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Opportunities for the development of seaweed farming as a supplementary income for small-scale fishermen in Nador lagoon: Experimental cultivations of *Gracilaria gracilis* (Stackhouse)

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ABSTRACT

The development of seaweed farming in Nador lagoon (NE Morocco, Mediterranean Sea) offers the best hope for raising incomes in fishing communities. The feasibility of growing red seaweed, Gracilaria gracilis (Gigartinales, Rhodophyta) in off-bottom and floating longline systems was investigated in Bouareg location. Several constraints such as epiphytism and wood borers arose in off-bottom cultures. The weight gains of G. gracilis in off-bottom cultures tested in winter, were low. The lowest daily growth rate (DGR) was recorded in sheet-lines (1.91 % day-1, $p < 0.01$) while the highest's DGR were observed in net-lines and ropes-lines (2.72 and 2.77 % day-1 respectively, $p < 0.01$). Plants of G. gracilis grew well in the floating longline culture tested at spring. The weight growth rates ranged between 2.54 and 4.26 % day-1. The highest growth rate in Nador lagoon was observed in treatment stocked with 0.6 kg m-2. The high stocking density (0.8 kg m-2) led to low growth most probably due to stress on the seaweed when competing for space and resources. Over a 60-day cycle, the harvest of G. gracilis cultivated on floating longline system in Nador lagoon was estimated at about 101 t FWT ha-1 year-1. With 8:1 as wet to dry ratio, the production yield per cropping was estimated at 3,156 kg (DW) per ha. However, the total sales per year was estimated at about $ 6,564 per ha. The Gracilaria farming may provide supplementary income to artisanal farmers in Nador lagoon.

Keywords: Gracilaria gracilis, culture, Nador lagoon, income, fishermen

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1. Introduction

Income and employment generated by aquaculture can benefit low-income communities (Dey et al., 2010; Paraguas et al., 2010; Haque et al., 2010; Jahan et al., 2010; Irz et al., 2007). The seaweed farming is often undertaken in locations where coastal communities are in front of few economic alternatives (Valderrama, 2012). Small-scale fishermen and their communities are among the poorest sectors of most economies, despite their social and cultural importance and their contribution to total fish production (Allison & Ellis, 2001; Béné et al., 2007). The seaweed farming is often suggested as a way to alleviate poverty and to reduce fisheries exploitation (Hill et al., 2011). Seaweed farming is an extensive practice, where inputs and labour are relatively low, compared to the highly controlled intensive culture (Baluyut & Balnyme,1995). The intensive production systems do not necessarily threaten efforts to reduce poverty while large-scale seaweed culture is attractive due to low cost technologies that have been in operation for decades, and the multiple uses of the product (Turan & Neori, 2010).

Development of alternative livelihoods has become a notorious policy to improve the socio-economic status of small-scale fishermen and to mitigate fishing pressure on overexploited fisheries. Seaweed farming is often utilized as an additional source of income (Sievanen et al., 2005). Valderrama (2012) reported that the Socio-economic impacts of seaweed farming have been positive. He attributed this mainly to small-scale, family operations resulting in the generation of substantial employment as compared to other forms of aquaculture.

Farmed seaweed production is expanding rapidly in shallow marine habitats as demand for seaweed products has outstripped supply from wild resources (Hehre and Meeuwig, 2016). Worldwide, seaweed production increases 5.7% every year and more than 18 million tons of seaweed were produced from global capture and aquaculture in 2011 (FAO, 2014). In Morocco, the seaweed industry based on the extraction of agar from wild Gelidium sesquipedale is well-established. To supplement the natural resources of Gelidium for agar production, suitable natural sites have been recently identified for Gracilaria farming by the National Agency for Aquaculture Development (ANDA). The genus Gracilaria is a most attractive candidate from seaweed species because of its ability to achieve high yields and its commercially valuable extracts (Santelices et al., 1993; Capo et al., 1999; Buschmann et al., 2001; Tseng, 2001). The rising demand for seaweed products and the need for fishermen to develop alternative or supplementary livelihoods are driving seaweed farms to emerge in some locations: Sidi Rahal (NW, Atlantic Ocean), Nador lagoon (NE, Mediterranean Sea), and Dakhla bay (SW, Atlantic Ocean). These locations have been identified, among others, as the most suitable sites for the development of seaweed farming in which aquaculture has secured use and priority over other activities. The coastal spatial planning for marine site selection was initiated since 2000, in Morocco, to allow for aquaculture to integrate and enhance its development at national level (Sanchez-Jerez, 2016).

The Nador lagoon constitutes a valuable regional resource for tourism, fisheries, and salt extraction industries, it is classified as site of biological and ecological interest (SIBE). It is, however, subject to pollution by sewage, industrial waste, and agricultural discharges (Ben Chekroun et al, 2013; Aknaf et al, 2015; Matoir et al, 2015). The Nador lagoon is considered as a eutrophic semi-enclosed basin. The disappearance of Posidonia oceanica, a seagrass, from the lagoon concerned many fishers because of its importance in primary production (Chuenpagdee, 2011). The pressures generated by these activities, and the uncontrolled discharge of nutrients, organic matter, and heavy metals led to detrimental changes that severely affected the functioning of the lagoon ecosystem (Najih et al. 2017). The restoration of Nador lagoon has become a priority and a prerequisite for the implementation of several projects undertaken in the region. The opening of the new artificial inlet contributed significantly to the reduction of eutrophication by enhancing the water circulation into the lagoon (Aknaf et al. 2015). A series of studies have demonstrated the potential beneficial effects of seaweeds on wastewater treatment and bioremediation (Schramm, 1999; Chung et al., 2002;

