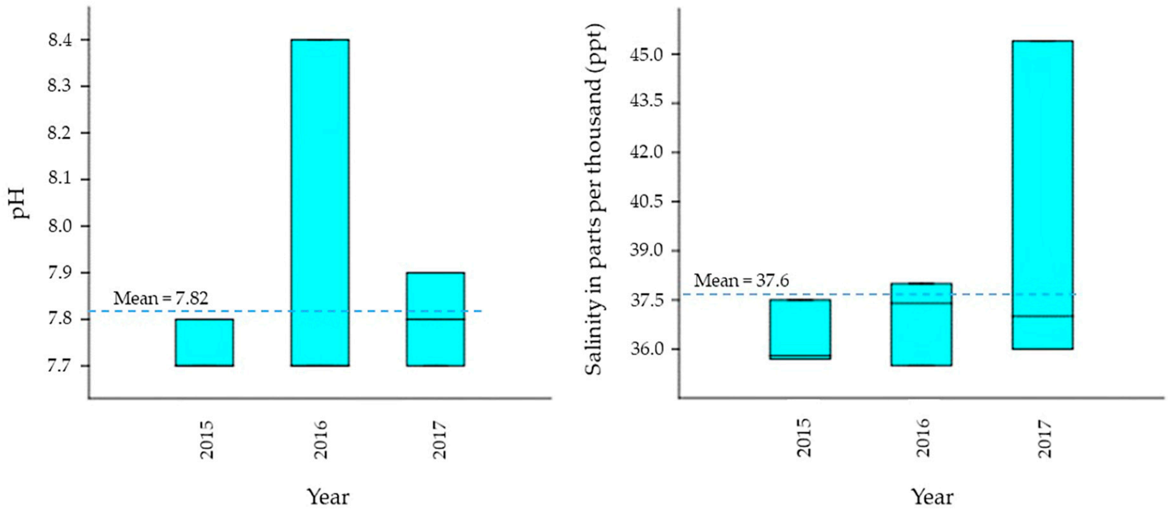

Figure 4. Mean values and data dispersion seawater quality variables; (**left**): pH, (**right**): Salinity in ppt. Periods—2015: July 2015–June 2016, 2016: July 2016–June 2017, 2017: July 2017–June 2018.

3.2. Plant Establishment and Growth

The germination starts from the second half of November until early January. The formation of the first articles was observed in January and February; the initial emergence occurs in times of cool temperature and when the substrate salinity has decreased slightly as a consequence of the light winter rains. The emerged seedlings were relatively uniform. The flowering stage starts around four months after the germination process ends, towards the beginning of March, by the end of the winter season, appearing the ninth and tenth articulations. For reaching the stage of fructification, the flowering period is relatively short; one month after 75% of the population finishes it, the fruiting starts by April–May, which was verified for more than 92% of the plants, while the lignification stage was observed in June, when temperature begins to increase. From the lignification stage, near 70% of the entire population reached the final stage of growth and finally, its life cycle. The population on which the samplings were carried out did not evidence a desirable uniform and homogeneous development, since the phenological stages showed a slight shift among plants (near 8% of individuals respect the population). Height data of sampled *Salicornia* plants are shown in Table 2.

Table 2. Average plant height per month for each sampled plots of *Salicornia* (cm).

Date	Naturally Flooded Plots				Seawater Irrigated Plots						
	1	2	3	4	5	6	7	8	Mean	S Dev	CV
						cm					
25 Jan–25 Feb	5.2	5.8	5.5	7.7	8.5	8.1	8.2	5.2	6.8	1.5	21.7
5–25 March	6.1	7.4	6.1	8.9	9.6	10.2	10.9	9.3	8.6	1.8	21.3
5–25 April	9.1	9.0	7.9	11.9	12.3	13.0	14.6	16.8	12.6	3.0	24.1
5–25 May	16.8	14.6	11.1	14.8	17.3	17.8	20.8	22.1	16.9	3.5	20.9
5–25 June	20.2	20.5	14.5	17.4	19.4	20.8	23.7	27.4	20.5	3.9	18.9
5 July–15 Aug	19.9	20.7	17.0	20.6	21.7	24.1	25.0	29.9	22.4	3.9	17.6

