Site selection for finfish cage farming using spatial multi-criteria evaluation and their validation at field in the Bay of Souahlia (Algeria)

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Abstract

The development of marine fish farming on the Algerian coast is facing a number of environmental and logistical constraints. In a multi-disciplinary approach, based on aquaculture activity planning and field validation, the aim of this study is to target suitable areas for the setting of floating cages for *Sparus aurata* breeding at the Bay of Souahlia, Algeria. Multi-criteria evaluation via GIS was applied, combining 3 sub-models (environmental, socioeconomic, and constraint sub-models). The field verification was carried out on *El Mokretar Aqua* farm, by comparing its position with the result of the multi-criteria evaluation and by studying the growth performance indicators, thermal unit growth coefficient, specific growth rate, and feed conversion ratio and biomass. The regeneration of the final suitability map allowed for the delimitation of the favorable area for the implantation of the floating cages, which corresponds to 32% of the total area, with 3 classes of suitability. The *El Mokretar Aqua* farm is located at station S11, with a significant relevance index of 0.69. The gilthead seabream reflects a good growth performance. It grows with an average weight of 5 to 305 g over a 306-day rearing period, due to the environmental conditions and the good management of the farm.

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Introduction

The Algerian coastline is characterized by its openness to the Mediterranean Sea. Its very small continental shelf, the absence of sheltered areas, and pollution problems and urbanization make the development of marine aquaculture difficult.

In recent years, the seabream breeding, *Sparus aurata*, in floating cages, has been widespread in the Mediterranean Sea, particularly in Algeria. About 65 major fish farm investment projects started in 2018, and many others were launched. The target production will be about 10,000 t/year, with growth of more than 20% at the end of 2019 (https://www.lemaghrebdz.com).

The Algerian experience in this field faced many environmental and regulatory constraints which hamper its development (Ministry of Agriculture, Rural Development and Fisheries 2017). Today, some fish farms experienced serious accidents such as massive mortality; destruction of cages; diseases spreading; and limited growth, in addition to economic risks due to poor sizing of the fish farm, poor site selection, pollution, and conflicts about the sea use.

These failures are due to poor spatial planning, inappropriate site selection, and inadequate management procedures (Kumer and Cripps 2012). Site selection is a prerequisite for any aquaculture activity ensuring the success and sustainability of the aquaculture farm (Falconer et al. 2018). Determining the suitability of a site is a difficult process as it combines biological, environmental, socioeconomic, legal, and engineering aspects to ensure planning and management (Falconer et al. 2018).

Moreover, floating cages should be located in areas where the environment is adequate, in which there is a balance between bathymetry, sedimentology, currents, and waves (Pérez et al. 2005). Since most offshore mariculture operations use open facilities in which livestock organizations are exposed to natural environmental conditions, the physicochemical properties of seawater can therefore affect the growth and survival of organisms and, therefore, their mariculture production potential (Oyinlola et al. 2018).

Currently, various studies have been published on the use of multi-criteria evaluation (MCE) for finfish cage farming site selection (Pérez et al. 2005; Szuster and Albasri 2010; Micael et al. 2015; Dapueto et al. 2015; Gimpel et al. 2018; Falconer et al. 2018). In addition, several studies on the growth of fish bred in floating cages, considering the prediction models and growth indicators, have been mentioned in the bibliography (Muller-Feuga 1990; Petridis and Rogdakis 1996; Mayer et al. 2008; Marco et al. 2017). The purpose of this article is to target suitable areas for *Sparus aurata* in floating cages, using the MCE, via geographic information system (GIS), applied to the Bay of Souahlia, in Chlef, Algeria. The MCE has been used to establish a suitability map, based on selection criteria, approved by both the Ministry of Agriculture, Rural Development and Fisheries and several authors (Pérez et al. 2005; Szuster and Albasri 2010; Micael et al. 2015; Dapueto et al. 2015; Gimpel et al. 2018; Falconer et al. 2018). Check this choice is made in comparison with the location of the existing farms and validate the aquaculture potential, by evaluating the gilthead seabream growth performance through several indicators. This study could be the first attempt to get rid of the mistrust that exists between the methodological approach (multi-criteria evaluation) and the traditional one, adopted by Algerian local authorities, involving suitable site identification for the installation of floating cages.

Material and methods

Study area

The Bay of Souahlia is open on the Mediterranean Sea. It is located in the North-West of Algeria. The coordinates are between 36° 30′ N and 36° 34′ N, and 1° 27′ E and 1° 32′ E (Fig. 1). It covers an area of about 8300 ha and has a narrow continental shelf and a maximum depth of 1400 m. This bay is crossed by the irregular regime of the Wadi "Oued Ghaussine."

This bay is characterized by a water temperature which is between 15 and 26 °C and a salinity typical of that of the Mediterranean waters which varies from 35.5 to 37.5 psu. Dissolved oxygen levels range from 5 to 8 mg/L. Nutrient concentrations such as ammonium, nitrite, nitrate, and phosphate are very low. They do not exceed a few milligrams per liter and reflect the oligotrophic character of the Mediterranean Sea (Laama and Bachari 2017). The Bay of Souahlia waters are of good bacteriological quality, especially in the absence of *Escherichia coli*, fecal streptococci (Laama and Bachari 2018). The Bay of Souahlia has more or less high contents of suspended matter in winter and spring, due to Oued Ghaussine terrigenous inputs (Laama and Bachari 2017).