McVey et al., 2002). The recovery of Nador lagoon may also be possible with an effective implementation of coastal management and alternative livelihood programs for coastal communities. In the context of declining fish returns and critical income, there is an urgent need to support the fishermen community. Since 2013, fishermen began exploring, the possibility of seaweed (G. gracilis) farming in Nador lagoon, under the supervision of the National Agency for Aquaculture Development (ANDA). Within the context of “Integrated coastal zone management (ICZM)” process, and the “Sustainable Med” program implemented by the Ministry of Environment, the “Marchica” fishermen cooperative, created on October 5th, 2013, has received a grant for Gracilaria farming from the Global Environment Fund (GEF) and the world Bank. The designated project plans to reach an annual production of 1,300 tons (dry weight) of G. gracilis at Bouareg location in Nador lagoon. The feasibility of growing red seaweed, Gracilaria gracilis (Gigartinales, Rhodophyta) in off-bottom and floating longline systems was then investigated in this location. The results of the experimental cultivations were discussed in this paper. In order to find a more efficient technique, different support lines (sheet, net and rope lines) using off-bottom cultures of *G. gracilis* were compared by its daily growth rate. Different stocking densities of *G. gracilis* (0.4, 0.6 and 0.8 kg m-2) in floating longline system were also tested. The return analysis was done for 1 ha Gracilaria farming using the floating longline method. This paper presents a case study of the transition of some fishermen at Nador lagoon from an exclusive dependence upon capture fishing to an extensive involvement in seaweed (*Gracilaria gracilis*) farming.

2. Materials and Methods

Field cultivation area

The experimental cultivations of *Gracilaria gracilis* were conducted on the south-western portion of Nador lagoon, at Bouareg location (35°07’41.8” N, 2°52’13.9” W) (Fig. 1). The farming area has moderate water movement, and sandy mud sediments (Najih et al., 2017). The organic matter in sediment ranged between 0.9 and 1.6 %. The Nador lagoon is situated in the Mediterranean coast of Morocco between ‘Trois-fourches’ cape and ‘Ras-El-Ma’ cape.

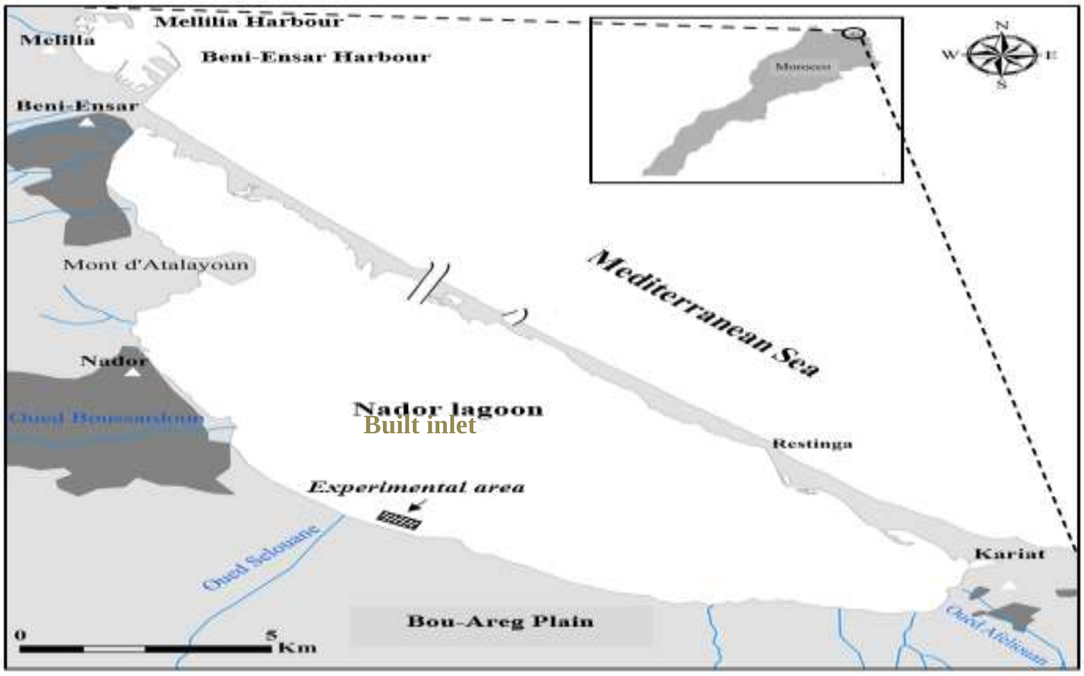

Figure 1. Map showing the experimental location in Nador Lagoon in North-eastern Morocco.

The lagoon basin has a volume of about 5.4 10^8 m^3 and a surface of about 115 km^2. The lagoon has an oval shape, quite regular. The lengths of major and minor axis of the lagoon are ~ 23 km and ~ 7 km respectively. The width of the new built inlet is about 300 m. The average depth of the lagoon is 4.8 m, with a maximum depth of 8 m. The prevalent wind come from W-NW and E, which is about the direction of the major axis of the lagoon. This lagoon is classified as a Site of Biological and Ecological Interest (SBEI) since 1996 and designated Ramsar site since 2005. Uncontrolled discharges of domestic wastes, agricultural pollutants, and industrial effluents have caused an imbalance in this ecosystem that tends towards eutrophication. The Nador lagoon is considered as a eutrophic semi-enclosed basin. A management plan was developed to reduce pollution in the lagoon. This will involve the construction of a drainage system and diversion channels, shoreline cleaning, and a program with farmers to reduce agricultural pollutants including pesticides (Chuenpagdee, 2011).

Small-scale fishermen community

Small-scale fishing is the main socio-economic activity in Nador lagoon. Populated by approximately 800 fishermen, this community has traditionally depended almost exclusively (92 %) upon fishing for its livelihood (Najih et al., 2015). The artisanal fisheries sites that surround the Nador lagoon is 16, including nearly 390 boats. Fishermen explored the waters of Nador lagoon in their motorized boats and used various forms of gear such as trammel nets, the "pallanza" (a form of set net), beach seine and small purse seines. Most boats have small outboard engines between 8 and 20 horse power. It is a mixed fishery, with eels, anchovies, seabream, cuttlefish and octopus. Fishing in this lagoon is an entirely male activity with women playing no role in the supply chain. The fishermen population is relatively poor and less likely to be literate than the regional average. Fishing in Nador lagoon is almost an exclusive profession (Chuenpagdee, 2011). Only 8% of fishermen combine fishing with subsistence agriculture or small commercial activities. Since the early 1980's, fishermen have experienced declining catches and incomes.