Plant height evidenced the highest rates from late March to mid-July, then growth appeared to stabilize (Figure 5). However, by 15 September, a high percentage (>95%) of the plant population was virtually dehydrated and evidenced a physiological death, beginning the release of mature seeds to the soil at the surrounding environment, to be ready for the next cycle; different values of plant growth were observed for both sites because of the natural variability exposed by seeds.

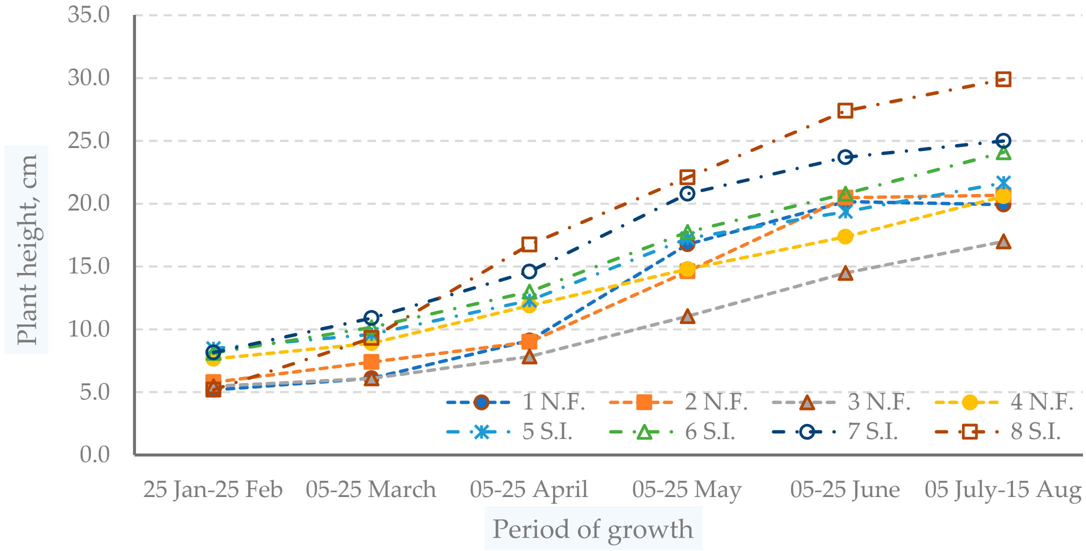

Figure 5. Plant height reached after the period of growth of *Salicornia bigelovii*, in a coastal area of La Paz Bay B.C.S., northwest of Mexico. (N.F.: Naturally flooded; S.I.: Seawater irrigated plots).

According to the climatic data registered for the period of growth, the average temperature exerted an influence on the growth reflected on the height of the plant, since it is a factor that fluctuates significantly in such period; the growth pattern reflected as plant height evidenced a power function, known as Freundlich equation or allometric model [power curve: $f(x) = kx^n$], expressed as:

$$y = 0.0035 \times 2.5375$$

$$y = 0.0053 \times 2.495$$

The obtained functions are valid up to a mean temperature of 32 °C (Figure 6), registered for the hottest months (July–September), when *Salicornia* plants stop growing and start the grain-filling stage. These records agree with a former study, which reported that days to seed production do not differentiate to a large extent among *S. bigelovii* populations, which was an average of 264 days [28].