The Bay of Souahlia hydrodynamism is characterized by two types of agitation: south-westerly agitation during the winter and spring seasons with a 4-m ridge and northwesterly agitation in summer and autumn with a significant wave height that does not exceed 2 m offshore. The greatest orbital current velocities are less than 1 m/s offshore, while maximum values (> 1 m/s) characterize the coastal zone (Laama and Bachari 2018).
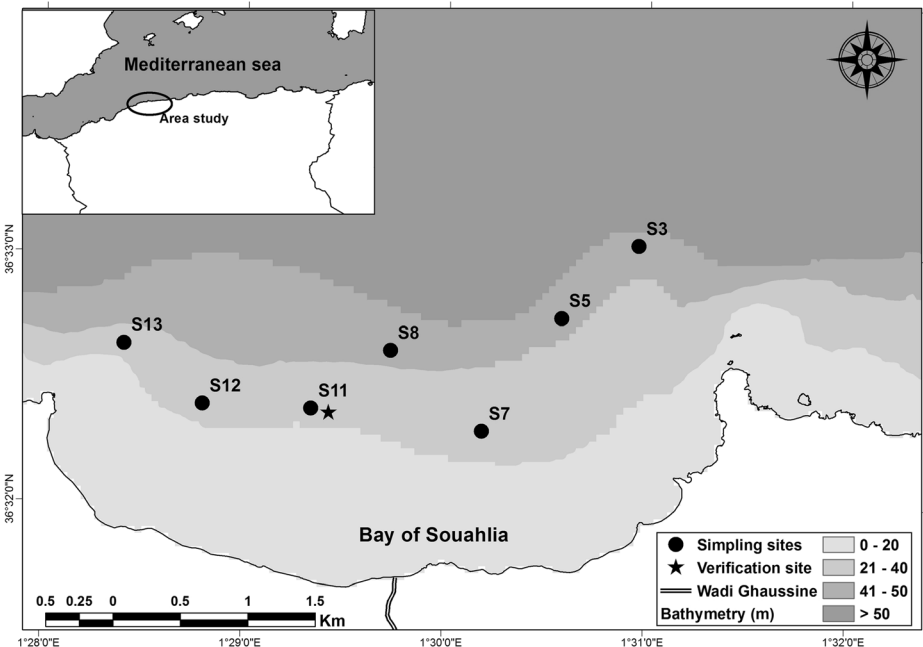

Fig. 1 Location of the Bay of Souahlia with sampling points and bathymetry

Multi-criteria evaluation decision model

The finfish site selection plays a critical role in determining the productivity, environmental impact, and interactions of aquaculture activities (Porporato et al. 2020). Several factors are used in the selection of suitable areas for gilthead seabream breeding in floating cages. The choice of these factors is based on the documentation provided by both the Algerian Ministry of Fisheries and Aquaculture Development in 2014 and literature (Pérez et al. 2005; Szuster and Albasri 2010; Micael et al. 2015; Dapueto et al. 2015; Gimpel et al. 2018; Falconer et al. 2018).

The approach used for spatial information management and decision-making is the multicriteria evaluation (MCE) (Malczewski 2000) (Fig. 2). It allowed for the organization of factors into criteria and constraints (Table 1). A criterion is a factor that increases or decreases the site relevance while a constraint is a factor that limits aquaculture activity in the site (Pérez et al. 2005).

Sub-model organization

The identified criteria are subdivided into two sub-models: the environmental sub-model and socioeconomic sub-model. In addition, the constraint sub-model is included.

Environmental sub-model

In the study area, five relevant criteria are identified, including water temperature (Wt), significant wave height (Hs), orbital current speed (Ub), bathymetry (Bath), and sedimentology (Sed). Water temperature is the criterion that has a great influence on the fish. It affects its growth and breeding period, as well as the feeding, the disease inhibition, and the finfish aquaculture feasibility (Pérez et al. 2003; Billard 2005). Monthly water temperature data were obtained by in situ measurement in 7 stations (Fig. 1), using a multiparameter of HANNA
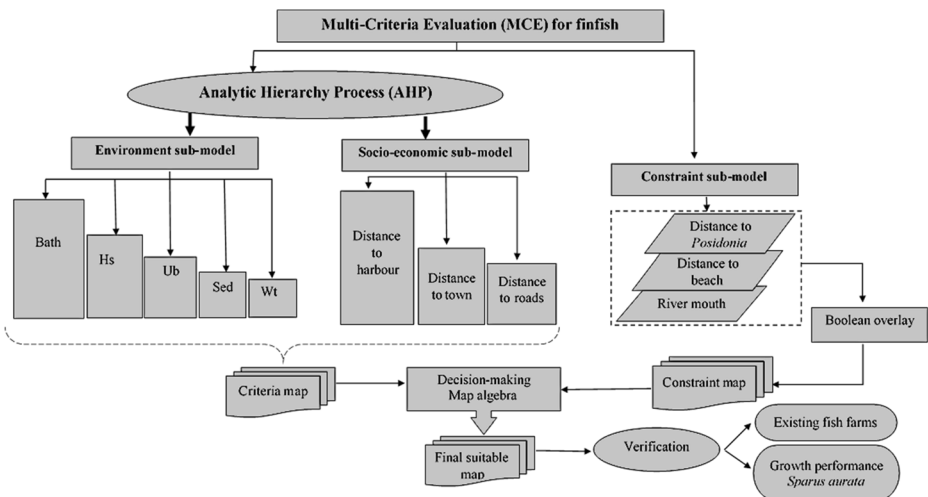

Fig. 2 Hierarchical scheme of the multi-criteria evaluation applied to the Bay of Souahlia for site selection for finfish aquaculture. Bath (bathymetry), Hs (significant wave height), Ub (orbital current speed), Sed (sedimentology), water temperature (Wt)

Table 1 Description of criteria used for site selection in the Bay of Souahlia. ED, Euclidean distance