Experimental cultivations

From 23 December, 2016 to 23 January, 2017, *Gracilaria gracilis* was cultivated by three off-bottom methods in three rectangular modules (5 m × 25 m). The wooden anchors (Eucalyptus) were staked firmly into the substratum by using heavy ball hammer about 5 meters apart. The stakes were arranged in rows at 1 m intervals. *G. gracilis* was cultivated in off-bottom systems using three different support lines: sheet, net and rope (Fig. 2). The sheet support (1 m wide and 5 m long) was developed by ATSEA Technologies Co. (Belgium) for vegetative growing red seaweeds. The different lines were then stretched tightly between wooden poles. The support lines were hung at about 0.5 m above the bottom. The *Gracilaria* seedlings of 100 g were tied to the lines at 25 cm intervals using soft plastic materials.

A

B

C

Figure 2. Fixed off-bottom cultures of *Gracilaria gracilis* in Nador lagoon using sheet (A), net (B) and rope (C) lines.

From 17 April to 31 May, 2017, *G. gracilis* was cultivated in floating longline systems under three stocking densities (0.4, 0.6 and 0.8 kg m^{-2}), in three rectangular modules (5 m × 25 m) (Fig. 3). The longlines (soft plastic netting of 5 m length) were attached to the anchored steel piles and suspended about 80-100 cm from the bottom. Each longline was seeded with 200 seedlings of 100 g wet weight, placed at equal intervals of 25 cm. Buoys were used as floats to maintain the seaweed line level. The three stocking densities of *G. gracilis* were tested by using 25, 38 and 50 longlines respectively.

Figure 3. Floating longline culture of *Gracilaria gracilis* in Marchica lagoon.

Growth measurement

The growth of *G. gracilis* was measured after 15 and 30 days of cultivation in off-bottom cultures, and after 45 days in longline cultures. Thereafter a total sample of 50 plants was taken randomly from each treatment. The plants were left in the air for two minute to remove excess water; after that, the biomass was determined. Each plant was individually weighed with a scale having a precision of 0.01 g. The daily growth rate (DGR) was measured using the formula DGR=100× (ln (W_f /W_i)/t), where W_f = final wet weight; W_i = initial wet weight, and t=cultivation days (Hurtado et al. 2001).

Abiotic parameters

The environmental parameters (temperature, oxygen concentration, pH, and salinity) were measured weekly over the experimental periods and their min-max ranges are shown in Table 1.

Table 1: Min-Max ranges of temperature, salinity, dissolved O_2 and pH during the both experimental periods.

Experimental periods	Temperature (°C)	Salinity (‰)	Dissolved oxygen (mg l^{-1})	pH
23 December 2016 - 23 January 2017 (Fixed off-bottom cultures)	15.3 - 16.8	37.2 - 38.2	8.3 - 9.2	8.0 - 8.4
17 April 2017 - 31 May 2017 (Floating longline culture)	20.0 - 23.1	36.6 - 38.1	5.9 - 7.8	8.0 - 8.1

Data analysis

To determine the influence of support line treatment on length and weight growth rates, One-way ANOVAs followed by Tukey test as post-hoc test were performed for both periods (23 December 2016 -07 January 2017 and 23 December 2016 - 23 January 2017). Similarly, the effect of stocking density on final biomass and growth rates was analyzed by ANOVA followed by Tukey test during the experimental period (17 Avril - 31 May 2017). The assumptions of normality and homogeneity of variances were previously tested with Shapiro-Wilk and Levene tests (p value > 0.05) respectively. A value of $p < 0.05$ was considered to indicate statistical significance. Statistical analyses were performed using the software IBM SPSS Statistics.

Results

Fixed off-bottom cultures

The type of lines has significant effect on growth in length and weight of *Gracilaria gracilis* in fixed off-bottom cultures (Table 2). The length growth rates were ranged between 1.91 and 2.77 % day^{-1} over 30 days (23 December 2016 - 23 January 2017). The lowest daily growth rate (DGR) was recorded in sheet-lines (1.91 % day^{-1}, $p < 0.01$) while the highest's DGR were observed in net-lines and ropes-lines (2.72 and 2.77 % day^{-1} respectively, $p < 0.01$).

Table 2: One-way ANOVA results testing the influence of line type (sheet, net and rope lines) on the length growth rate (% day^{-1}) and weight growth rate (% day^{-1}) of *Gracilaria gracilis* in off-bottom cultures.

Source of variation	d.f.	S.S.	M.S.	F	P value*
Length					
Line type	2	91,900	45,950	26.35	1.6e-10***
Residuals	147	256,250	1,743.19		
Weight					
Line type	2	5,633.3	2,816.6	126.6	1.0e-32***
Residuals	147	3,270.0	22.24		

$p < 0.05$* $p < 0.01$** $p < 0.001$***

Thalli had low weight gain in all treatments over the experimental period (23 December 2016 - 23 January 2017) (Table 3). The lowest growth rate was recorded in sheet-lines (0.43 % day^{-1}, $p < 0.001$) while the highest DGR was observed in net-lines (0.97 % day^{-1}, $p < 0.01$). All three treatments elicited the same pattern of growth response of thalli (Table 3); growth has been faster up to day 15, but slower between day 16 and day 30. Significant differences in growth rate were found among treatments in both periods (Table 3).

Table 3. Growth rates (% day^{-1}) of length and weight of *Gracilaria gracilis* in off-bottom cultures using sheet, net and rope lines. Different letters significant differences between groups ($p < 0.05$).