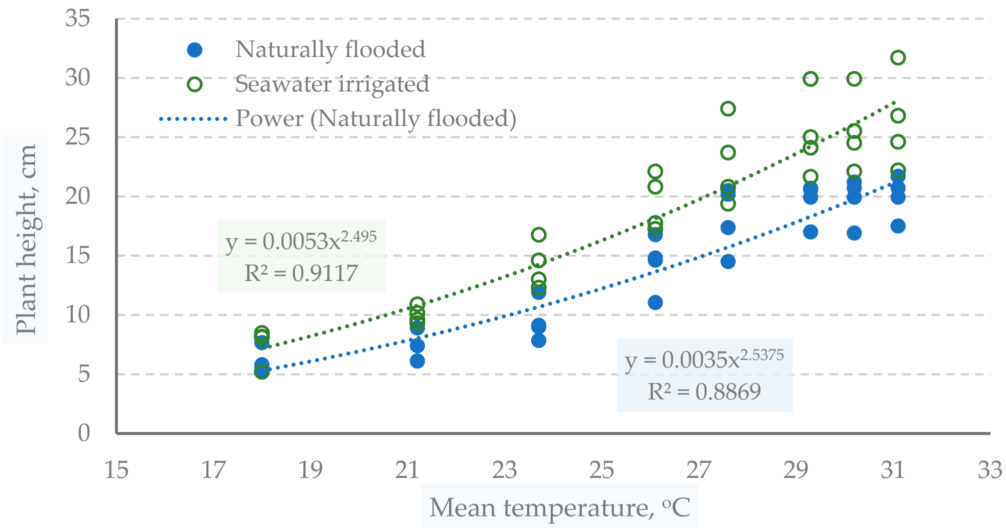

Figure 6. Effect of the environmental temperature on the plant height of *Salicornia*, in eight subpopulations in the Bay of La Paz BCS, NW Mexico (n: 64); eight data sets, from January to August.

Based on the collected and analyzed data, a clear limitation related to its life cycle was detected for adopting this species as a new crop, contrasting with traditional crops, whose life cycle usually ranges between three and four months. Moreover, one of the fundamental objectives of the classic plant breeding is the shortening of the life cycle, which entails a saving in the cost of crop management and agronomic inputs [29].

3.3. Irrigation Requirements

The water needs and irrigation requirements were estimated in four weekly applications, estimating a total of 80 irrigations, distributed in seven months, until the mid-period of maturation, by early September; by combining the saline quality of the aquaculture discharge water with the prevailing high temperatures and evaporation, deposition of precipitated salts is observed on the outer surface of the irrigation hoses, in the location sections of the emitters (Figure 7). Each application of water consisted of light irrigation, calculated at 2 cm of water depth, with the available water derived from seawater aquaculture ponds, a highly-saline type, with a CE of 49.6 dS m^{-1}; therefore, a total irrigation depth was estimated in 240 cm, for a cycle of 120 days (from germination to seed maturity). Such water requirement is significantly higher than conventional agricultural crops. For corn, the maximum production a medium maturity crop requires between 50 and 80 cm (avg. 65 cm) of water; in the case of wheat, for high yields water requirements are 45 to 65 cm (avg. 55 cm), both depending on climate and length of the growing period [30]. On the other hand, alfalfa water requirements vary from 80 to 160 cm (avg. 120 cm)/growing period, also depending on climate and length of growing period; other estimates have been published elsewhere [31]. Possible scenarios of *Salicornia* water requirements per ha, compared with alfalfa, corn, and wheat, are presented in Table 3, estimating a significantly higher amount of water for *Salicornia* irrigation as compared to the other crops. For the case of Mexico, electricity costs for pumping water for irrigation are low, because agriculture receives an electric subsidy for this purpose (Table 4), in consequence, with low energy costs and readily available connections, there are few financial disincentives for farmers to limit pumping [32].

Figure 7. Irrigation system with *Salicornia bigelovii* at the coastal line of CIBNOR, S.C., at the west side of La Paz Lagoon, Sea of Cortés, Baja California Sur, Mexico.

Table 3. Scenarios of water requirements per ha and per cycle for *Salicornia*, as compared to corn and wheat [30], and alfalfa [31].