Factor	Data source and method	Data value range	Suitability score
Environment sub-model			
Water temperature (°C)	In situ measurement	18–28	3
Significant wave height (Hs) (m)	Kriging interpolation	15–18	2
	Swan model (1992–2012)	≤2	3
		2–3	2
		>3	1
Orbital current speed (Ub) (m/s)	Swan model (1992–2012)	0.5–1	3
		0–0.5	2
		>1	1
Bathymetry (m)	Map scale 1:50,000	35–50	2
	Interpolation	0–20 and >50	1
		20–35	3
Sedimentology	Marine map	Sand	3
	Scale: 1/120,000	Sand-mud	2
	Scuba diving	Rock	1
Socioeconomic sub-model			
Distance to harbor (km)	Google earth, open street map	ED <3 km	3
	ED	ED 3–5 km	2
		ED >5 km	1
Distance to town	Google earth, open street map		
Distance to roads	ED		
Constraint sub-model			
River mouth	Google earth	Buffer of 2 km (ED > 2 km)	
Distance to beach	Google earth, open street map	Buffer of 500 m (ED > 500 m)	
Distance to sensitive habitats (Posidonia oceanica)	Scuba diving	Buffer of isobath 15 m	

type, from July 2015 to June 2016. Moreover, daily temperatures were provided by the *El Mokretar Aqua* farm, from July 2016 to May 2017.

The wave action on floating cages is the biggest problem during site selection (Pérez et al. 2003; Falconer et al. 2013; Micael et al. 2015). The significant wave height (Hs) allows for the evaluation of the site hydrodynamic conditions, the choice of cage, and the mooring system (Falconer et al. 2013). In addition, the high speed of the current affects not only the cages' physical structure but also the production and behavior of the fish by net deformation, oxygen supply reduction, or waste dispersion (Falconer et al. 2013). These hydrodynamic parameters are obtained by modeling (Booij et al. 1999), using the Swan software over a period of 20 years (1992–2012) (Laama and Bachari 2018).

Floating cages must be installed where water depth is sufficient both for cost reduction and issues associated with mooring, to allow diving operations (Dapueto et al. 2015) and maximize water exchange to disperse metabolic wastes (Pérez et al. 2005; Falconer et al. 2013; Dapueto et al. 2015). Regarding this criterion, a map (1:50,000 published by War Office 1942) was digitized and interpolated (Falconer et al. 2013), using ArcGIS 10.3 software to define the most appropriate isobaths for cage installation.

Bedrock should be excluded from floating cage fish farming areas as it is more difficult to anchor structures on rocky sea floors (Falconer et al. 2013; Micael et al. 2015; Dapueto et al. 2015). In the present study, sedimentology is obtained using the marine map (National Institute of Cartography 1998, scale: 1/120,000) and field verification by performing several dives.

Socioeconomic sub-model

Socioeconomic criteria include bylaws, competing resources, market conditions, infrastructure support, and technical expertise availability (Nath et al. 2000). At the Bay of Souahlia, three criteria have been identified: distance from the harbor, distance to town, and distance to roads. The harbor provide the necessary services for the finfish farm operation.

Depending on the chosen harbor position, the maximum distance at which the farm can be located has been identified to reduce costs and facilitate the marketing of livestock products (Dapueto et al. 2015; Micael et al. 2015).

Distance to the city and distance to roads are important for any successful aquaculture operation, ensuring access, supply, and marketing markets (Falconer et al. 2013; Falconer et al. 2016). They are determined based on the distance calculation (Falconer et al. 2016; Gimpel et al. 2018; Vianna and Filho 2018), particularly the Euclidean distance (Vianna and Filho 2018).

Constraint sub-model

The constraint identification was made according to the legislation defined by the ex-Ministry of Fisheries and Fisheries Resources (2014). Less than 1 km from the river mouth (Oued Ghaussine), more than 800 m to the protected areas (*Posidonia* seagrass), and more than 500 m from bathing beaches and tourist areas.

The constraint map indicates the areas where no aquaculture activity can be performed. It was obtained through Boolean overlay, where the layers were combined through the Boolean intersection (AND) or Boolean of the union (OR) (Nath et al. 2000; Ross et al. 2009; Falconer et al. 2013; Hadipour et al. 2014; Dapueto et al. 2015; Falconer et al. 2018).

Criteria weighting and standardization

There are many techniques for weighting criteria, but the pairwise comparison, developed by Saaty (1977), remains the most common. This analytical hierarchy process (AHP) is most commonly used in aquaculture site selection (Gimpel et al. 2015). This method consists in establishing a pairwise criterion comparison matrix, based on expert judgments, according to a priority scale (Table A1), to determine the weight relative to each criterion, proportional to its importance (Saaty 1991). The latter was performed through extensive discussions with aquaculture experts and stakeholders, during visits to the site, workshops, and meetings with a panel of 15 people.

Once the pairwise comparison matrix was filled in, the vector associated with the maximum value of this matrix was calculated. It then corresponds to the relative weights of the criteria (Bhushan and Rai 2004).

The criteria listed within the environmental and socioeconomic sub-models have different units. The standardization of these criteria makes it possible to transform them into comparable units. It was carried out using the function of classify by ArcGIS 10.3, according to scores, from 1 (not suitable) to 3 (most suitable).