	Fixed off-bottom cultures		
	Sheet-lines	Net-lines	Rope-lines
23 December 2016 - 08 January 2017			
Mean Length	**3.84^{b}**	**4.33^{a}**	**4.30^{a}**
SD	0.65	1.14	0.92
Mean Weight	**0.51^{c}**	**1.10^{a}**	**0.75^{b}**
SD	0.24	0.21	0.27
23 December 2016 - 23 January 2017			
Mean Length	**1.91^{b}**	**2.72^{a}**	**2.77^{a}**
SD	0.38	0.42	0.40
Mean Weight	**0.43^{c}**	**0.97^{a}**	**0.71^{b}**
SD	0.15	0.14	0.11

Shipworms damage

The shipworms caused serious damage to wooden poles used in off-bottom cultures, stacked since October 2016 into the substratum (Figure 4). About 30% of poles were destroyed by these molluscans which are notorious for boring into wood that is immersed in sea water. The destructive ability of shipworms is illustrated in Figure 4. They drilled passages or tunnels which they rasped their way through (Figure 4).

Figure 4. Damage caused by shipworms at wooden poles used in fixed off-bottom cultures of *Gracilaria gracilis* (A) and tunnels occupied by calcareous tubes of shipworms (B).

Infestation by parasitic epiphytes

Algal epiphytism was the major problem during this study, especially in off-bottom cultures tested in winter when infestations by green algae occurred. The most common epiphytes were *Chaetomorpha aerea* and *Ulva lactuca*. The green algae *Ulva intestinalis* appeared in minor quantities. Heavy loads of epiphytes were observed, particularly on sheet lines. During spring, plants of *G. gracilis* cultivated in a floating longline were free of epiphytes and healthy.

Floating longline cultures

A two-way ANOVA showed that stocking density significantly affected biomass ($p < 0.001$), and growth rate ($p < 0.001$), but there was no significant difference ($p > 0.05$) between Treatments 1 and 3 (Tables 3 and 4). Maximal growth rate was 4.26 % day^{-1} for the 0.6 kg m^{-2} stocking density; it declined, with stocking density, to only 2.77% day^{-1} at the 0.8 kg m^{-2} density. The lowest growth rates varied not significantly between 2.54 and 2.77 % day^{-1} in T1 and T3 respectively. Changes in biomass production under three experimental treatments are shown in Table 4.

Table 4. One-way ANOVA results testing the influence of stocking density (0.4, 0.6 and 0.8 kg.m^{-2}) on the final biomass (g m^{-1}) and weight growth rate (% day^{-1}) of *Gracilaria gracilis* in floating longline cultures.

Source of variation	d.f.	S.S.	M.S.	F	P value*
Final biomass					
Stocking density	2	4,549,066.3	2,274,533.1	44.78	6.4e-16***
Residuals	147	7,465,468.5	5,078.5		
Weight growth rate					
Stocking density	2	89.22	44.61	503.0	1.8e-66***
Residuals	147	13.03	0.08		

$p < 0.05$* $p < 0.01$** $p < 0.001$***

Seaweed biomass increased with time. Indeed, biomass increases in the 0.4, 0.6 and 0.8 kg m^{-2} stocking densities represented increases of 214%, 580% and 76% of initial weights, respectively (Table 5). At the end of the experiment, the highest production reached 3,402.2 g m^{-1} (initial biomass 500.0 g m^{-1}) was observed in Treatment 2 with 0.6 kg m^{-2} stocking density. Thalli of *Gracilaria gracilis* has low weight gain in treatments T1 and T3, reaching 1,570.0 and 1,738.0 g m^{-1}

respectively with no significant differences among them ($p < 0.05$).

Table 5. Growth of *Gracilaria gracilis* cultivated under different stocking densities (T_1: 0.4 kg.m^{-2}, T_2: 0.6 kg.m^{-2} and T_3: 0.8 kg.m^{-2}) in floating longline cultures. Different letters significant differences between groups ($p < 0.05$).

Treatments	Initial biomass (g m^1)	Final biomass (g m^1)	Period of growth (days)	Increase times	Growth rate (% day^{-1})
T_1	500.0 ± 0.0	1,570.0^b ± 378.5	45	3.14	2.54^b ± 0.54
T_2	500.0 ± 0.0	3,402.2^a ± 394.2	45	6.80	4.26^a ± 0.27
T_3	500.0 ± 0.0	1,738.0^b ± 203.1	45	3.47	2.77^b ± 0.26

Discussion

Fixed off-bottom cultures

The weight gains of *Gracilaria gracilis* in off-bottom cultures tested in winter, were low. Seaweed growth rate and yield depend on species, the site of cultivation, the season and the cultivation methodology (Titlyanov and Titlyanova, 2010). Water temperature is one of the important factors determining the production of *Gracilaria sp.* Plants of *G. gracilis* did not grew well, because the experimental period had unfavourable temperature range (15.3-16.8°C). Most species in *Gracilaria* grow well when the temperature is 20 °C or higher (Mclachlan & Bird, 1986; Raikar et al., 2001^a) while the optimum growth rate of *G. gracilis* was reached at 18°C at Tosa Bay, southern Japan (Rebello et al, 1996).

The off-bottom line method tested in this study is commonly used in *Gracilaria* farming (Castaños & Buendia, 1998; Jørgensen, 2009, Kim et al, 2017; Rejeki et al., 2018). This is due to lower cost of materials, labour and maintenance compared to the net, raft and floating longline methods (Castaños & Buendia, 1998). However, the shipworms caused serious damage to wooden poles used in the experimental cultivations. These organisms are notorious for boring into wood that is immersed in sea water, including docks and ships (Quayle, 1992; Nayak et al., 2012). Ever since marine wood borers became a problem to wooden marine installations, there has been a worldwide search for timber naturally impervious to both teredinid and limnorid wood borers under all conditions of temperature and salinity (Quayle, 1992). There is wide variation in susceptibility to attack based partly on wood hardness, content of chemicals such as resin, silicate, and alkaloids (Chudnoff, 1980; Quayle, 1992). Treated woods are nearly impervious to shipworms, making them good for use in seawater (Edmondson, 1953). However, woods must be treated with natural products to prevent environmental and health risks. The naturally durable, untreated wood such as redwood cannot be used in off-bottom cultures at Nador lagoon because of its high cost. Given damages caused by shipworms to wooden poles, the experimental cultivations of *Gracilaria* were shifted to the floating longline method by using steel piles for anchoring.