Crop	Main Use	Water Depth	Water Vol/ha	Water Vol 65% Space Distribution
		cm	m^3	m^3
Salicornia	Forage/vegetable	240	24,000	15,600
Alfalfa	Forage	120	12,000	7800
Corn	Grain/forage	65	6500	4225
Wheat	Grain	55	5500	3575

Source: Food and Agriculture Organization of the United Nations. Land and water—Databases and software [31]; FAO Irrigation and Drainage Paper 1994, 29. Rev. 1. Reprinted 1989 [33].

Table 4. Estimated electric energy from the Electricity Federal Commission (CFE, México) required for irrigation pumping and its cost in a one-ha *Salicornia* coastal plot.

Irrigations Per Day	Water Depth Per Irrigation	Water Depth Per Day	Water Depth Per Cycle	Pump Efficiency	Electricity Consumption			Electric Cost Per Cycle/ha *	
					Per Day	Per Month	Per Cycle		
Number		mm		%		kW h		Mex Peso	$USD
1	20	20	2400	70	11.3	337.9	900.9	764.90	38.30
2	15	30	3600	70	16.9	506.8	1351.4	1147.40	57.40
3	15	45	5400	70	25.3	760.2	2027.1	1721.10	86.10

Note: * The electric cost is an average from a sample of 15 electrical bills (Federal Commission of Electricity CFE, México) from local farms. Currency: $1 USD = 20 Mex pesos.

Since many decades ago, increasing salinity of soil and water threatens agriculture in arid and semiarid regions, in this sense, the idea of harnessing seawater to diversify food production is interesting and promising [34]. On the other hand, targeting *Salicornia* towards agri-aquaculture integrated farms, the use of water in aquaculture activities near coastal lines can reach sustainability by using this halophyte as a biofilter barrier, when irrigated with discharged effluents. In southern Israel, *Salicornia persica* was used as a biofilter for seawater-culture effluents, effectively removing N, P, and suspended solids from this activity with proven emissions [35,36].

3.4. Environmental Regulations

Because *Salicornia* is associated with mangroves in their natural environment, for the use of coastal soils, the main regulation is linked to its protection. In this sense, Baja California Sur is one of 17 Mexican states that protects mangrove zones with the official Mexican norm NOM 059 SEMARNAT-2010, which includes four mangrove endangered species, *Rhizophora mangle* (endemic), *Avicennia germinans*, *Laguncularia racemosa*, and *Conocarpus erectus* [37].

3.5. Scenarios Towards Sustainability of Seawater Irrigation

The idea of domesticating halophyte plants dates back to 1972, in the case of Mexico, when experiments in the Texcoco Lagoon project aimed at a uniform vegetation cover on the lake's silted lands and, in this way, diminishing the water-funnels that affected Mexico City [38]. In previous trials carried out in Puerto Peñasco and Bahía Kino, Sonora, no negative effect on soil characteristics or an elevation of the water table has been observed, even though some of the fields were in continuous operation from 1984 to 1988 [11,39]. However, this was expected, since most of the coastal soils have predominantly a sandy texture, with a natural drainage to the ocean [40]. Anyway, agro-aquacultural producers will have to face the risk of salinization after scaling a cropping system on other texture soils, including the clayey fraction is evident, due to the intensity and frequency of irrigation that will have to be programmed, exacerbating the high evaporative rate and the high water demand of this species [41]. About the implications related to the change of land use, the identification of this geographical modification must be done through photointerpretation with field verification, whose results must be processed in a geographic information system, accordingly, to consider *S. bigelovii* as an emergent or optional resource, a careful inventory of the vegetation and land use must be carried out in order to know the composition and distribution of the areas susceptible to exploitation [13,39,42].

In any case, environmental impacts on natural resources must be anticipated; possible modifications or alterations in natural resources and their environment as a result of saline irrigation are presented in Table 5.