Determination of the suitability index and mapping

Regeneration of the final suitability map was performed by the combination of environmental and socioeconomic sub-models and constraint map. This combination was performed using a multi-criteria decision rule called "weighted linear combination (WLC)" to calculate the suitability index represented in Eq. (1) (Malczewski 2000). The SI represents the suitability of the ith pixel in the final map, which is the sum of the relative weights (W_j) of the jth criterion, obtained by the AHP method, to the standardized score (X_{ij}) multiplied by the product of constraints (C_j) (Malczewski 2000; Hadipour et al. 2014). Raster map (a set of pixels) of each sub-model was combined by the WLC using the ArcGIS 10.3 software. This approach is easy to implement using map algebra operations and geospatial overlay (Dapueto et al. 2015). In fact, the suitability index was obtained via map algebra, using raster calculator (Ross et al. 2009; Falconer et al. 2018; Vianna and Filho 2018).

$$\text{SI} = \sum_j W_j X_{ij} \times \prod_j C_j \tag{1}$$

Verification and validation of choice

The result checking obtained by the MCE is essential, both for the quality control of certain data sources and for the model result testing. This is done in the field, using standard survey techniques and environmental measures (Nath et al. 2000). Indeed, this operation was carried out to determine whether the *El Mokretar Aqua* farm, installed by the local authorities in May 2016, through a private concession, matches with the sites established by the MCE or not.

The approach used was to compare the location of the *El Mokretar Aqua* farm with the location provided by the MCE and evaluate the growth performance of the gilthead seabream rearing in floating cages. This species growth performance was evaluated in terms of body weight (W_i) (W_f), thermal unit growth coefficient (TGC), specific growth rate (SGR), and feed

conversion ratio (FCR) (Muller-Feuga 1990; Petridis and Rogdakis 1996; Mayer et al. 2008; Marco et al. 2017).

$$SGR = \frac{\ln(W_f) - \ln(W_i)}{t} \qquad (2)$$

where W_f is the final weight (g) and W_i is the initial weight (g), and t is time (day)

$$TGC = \frac{W_f^{\frac{1}{3}} - W_i^{\frac{1}{3}}}{\sum Tef} \qquad (3)$$

where $\sum Tef$ is the sum of daily effective temperature (°C)

$$FCR = \frac{F_g(kg)}{BM_f(kg)} \qquad (4)$$

where F_g is the amount of feed distributed (kg) and BM_f is the final biomass in (kg).

The commercial farm "El Mokretar Aqua" is located at the Bay of Souahlia, 30 m deep. This aquaculture farm started in July 2016, with an area of 8 ha and an average production capacity of about 650 t/year. The marine cages are divided into 2 reticles of 8 cages, with a diameter of 20 m and a depth of 10 m. The fingerlings were introduced in July 2016, with an initial weight (W_i) of 6 ± 0.81 g and a density of 0.6 ± 0.09 kg/m^3 where they are feedstuff diet (Narurulleva Ecomarine) and whose energy distribution by size of food is as follows: 3 mm (52% protein, 30% lipid, and 17% NFE); 4.5 mm (46% protein, 37% lipid, and 17% NEF); and 6.5 mm (44% protein, 38% lipid, and 17% NFE). *El Mokretar Aqua* farm is among successful experiments for floating cage fish farming. It has made up for the lack of seafood with production reached 700 t in 2017.

The weight data were obtained by fishing, carried out each month (August 2016–May 2017), in 4 floating cages, using a dip net (Fig. 3). The weighing of harvested individuals was carried on board using a precision balance.

Results

Suitable sites for finfish

The results obtained by the analytical hierarchy process (AHP) for the sub-models, prepared for the installation of a farm for rearing gilthead seabream in floating cages, are shown in Table 2 and Table 3, respectively. Also, the relative weight of each criteria is reported in Table 4.

Table 5 shows the data value (mean ± standard deviation) for water temperature, Hs, Ub, bathymetry, and distance to harbor in 7 sampling station of the Bay of Souahlia. The reclassification of the environmental sub-model data generated thematic maps that can be seen in Fig. 4.

In the Bay of Soushlia, the suitability index by station for the environment and the socioeconomic sub-models, along with the final suitability index for finfish site selection, is presented in Table 6. The suitability index values of the environment sub-model, shown in this table, are higher (>0.50) than those of the socioeconomic sub-model because of their more

Fig. 3 Steps followed to study the growth performance of *Sparus aurata* at El Mokretar Aqua farm

important influence. The best suitability index for the environment sub-model is observed in stations S7, S11, S12, and S13.

The final suitability map, based on the combination of criteria and constraints, using the MCE in the Bay of Souahlia is shown in Fig. 5. The appropriate area, for the implementation of finfish cage farming, was about 554 ha, therefore around 32% of the total area of the bay. This area is subdivided into two categories, according to the suitability index. The first has an important score (most suitable); it includes the stations S7, S11, S12, and S13, with a 258-ha

Table 2 Pairwise comparison matrix of environmental criteria

	Bath	Hs	Ub	Sed	Wt
Bath	1	3	3	9	9
Hs	1/3	1	3	7	9
Ub	1/3	1/3	1	7	7
Sed	1/9	1/7	1/7	1	1
Wt	1/9	1/9	1/7	1	1

Bath, bathymetry; *Hs*, significant wave height; *Ub*, orbital current speed; *Sed*, sedimentology; *Wt*, water temperature. Consistency ratio (RC) = 0.05

area. The second category includes stations S3, S5, and S8; it is moderately favorable, with an area of 296-ha. The remaining area is unsuitable for rearing gilthead seabream in floating cages.

Verification and growth study of gilthead seabream

The position of the *El Mokretar Aqua* farm, implemented by the local authorities, coincides with the favorable area, determined by the MCE at the S11 station, where it corresponds to the highest score (0.69). This farm's characteristics along with growth performance data are presented in Table 7.