The another serious problem for the off-bottom cultures tested in winter at Nador lagoon was the colonization by the parasitic algae (*Chaetomorpha aerea* and *Ulva lactuca*). Epiphytes can reduce productivity of the farm directly by shading the seaweed and consequently reducing its growth or indirectly by sinking culture lines (Asaeda et al., 2004, Lyimo et al., 2006; Vairappan et al., 2008; Marroig & Reis 2011, Msuya & Salum, 2011; Drummond, 2017). Moreover, epiphytes can turn on seedlings causing damage to thalli and reducing production (Hurtado et al. 2008). Buschmann et al. (1994a) also reported that winter favoured epiphytes, which decreased with the approach of spring and renewed growth of *Gracilaria*. Emergence of an epiphytic outbreak is a complex problem, and the extent of the outbreak often depends on the quality of the cultivated strain, abiotic parameters of the culture site, and seasonal weather fluctuations (Borlongan et al., 2011). There are several methods available for minimizing fouling. Indeed, depth can be adjusted to reduce settlement or survival of fouling organisms (Yarish et al., 2012). Increasing stocking density will allow the thalli to outcompete the parasitic algae (Carney & Lane, 2014). Timing the seeding of the lines and harvest of the crops can be efficient for avoiding fouling settlement (Yarish et al., 2012).

Floating longline cultures

Plants of *G. gracilis* grew well in floating longline culture tested in spring because the temperatures were ranged between 20.2 and 23.1°C. *Gracilaria sp* has an optimal range of 20-28°C (Yokoya et al. 1999, Raikar et al. 2001b, Abreu et al. 2011, Kim et al. 2016). The range of 2.54 - 4.26 % day^{-1} in weight growth rates falls within the range reported for *Gracilaria sp* (Largo *et al*., 1989). The growth rates achieved in Nador lagoon were almost similar to those obtained in experimental cultivation in Namibia where the daily growth rate ranged between 3.2 to 4.5% (Dawes, 1995). Salinity was ranged between 36.6 and 38.1 ‰ during the experimental period (17 April – 31 May 2017). *Gracilaria sp* are euryhaline species, which can tolerate a wide range of salinities, from about 10-40 ‰ (Yokoya et al., 1999; Weinberger et al., 2008; Kim et al., 2016; Gorman et al., 2017).

The results indicated that the initial stocking density is an important factor in determining the production obtained. The highest growth rate in Nador lagoon was observed in treatment stocked with 0.6 kg m^{-2}. The high stocking density (0.8 kg m^{-2}) leaded to low growth most probably due to stress on the seaweed when competing for space and resources. Generally, the lower stocking densities would result in higher growth rates of the seaweeds (Yang et al., 2006; Msuya, 2013). However, the lowest initial density (0.4 kg m^{-2}) tested in this study leaded on the contrary to low growth. The macroscopic diagnosis of the thalli revealed the presence of isopods (*Idotea baltica*). The major problems of economically effective seaweed farming are: reduction of fouling alga and epiphyte growth, control of grazing animals, and a low level of planting stock (Titlyanov & Titlyanova, 2010). The role of the floating system is to maintain the culture lines at a level sufficiently high to prevent colonization by fouling and ensure the stability of the longlines in order to allow routine activities to be carried out smoothly. However, it is well known that grazing by small crustaceans, such as amphipods and isopods, can consume significant amounts of seaweed under field conditions (Bell 1991; Duffy &Hay 1991; Valiela et al., 1997). The first-order effect of grazing is to decrease biomass of a preferred seaweed species (Hauxwell et al., 1998). Nevertheless, we did not find any evidence to explain why isopods did not graze the thalli of *G. gracilis* in the other treatments initially stocked with 0.6 and 0.8 kg m^{-2}.

Seaweed farming a potent solution against eutrophication

The *G. gracilis* grew well in the eutrophic waters of Nador lagoon by using the floating longline method. The seaweeds are able to absorb large quantities of N and P, and produce large amounts of O_2, and, consequently, reduce eutrophication (Fei, 2004; Seghetta, 2016; Xiao et al., 2017). Xiao et al. (2017) estimated that one hectare of seaweed aquaculture removes the equivalent nutrient inputs entering 17.8 ha for nitrogen and 126.7 ha for phosphorus of Chinese coastal waters, respectively. They also reported that the magnitude of nutrient removal by seaweed aquaculture is dependent on the yield and the nutrient concentration in the seaweed tissues, which depends, in turn, on the species composition (Xiao et al., 2017). Given the high capacity of seaweeds in bioextraction of nutrients, it is essential that other fishermen in Nador lagoon turn toward seaweed farming. The role of seaweeds in mitigating eutrophication may be significant with a future growth of seaweed aquaculture in Nador lagoon.