Table 5. Possible environmental impacts expected from the use of resources for the establishment of a halophyte plot to irrigate with seawater on a coastal zone.

Issue	Expected Environmental Impact	Bio-Economical Significance	
1. Freshwater demand	Null; the use of seawater in agriculture will mitigate the intense demand for freshwater.	Highly positive	😬
2. Biodiversity	It increases. Birdlife, entomofauna and soil microorganisms are increased by oasis effect.	Positive	😬
3. Land-use change	Minimum if it is coupled to aquaculture, but as monoculture may cause soil damages.	Positive when properly planned	😬
4. Soil/substrate quality in irrigated plot	It deteriorates gradually but stabilizes with proper management.	Positive if managed	🤔
5. Surrounding soil quality	It can be salinized and degraded in physical and chemical properties in a few years.	Negative; it needs to be monitored	🙁
6. Harvest—marketing	The markets are small and specialized; it is a food that has yet to be promoted.	At this time, it is negative; new markets are needed	🤔
7. Harvest—economic profitability	Because it has been subsidized for research, its real profitability is unknown.	At this time it is negative; detailed analysis is needed	🤔

4. Conclusions

The life cycle of *Salicornia* was estimated at nine months, which is inappropriate for common agricultural practices since it would virtually cover an entire annual cycle, which would correspond to two conventional crops, agreeing with other studies that this issue is costly and inoperative for the conventional farmer [43,44]. The estimated irrigation needs reached a depth of 240 cm, significantly exceeding those of conventional crops, which would be unacceptable for conventional agriculture, because of the energy and management requirements.

Anyway, for seawater irrigation purposes, the exploitation of mudflats and salt marshes can relieve the stress of inadequate land resources, in this sense, aquaculture and agriculture are the primary modes of utilization of mudflats [45].

From the detailed analysis of the halophytic vegetation and its environmental environment, and considering the availability of *Salicornia* genotypes, viable areas for its management and sustainable production can be identified according to its life cycle [46,47]. In relation to the water requirements fulfilled with seawater, the total irrigation depth estimated in 240 cm represents an obvious risk to salinizing the soil sustaining the agroecosystem, in addition to exacerbating the problem related to marine intrusion in coastal areas [47].

Salicornia or sea asparagus, may represent a solution for the use of saline soils, although the salt balance should be monitored. Irrigated agriculture is dependent on adequate water supply of usable quality. Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available. In this sense, groundwater has been considered the most important freshwater resource for drinking and irrigation in coastal regions with an arid or semiarid climate [48]. One of the main benefits to develop and adopt new seawater-irrigated crops is the optimization of land and water already targeted for aquaculture. In this sense, *Salicornia* may be considered as a potential new crop if it is managed sustainably on land not suitable for conventional agriculture and if it does not compete with commercial agricultural crops for available fresh water, but must be adequately coupled with a feasible seawater source.

Other environmental advantage relates to restoration; in this context, *Salicornia* has been studied under different factors as fresh vegetable and valuable oilseed, additionally, the setting up of a *Salicornia* plantation on coastal land has a real potential to sustainably restore affected or threatened mangroves forests [49]. There have been reports of successful projects of mangroves afforestation, and other failed attempts [50]. A former research studied critical factors as to understand the hydrologic patterns of the site's tide (depth, duration, and frequency of tidal flooding) for establishing and growing mangrove species to successfully restore this ecosystem [51].

In summary, in this work we corroborate the duration of the period of life of *Salicornia*, which in agricultural terms can be very long, which can increase handling costs. Even when the demand for water is high, in the case that it can be satisfied with the same energy invested for the management of aquaculture ponds, this may represent an advantage, in the sense that agricultural water is not used. The real possibility of providing a dual-purpose use of the water resource destined to aquaculture is perceived.

Finally, it is important to remark that the notion of irrigation sustainability will vary among regions and over time with differences in public preferences [52].

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