Gilthead seabream, reared at the *El Mokretar Aqua* farm, grows at an average weight of 5 to 305 g over a 306-day period, but during sampling, large-size individuals of about 400 g are observed. The high standard deviation of 50.29 showed the high dispersion of *Sparus aurata* weight at the farm, as individuals' weight between 90 and 285 g is observed. Nevertheless, *Sparus aurata* is believed to reach a commercial size of over 250 g in 306 days.

The average weight grows rapidly (from 5 to 70 g) with the increase in temperature, from July to October 2016 (about 24 °C); then, the growth rate decreases with the fall of the water temperature until March (Fig. 6). The *Sparus aurata* growth curve, in Fig. 7, shows that specific growth rates (SGR) ranging from 3%. The curves for all cages studied are similar. In fact, the SGR is highest in the first period of the breeding, around 3%, in August, September, and October; then, it decreases in the end of cycle (about 1%).

Discussion

This study is based, on the one hand, on the multi-criteria evaluation to examine the sites suitability for setting up a fish farm, accompanied by field verification of the existing farm, and, on the other hand, on the growth performance study according to the approach proposed by several authors, such as Nath et al. (2000), Pérez et al. (2005), Szuster and Albasri (2010), Falconer et al. (2013), Micael et al. (2015), and Dapueto et al. (2015).

The environmental sub-model, combined with the socioeconomic sub-model, was used to identify areas favorable for the setting of aquaculture farms through the multi-criteria evaluation (MCE). At the Bay of Souahlia, inappropriate sites for rearing gilthead seabream in cages are due to environmental constraints: Wadi mouth (Dapueto et al. 2015), *Posidonia* seagrass habitats (Dapueto et al. 2015; Brigolin et al. 2015; Kletou et al. 2018), and tourist areas and beaches (Pérez et al. 2005; Radiarta et al. 2008; Longdill et al. 2008; Dapueto et al. 2015;

Table 3 Pairwise comparison matrix of socioeconomic criteria

	Distance to harbor	Distance to town	Distance to roads
Distance to harbor	1	3	5
Distance to town	1/3	1	2
Distance to roads	1/5	1/2	1

Consistency ratio (RC) = 0.0004

Brigolin et al. 2015). Many studies such as Laama and Bachari (2018) and Brigolin et al. (2015) consider the habitats of *Posidonia oceanica* as a constraint for the development of finfish cage farming. The latter has damaged *Posidonia* meadows around the world and in the Mediterranean, because farm waste can kill these habitat-creating meadows (Kletou et al. 2018).

On land, aquaculture naturally interferes with other activities developed on the coast, particularly with urbanization, industry, tourism, and agriculture (PAP/CAR 1996). However, effluents from agriculture and population are discharged through water courses which could be a potential source of pollution. The cages occupy a space that can affect local amenities, marine traffic, and sedimentation dynamics and reduce the water quality of nearby beaches. Therefore, the location of cages should be planned to avoid interferences and conflicts of space and water (Pérez et al. 2005).

Pérez et al. (2005) assessed the suitability of beaches for the establishment of an aquaculture farm cage through several criteria. It appears that short beaches, with a low occupancy and urbanization rate and composition other than sand, are the most suitable for fish farming. In the Bay of Souahlia, Doumia Beach and Oued Ghaussine Beach have features similar to these areas.

The study by Pérez et al. (2005) also indicates the coexistence of marine cage aquaculture and the tourism industry (Ross et al. 2009). Moreover, the presence of tourism plays a major role in the development of mariculture activities and their future expansion (Oyinlola et al. 2018). This industry not only positively stimulates the development of a future aquaculture activity by increasing the local demand for aquatourism but also sets restrictions related to the presence of fish cages in the coastal areas facing sand beaches, which are also frequented by people interested in recreational boat traffic (Brigolin et al. 2015 in ANDI 2013).

Environmentally, the water temperature is the most important factor for site selection due to its effect on the farmed fish growth as they are fed following this criterion (Marco et al. 2017). Growth of gilthead seabream is modeled using the time series of water temperature (Brigolin

Table 4 Relative weight of each criterion based on the pairwise comparison matrix to evaluate the potential of the Bay of Souahlia for finfish cage farming

	Relative weight (W_i) (%)
Environment sub-model	0.70
Bath	0.46
Hs	0.29
Ub	0.18
Sed	0.04
Wt	0.03
Socioeconomic sub-model	0.30
Distance to harbor	0.65
Distance to town	0.23
Distance to roads	0.12

et al. 2015). Growth performance indicators of gilthead seabream is modeled using the time series of water temperature, to determine the suitability of aquaculture activities (Porporato et al. 2020). The anabolic and catabolic processes are also strongly affected by water temperature (Brigolin et al. 2015). In a local area such as the Bay of Souahlia where the water temperature does not change too much in time and space (Table 5), the stockholders consider that the priority in the analytical hierarchy process is given first to bathymetry, followed by hydrodynamics and sedimentology. Indeed, the bathymetry is the most important criterion than hydrodynamics and sedimentology. Floating cages should be placed on sites where water is deep enough to keep the bottom of the cage well clear of the seabed, thus avoiding harmful effects of a possible accumulation of waste (Pérez et al. 2005). It influences both the size of the floating cages and the anchoring system (Micael et al. 2015). The best depths for setting up aquaculture facilities are between 20 and 50 m (UICN 2009). Significant wave height plays a larger role (0.29%) than sedimentology (0.04) and water temperature (0.03). In the socioeconomic sub-model, the distance to the harbor has the major role (0.65%) for facilitating the various interventions and feeding operations.