Income diversification by seaweed production

The results show that *G. gracilis* can be grown in Nador lagoon to produce a reasonable harvest weight over a 45-day cycle in floating longline cultures. When *Gracilaria* biomass is high enough, the seaweed to attached the rope can be harvested easily. The outer portion of fronds can be cut and leaving fronds to provide continuous cultivation. About 5,320 kg of seedlings will be needed during each cycle by using the cultivation parameters detailed in Table 6. Over a 60-day cycle, the harvest of *G. gracilis* cultivated on floating longline system in Nador lagoon was estimated at about 101 t FWT ha^{-1} year^{-1}. *Gracilaria* in the tropics and subtropics grows on ropes in Sri Lanka for about two months, constitutes only 35 t (FW: fresh weight) ha$^{–1}$ year$^{–1}$ (in Sri Lanka) (Santelices & Fonck, 1979). In brackish water estuaries in southern Chile, the harvest of *Gracilaria* cultivated on ropes constitutes, however, about 100 t (FW) ha$^{–1}$ per season (Westermeier, Gomez & Rivera, 1993). In Morocco, the price of seaweeds at farm level is determined by the exclusive buying company SETEXAM, which in turn depends on prices determined in international markets, their costs and profit margins. In 2017, the price per tonne was $ 520 (Table 6). In terms of local currency, this was equivalent to 5 DH per kg. However, the farmers complained that local market prices were depressed compared with the volume of work required in seaweed production.

Table 6. Cultivation parameters and return analysis for a 1 ha seaweed (*Gracilaria gracilis*) farming using the floating longline method

Cultivation parameters		Return per cropping	
Length of line (m)	100	Initial weight of seedlings (fresh weight in kg)	5,320
Number of monoline	133	Average growth rate (% day^{-1})	3
Number of plants per line	400	Final weight (fresh weight in kg)	32,184
Initial weight per plant (g)	100	Biological loss in kg (5%)	1,609
Distance between tie per plant (m)	0.25	Seedling for next cropping (fresh weight in kg)	5,320
Distance between lines (m)	0.75	Net fresh weight for drying (in kg)	25,255
Culture period (days)	60	Wet to dry ratio	8 : 1
Number of cropping per year	4	Production yield (dried in kg)	3,156
		Price per kilo ($)	0.52
		Total sale ($)	1,641
		Return per year	
		Total sales ($)	6,564

The operating and maintenance expenses were supported by the external donors. Farming materials such as plastic netting, buoys and steel piles for anchoring were provided free of charge to the farmers. The seaweed farming project developed in Nador lagoon is recognized as an ‘interventionist’ system, in which external donors (Global Environment Fund and the World bank) support the promotion of small-scale subsistence aquaculture systems to alleviate poverty. Reducing the vulnerability of fishers to income volatility is their first priority. It is also well-known that fisher’s cooperatives had also multiple benefits, including marketing, access to microloans, and providing a channel for communicating with the authorities (Chuenpagdee, 2011). After harvesting, seaweed was dried in the sun and packed in sacks before being sold. With 8:1 as wet to dry ratio, the production yield per cropping was estimated at 3,156 kg (DW) per ha (Table 6). However, the total sales per year was estimated at about $ 6,564 per ha.

Actually, the National Aquaculture Development Agency (ANDA) and the National Institute of Fisheries Research (INRH) contribute in the development of seaweed farming in Morocco by assisting small-scale fishermen in carrying out their projects. ANDA acts also to simplify administrative procedures to create and exploit seaweed farms. In the framework of its strategy of aquaculture development in Morocco, several calls for expression of interest (CEIs) were launched by ANDA for the development of seaweed farming according to the coastal spatial planning.

Conclusion and recommendations

In conclusion, this study demonstrated that the cultivation of *G. gracilis* in floating longline system is a technically viable method, which obtains reasonably good growth and productivity. Suspended cultivation of *Gracilaria* has potential in bioremediation, where the seaweed can be used to absorb some of the excess nutrients discharged from other human activities into the eutrophic waters of Nador lagoon. Moreover, *Gracilaria* cultivation is a promising approach for sustainable resource cycling in a future regenerative economy. Seaweed farming may provide supplementary income to artisanal farmers. The small-scale fishers in Nador lagoon should therefore be encouraged to create new cooperatives, and the cooperative which already exist should be also strengthened. The seaweed farming was met by such a high degree of enthusiasm by the fishers in Nador lagoon. The likely role of cooperatives in promoting education and literacy, access to scientific information and research institutions on fisheries, and helping enforce regulations will also be emphasized.

Conflict of interests

The authors declare no conflict of interests.

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References

Abreu, M. H., Pereira, R., Buschmann, A. H., Sousa-Pinto, I., Yarish, C. (2011) Nitrogen uptake responses of *Gracilaria vermiculophylla* (Ohmi) Papenfuss under combined and single addition of nitrate and ammonium. Journal of Experimental Marine Biology and Ecology 40, 190-199

Aknaf, A., Akodad, M., Moumen, A., Chekroun, K. B., Elhamouti, C., Bailal, A., Baghour M. (2015) Impact of the new pass on the eutrophication of the lagoon Marchica: Study of the two sites Bou Areg and Mohandis. Journal of Material and Environmental Science 6 (10): 2939-2943.

Allison, E. H., Ellis, F. (2001) The livelihoods approach and management of small-scale fisheries. Marine policy 25(5), 377-388.

Ang P. O. J. (2004) Asian pacific phycology in the 21st centruy: prospects and challenges, Hydrobiologia 512.

Asaeda, T., Sultana, M., Manatunge, J., Fujino, T. (2004). The effect of epiphytic algae on the growth and production of *Potamogeton perfoliatus* L. in two light conditions. Environmental and Experimental Botany 52(3), 225-238.

Baluyut, E. A., & Balnyme, E. (1995). Aquaculture systems and practices: a selected review. Daya Books.

Bell, S. S. (1991) Amphipods as insect equivalents? An alternative view. Ecology 72, 350-354.

Belton, B., Little, D. C. (2011). Immanent and Interventionist Inland Asian Aquaculture Development and its outcomes. Development Policy Review 29(4), 459-484.

Ben Chekroun, K., Moumen, A., Rezzoum, N. (2013) Role of macroalgae in biomonitoring of pollution in «Marchica», the Nador lagoon. *Phyton (Buenos Aires)*, 82 (1), 31-34.

Béné, C., Macfadyen, G., Allison, E. H. (2007). Increasing the contribution of small-scale fisheries to poverty alleviation and food security (No. 481). Food & Agriculture Organisation.