The multi-criteria evaluation identified almost 32% (554 ha) as favorable for the fish farm implementation. Most sampled stations have high score (most suitable) which reveals the highest aquaculture potential of the Bay of Souahlia. This approach would analyze the site capacity to biologically and physically support *Sparus aurata* rearing (Radiarta and Saitoh

Table 5 Data value (mean ± standard deviation) for water temperature, Hs, Ub, bathymetry, and distance to harbor in 7 sampling stations of the Bay of Souahlia

| Station	Water temperature (°C)		Hs (m)	Ub (m/s)	Bathymetry (m)	Distance to harbor (km)
S3	Summer	23.13 ± 1.41	1.83 ± 0.040	0.005 ± 3.51E-04	50.00	6.19
	Autumn	19.76 ± 1.14	1.25 ± 0.041	0.0004 ± 2.55E-05		
	Winter	16.61 ± 0.79	3.37 ± 0.003	0.053 ± 6.88E-06		
	Spring	17.76 ± 1.79	2.82 ± 0.012	0.018 ± 8.65E-03		
S5	Summer	23.20 ± 1.94	1.77 ± 0.021	0.008 ± 4.85E-04	47.68	6.60
	Autumn	20.83 ± 2.04	1.20 ± 0.022	0.0008 ± 1.56E-05		
	Winter	16.58 ± 0.82	3.26 ± 0.003	0.07 ± 9.20E-06		
	Spring	17.75 ± 1.8	2.74 ± 0.012	0.027 ± 1.32E-02		
S7	Summer	23.49 ± 1.86	1.71 ± 0.011	0.066 ± 2.77E-03	30.00	7.11
	Autumn	20.92 ± 1.87	1.17 ± 0.003	0.016 ± 2.77E-04		
	Winter	16.52 ± 0.86	2.97 ± 0.003	0.254 ± 6.84E-05		
	Spring	17.82 ± 1.82	2.56 ± 0.014	0.14 ± 6.14E-02		
S8	Summer	22.69 ± 2.34	1.81 ± 0.012	0.005 ± 2.05E-04	47.44	7.86
	Autumn	19.74 ± 0.96	1.21 ± 0.023	0.0004 ± 1.98E-05		
	Winter	16.53 ± 0.89	3.17 ± 0.003	0.047 ± 6.02E-06		
	Spring	17.82 ± 1.86	2.67 ± 0.013	0.016 ± 7.60E-03		
S11	Summer	22.88 ± 2.10	1.78 ± 0.017	0.034 ± 9.21E-04	25.99	8.36
	Autumn	19.47 ± 0.75	1.19 ± 0.050	0.006 ± 5.30E-04		
	Winter	16.61 ± 0.82	2.97 ± 0.003	0.16 ± 2.83E-05		
	Spring	17.8 ± 1.85	2.56 ± 0.012	0.081 ± 3.49E-02		
S12	Summer	23.22 ± 2.69	1.75 ± 0.021	0.14 ± 1.60E-03	29.50	9.17
	Autumn	19.72 ± 1.035	1.18 ± 0.071	0.04 ± 5.00E-03		
	Winter	16.60 ± 0.83	2.78 ± 0.0025	0.39 ± 1.00E-04		
	Spring	17.68 ± 1.82	2.41 ± 0.012	0.25 ± 9.51E-02		
S13	Summer	23.15 ± 2.00	1.85 ± 0.031	0.049 ± 3.75E-04	27.98	9.80
	Autumn	21.11 ± 2.07	1.21 ± 0.091	0.01 ± 1.41E-03		
	Winter	16.6 ± 0.83	2.87 ± 0.002	0.19 ± 3.04E-05		
	Spring	17.7 ± 1.84	2.50 ± 0.009	0.10 ± 4.27E-02		
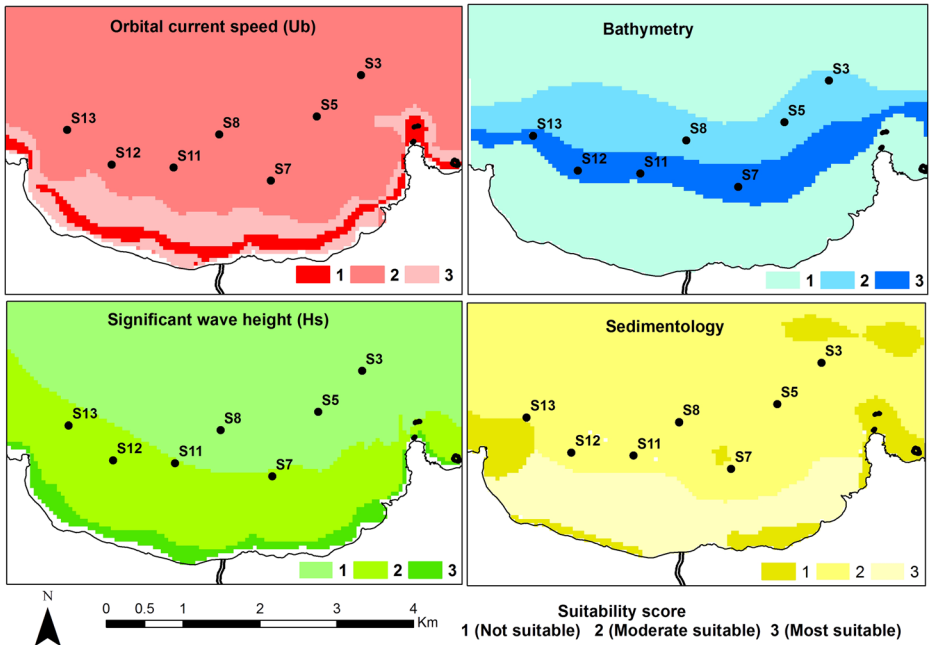
Fig. 4 Thematic maps of the environmental sub-model following scores by ArcGIS

2009): the floating cages resist the sea strength, namely the wave (Pérez et al. 2003; Micael et al. 2015); currentology must be sufficient for the metabolic waste dispersion and water reoxygenation (Falconer et al. 2013); the favorable bathymetry for the implantation of cages (Pérez et al. 2005; Dapueto et al. 2015); sedimentology strengthens the anchoring system (Micael et al. 2015; Dapueto et al. 2015); and water temperature influences the feeding and growth of the bred species (Muller-Feuga 1990; Pérez et al. 2003; Billard 2005), with the integration of socioeconomic criteria to reduce costs and facilitate the marketing of livestock products (Nath et al. 2000; Dapueto et al. 2015).