Béné, C., Arthur, R., Norbury, H., Allison, E. H., Beveridge, M., Bush, S., Thilsted, S. H. (2016).

Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. World Development 79, 177-196.

Borlongan, I. A. G., Tibudos K. R., Yunque D. A. T., Hurtado A. Q., Critchley, A. T. (2011) Impact of AMPEP on the growth and occurrence of epiphytic *Neosiphonia* infestation on two varieties of commercially cultivated *Kappaphycus alvarezii* grown at different depths in the Philippines. Journal of Applied Phycology 23, 615–621.

Brummett R, Gockowski J., Pouomogne V., Muir J. (2011). Targeting agricultural research and extension for food security and poverty alleviation: A case study of fish farming in Central Cameroon Food Policy 36(6), 805-814.

Buschmann, A. H., Mora O. A., Gomez P. Bdttger, M., Buitano S., Retamales, C., Vergara, P. A. , Gutierrez A (1994) *Gracilaria chilenvis* outdoor cultivation in Chile: use of land-based salmon culture effluents. Aquaculture Engineering 13, 283-300.

Buschmann, A. H., Westermeier, R., Retamales, C. A. (1995) Cultivation of *Gracilaria* on the Sea Bottom in Southern Chile: A Review. Journal of Applied Phycology 7, 291–301.

Buschmann, A. H., Correa, J. A., Westermeier, R., Hernandez-Gonzalez, M. C., Norambuena, R. (200). Red algal farming in Chile: a review. Aquaculture 194, 203–220.

Capo, T. R., Jaramillo, J. C., Boyd, A. E., Lapointe, B. E., Serafy, J. E. (1999) Sustained high yields of *Gracilaria* (Rhodophyta) grown in intensive large-scale culture. Journal of Applied Phycology 11, 143–147.

Carney, L. T., Lane, T. W. (2014). Parasites in algae mass culture. Frontiers in microbiology 5, 278.

Castaños, M., & Buendia, R. (1998). Farming techniques for seaweeds. *SEAFDEC Asian Aquaculture*, *20*(1), 14-19.

Chudnoff, M. (1980). Tropical timbers of the world. Forest products Lab Madison WI.

Chuenpagdee, R. (Ed.). (2011). World small-scale fisheries: contemporary visions. Eburon Uitgeverij BV.

Chung, I. K., Kang, Y. H., Yarish, C., Kraemer, G. P., Lee, J. A. (2002) Application of seaweed cultivation to the bioremediation of nutrient-rich effluent. Algae 17, 187–194.

Drummond, H. (2017). Distribution and Biomass of Epiphytic Seaweeds on the Kelp *Ecklonia Maxima* (Osbeck) Papenfuss, and the Potential Effects of Two Kelp-harvesting Methods in the Western Cape (Doctoral dissertation, University of Cape Town).

Duffy, J. E., Hax M. E. (1991) Amphipods are not all created equal: A reply to Bell. Ecology 72, 354-358.

Edmondson, C. H. (1953) Response of marine borers to chemically treated woods and other products. Bishop Museum Press.

FAO (2014) Fisheries and Aquaculture Information and Statistics Service - 16/03/2014.

Fei, X. (2004). Solving the coastal eutrophication problem by large scale seaweed cultivation. In Asian Pacific Phycology in the 21st Century: Prospects and Challenges (pp. 145-151). Springer, Dordrecht.

Gonzalez, M. A., Barrales, H. L., Candia, A., Cid, L. (1993) Special and Temporal Distribution of Dominant Epiphytes on *Gracilaria* from a Natural Subtidal Bed in Central_Southern Chile. Aquaculture 116,135–148.

Gorman, L., Kraemer, G. P., Yarish, C., Boo, S. M., Kim, J. K. (2017) The effects of temperature on the growth and nitrogen content of Gracilaria vermiculophylla and Gracilaria tikvahiae from LIS, USA. Algae 32, 57-66.

Hauxwell, J., McClelland, J., Behr, P. J., Valiela, I. (1998) Relative importance of grazing and nutrient controls of macroalgal biomass in three temperate shallow estuaries. Estuaries 21(2), 347-360.

Hehre, E. J., Meeuwig, J. J. (2016) A global analysis of the relationship between farmed seaweed production and herbivorous fish catch. PloS one 11(2), e0148250.

Hill N., Rowcliffe J. M., Koldewey H. J., Milner-Gulland E. J. (2011) The Interaction between Seaweed Farming as an Alternative Occupation and Fisher Numbers in the Central Philippines. Conservation Biology 26, 324–334.

Hurtado A. Q., Agbayani R. F., Sanares R., Castro-Mallare M. T. R. (2001) The seasonality and economic feasibility of cultivating Kappaphycus alvarezii in Panagatan Cays, Caluya, Antique, Philippines. Aquaculture 199, 295–310.

Israel, A., Einav, R., Seckbach, J. (Eds.). (2010). Seaweeds and their role in Globally

Changing Environments (Vol. 15). Springer Science & Business Media.

Jørgensen, S. E. (Ed.). (2009). Applications in ecological engineering. Academic Press.

Kim, J. K., Yarish, C., Pereira, R. (2016) Tolerances to hypoosmotic and temperature stresses in native and invasive species of Gracilaria (Rhodophyta). Phycologia 55, 257- 264

Kim, J. K., Yarish, C., Hwang, E. K., Park, M., Kim, Y. (2017) Seaweed aquaculture: cultivation technologies, challenges and its ecosystem services. Algae 32(1), 1-13.

Lüning, K., Pang, S.J. (2003) Mass Cultivation of Seaweed: Current Aspects and Approaches. Journal of Applied Phycology 15, 115–119.

Lyimo, T. J., Mvungi, E. F., Lugomela, C., Björk, M. (2006). Seagrass biomass and productivity in Seaweed and Non-Seaweed Farming areas in the East Coast of Zanzibar. Western Indian Ocean Journal of Marine Science, 5(2), 141-152.