Exploitation of the growth data on the of gilthead seabream at the *El Mokretar Aqua* farm can provide information on its management and profitability (Muller-Feuga 1990). After targeting areas favorable to the establishment of marine farms, the results obtained with the MCE were approved by the Ministry of Agriculture, Rural Development and Fisheries,

Table 6 Results of suitability index for environment and socioeconomic sub-models with final suitability in sampling station in the Bay of Souahlia

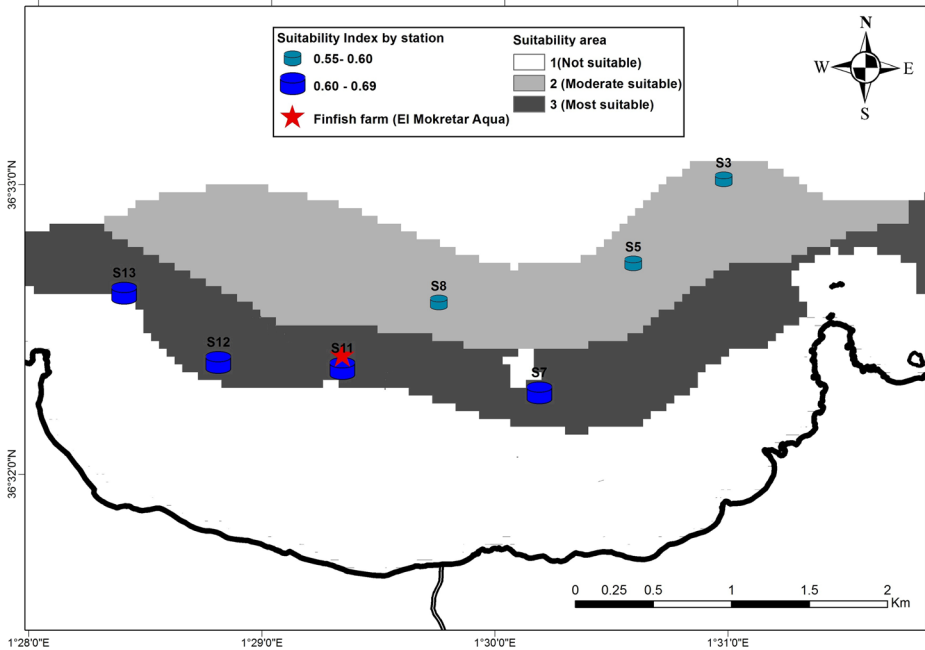| Station	Suitability for environment sub-model	Suitability for socioeconomic sub-model	Final suitability index
S3	0.50	0.73	0.57
S5	0.54	0.69	0.59
S7	0.68	0.66	0.67
S8	0.58	0.51	0.56
S11	0.75	0.54	0.69
S12	0.72	0.43	0.63
S13	0.77	0.23	0.60

Fig. 5 Final map of suitability in the Bay of Souahlia

through the establishment of the *El Mokretar Aqua* farm by a private concession located at station S11. Field validation was established using growth performance indicators. Among the indicators used, the specific growth rate (SGR) provides a measure approximation of weight gain over time (Mayer et al. 2008). The growth of *Sparus aurata* reared in the Bay of Souahlia is higher (SGR = 1.26% day^{-1}) than that reported from the western part of the Mediterranean Sea, Valencia, Spain (SGR = 0.97% day $^{-1}$) (Mayer et al. 2008). On the other hand, it is slightly lower than that reported by Petridis and Rogdakis (1996) in the Ionian Sea (SGR = 1.45% day^{-1}). This difference may be due to several factors, such as density, food nutritive value, the feeding rate, the environmental conditions, the origin of the fry, and mainly water temperature (Mayer et al. 2008). Moreover, low temperature shows an efficiency loss of food capture. This gives way to a slowdown and a growth stop and even weight loss (Muller-Feuga 1990).

Table 7 Growth performance of *Sparus aurata* at *El Mokretar Aqua* farm

|	Mean ± standard deviation
Initial weight (W_i) (g)	5.50 ± 0.81
Final weight (W_f) (g)	305.50 ± 50.29
Duration of the growing (days)	306
Maximum weight (W max) (g)	400
Initial biomass (kg)	1476.14 ± 219.01
Final biomass (kg)	$36,914.65 \pm 2702.99$
$\sum$ °C days^{-1}	2089.30
Specific growth rate (% day^{-1}) (SGR)	2.03 ± 0.05
Thermal unit growth coefficient (TGC)	0.0023 ± 0.00015
Final density (kg/m^3)	7.52 ± 0.55
Feed conversion ratio (FCR)	2.01 ± 0.043
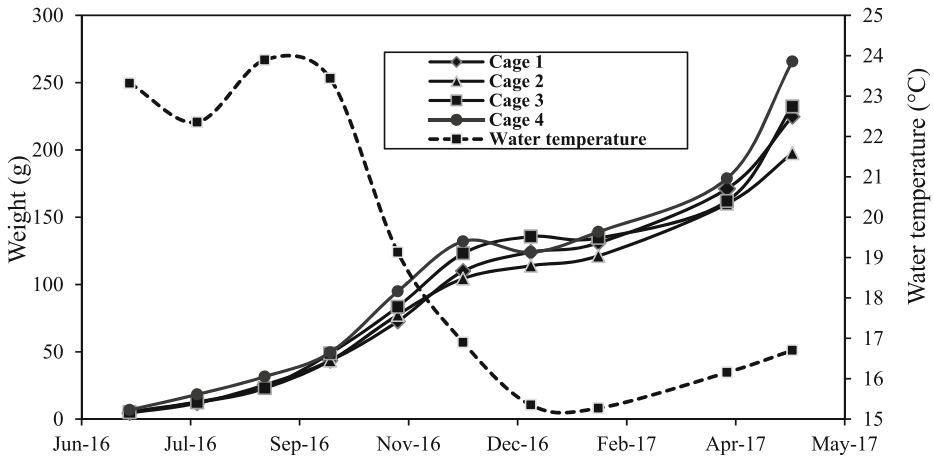
Fig. 6 Evolution of mean weight of *Sparus aurata* and water temperature in the cage according to time

Nevertheless, the value of a second indicator, the thermal unit growth coefficient (TGC), calculated in this farm is higher than the average values quoted by Mayer et al. 2008 (TGC = 0.00169); Kaushik (1998) (TGC = 0.00087); and Petridis and Rogdakis (1996) (TGC = 0.00199). This is due to important temperatures recorded in the Bay of Souahlia; they vary throughout the year between a minimum of 15 °C (in winter) and a maximum of 26 °C (in summer) (Laama and Bachari 2018). The works of Liorente and Luna (2013) confirm these results where the economic result is greater as the average temperature of the water is higher.

The mean temperatures observed in the Bay of Souahlia (23.18 ± 0.22) (Laama and Bachari 2018) are higher than the average temperatures recorded south of Turkey (22 ± 3.93 °C), in Greece (19 ± 3, 55 °C), in Italy (17.5 ± 2.73 °C), and in Spain (19 ± 4.32) (Liorente and Luna 2013). The best result for the economic optimization of gilthead seabream has been recorded in the south-east of Turkey than those in Greece and western Turkey ones, where the weight of the harvested *Sparus aurata* is 500 g instead of 300 g in the other areas (Liorente and Luna
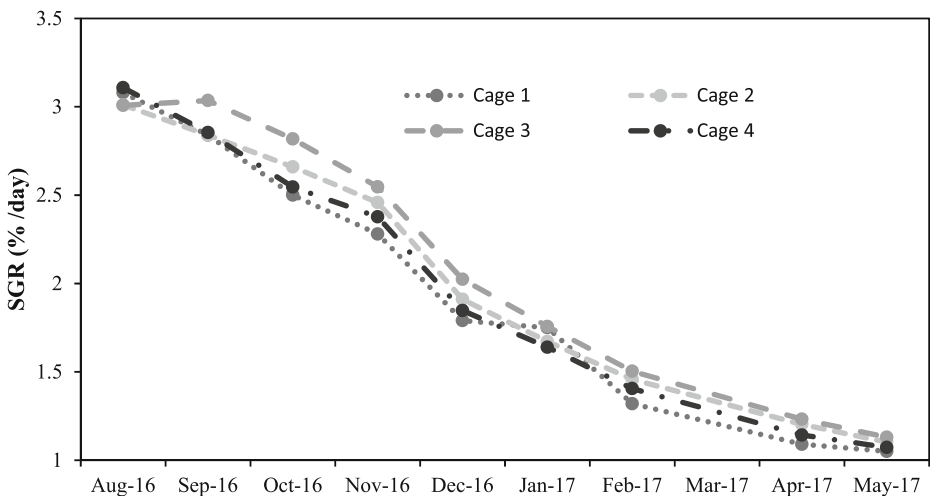

Fig. 7 Specific growth rates (SGR) for each cage according to time

2013). Currently, the water temperature is integrated into mechanistic models based on the dynamic energy budget theory simulating eco-physiology and growth of seabream over time (Porporato et al. 2020).

However, the weight of the crop is one of the main profitability factors of the farm. It is the biggest concern for the investor to determine a sales calendar (Petridis and Rogdakis 1996). Large individuals tend to be more valuable than smaller ones as the former are sold with higher prices in the market (Hernández et al. 2003). In fact, the growth results of *Sparus aurata* in the *El Mokretar Aqua* farm show a good growth performance because the development of the fish depends on its physical state and environment, and food and water quality (Seginer 2015).

The approach adopted in this study made it possible to delimit the zones favorable to fish farming with different levels of relevance. This selection coincides with the Algerian authorities' choice.

Conclusion

In this article, we presented, in a multi-disciplinary context, the importance of AHP as an optimum tool for site selection in future marine farm projects, accompanied by a field verification. This study showed that there are both a great divergence and a lack of information transfer between scientists and local communities. The latter adopt a traditional and slow approach to the aquaculture site selection process. As a result, it faces many problems and lacks accuracy. Although the result is the same, this distance between the two communities causes trade blockage and time and resource losses. The availability of the multi-criteria evaluation allows for the combination of numerous criteria as well as spatial information management in short time for decision-making.

A general perception of the *El Mokretar Aqua* farm gave a general overview of the growth of *Sparus aurata* in breeding, as well as a fish farm operation. This farm could be an experimental site for the rational management of a commercial farm. The same management strategy would be adopted by other farms of similar characteristics.

Compliance with ethical standards

Conflict of interest   The authors declare that they have no conflict of interest.

Ethical approval   All applicable international, national, and/or institutional guidelines for the care and use of animals were followed by the authors.

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