Marroig, R., Reis, R. P. (2011) Does biofouling influence *Kappaphycus alvarezii* (Doty) Doty ex Silva farming production in Brazil? Journal of Applied Phycology 23, 925–931.

Matoir, M., Belabed, A., Najih, M., Kada, O., Rezzoume N. (2015) Surrounding influence on the Ecological state of the lagoon of Marchica. Journal of Material and Environmental Science 6 (5), 1260-1265

McLachlan, J., Bird, C. J. (1986). Gracilaria (Gigartinales, Rhodophyta) and productivity. Aquatic Botany, 26 27-49.

Msuya, F. E., Salum, D. (2011). Effect of the presence of seagrass and nutrients on growth rates of farmed *Kappaphycus alvarezii* and *Eucheuma denticulatum* (Rhodophyta). *Western Indian Ocean Journal of Marine Science 10*(2), 129-135.

Msuya, F. E. (2013). Effects of stocking density and additional nutrients on growth of the commercially farmed seaweeds *Eucheuma denticulatum* and *Kappaphycus alvarezii* in Zanzibar Tanzania. Tanzania Journal of Natural and Applied Sciences 4 (1), 605-612

Quayle, D. B. (1992). *Marine wood borers in British Columbia* (Vol. 115). Canadian Government Pub Centre.

Pizarro, A. (1986) Conocimiento Actual y Avances Recientes Sobre el Manejo y Cultivo *Gracilaria* en Chile, *Monogr. Biol.* 4, 63–96.

Raikar, S. V., Iima, M., Fujita, Y. (2001a) Effect of temperature, salinity and light intensity on the growth of Gracilaria spp. *Gracilariales*. Rhodophyta, 98-104.

Raikar, S. V., Ima, M., Fujita, Y. (2001b). Effects of temperature, salinity and light intensity on the growth of Gracilaria spp. (Gracilariales, Rhodophyta) from Japan, Malaysia and India. Indian Journal of Marine Science 30, 98-104.

Rejeki, S., Ariyati, R. W., Widowati, L. L., Bosma, R. H. (2018). The effect of three cultivation methods and two seedling types on growth, agar content and gel strength of Gracilaria verrucosa. The Egyptian Journal of Aquatic Research 44(1), 65-70.

Sanchez-Jerez, P., Karakassis, I., Massa, F., Fezzardi, D., Aguilar-Manjarrez, J., Soto, D., Chapela R., Avila, P., Macias, J. C., Tomassetti, P., Marino G., J. A. Borg J. A., Franičević V., Yucel-Gie, G., Fleming I. A., Biao X., Nhhala H., Hamza H., Forcada A., Dempster, T. (2016). Aquaculture's struggle for space: the need for coastal spatial planning and the potential benefits of Allocated Zones for Aquaculture (AZAs) to avoid conflict and promote sustainability. Aquaculture Environment Interactions 8, 41-54.

Santelices, B., Fonck, E. (1979). Ecologia y Cultivo de *Gracilaria lemaneiformis* en Chile Central, Actas Sobre el Primer Symposium Sobre Algas Marinas Chilenas. Santelices, B., Ed., Subsecretaria de Pesca. Ministerio de Economia Fomento y Reconstruccion. Santiago, Chile. pp. 165–200.

Santelices, B., Westermeier, R., Bobadilla, M., 1993. Effects of stock loading and planting distance on the growth and production of *Gracilaria chilensis* in rope culture. Journal of Applied Phycology 5, 517–524.

Seghetta, M., Tørring, D., Bruhn, A., Thomsen, M. (2016). Bioextraction potential of seaweed in Denmark—An instrument for circular nutrient management. Science of the Total Environment 563, 513-529.

Sievanen, L., Crawford, B., Pollnac, R., Lowe, C. (2005) Weeding through assumptions of livelihood approaches in ICM: Seaweed farming in the Philippines and Indonesia. Ocean & Coastal Management 48, 297–313.

Titlyanov, E. A., Titlyanova, T. V. (2010). Seaweed cultivation: methods and problems. Russian Journal of Marine Biology 36(4), 227-242.

Turan, G., Neori, A. (2010). Intensive Sea weed aquaculture: a potent solution against global warming. In Seaweeds and their Role in Globally Changing Environments (pp. 357-372). Springer, Dordrecht.

Valderrama, D. (2012). Social and economic dimensions of seaweed farming: a global review. IIFET Tanzania Proceedings. https://ir.library.oregonstate.edu/xmlui/handle/1957/33886.

Xiao, X., Agusti, S., Lin, F., Li, K., Pan, Y., Yu, Y. , Duarte, C. M. (2017). Nutrient removal from Chinese coastal waters by large-scale seaweed aquaculture. Scientific Reports, 7, 46613.

Weinberger, F., Buchholz, B., Karez, R., Wahl, M. (2008) The invasive red alga Gracilaria vermiculophylla in the Baltic Sea: adaptation to brackish water may compensate for light limitation. Aquatic Biology 3, 251-264.

Westermeier, R., Gomez I., Rivera, P. (1993). Suspended Farming of *Gracilaria chilensis* (Rhodophyta) at Carquilda River, Maullin, Chile. Aquaculture 113, 215–229.

Yang, Y. F., Fei, X. G., Song, J. M., Hu, H. Y., Wang, G. C., Chung, I. K. (2006). Growth of *Gracilaria lemaneiformis* under different cultivation conditions and its effects on nutrient removal in Chinese coastal waters. *Aquaculture 254(1-4), 248-255.*

Yarish, C., Redmond, S., Kim, J. K. (2012). *Gracilaria* culture handbook for New England.

Yokoya, N. S., Hirotaka, K., Obika, H. & Litamura, T. (1999) Effects of environmental factors and plant growth regulators on growth of the red alga *Gracilaria vermiculophylla* from Shikoku Island, Japan. Hydrobiologia 398/399, 339- 347.