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Site selection for fish farming using integrated GIS-spatial multi-criteria evaluation and carrying capacity approaches: case study of M'diq bay, Morocco

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ABSTRACT

Aquaculture is considered one of the fastest-growing food production systems in the world; however, its development is still facing constraints in Morocco, particularly in its marine branch. There is, among others, a great need for integrated site selection to ensure the sustainable development of aquaculture. In an attempt to contribute to the sustainable concept of suitable fish farm sites selection in Morocco, the present work focused on a marine zone, known as M'diq Bay. Based on FAO and GFCM recommendations for the implementation of allocated zones for aquaculture (AZA) and carrying capacity (CC) concepts, site selection was performed in this bay using GIS-spatial multi-criteria evaluation (SMCE) method, aligned with the analytic hierarchy process (AHP) and weighted linear combination (WLC). This procedure allowed us to identify and select suitable areas for fish farming in M'diq bay. In addition, the carrying capacity approach was implemented on physical, productive, ecological, and socio-economic dimensions to define their sustainable levels and harmonious combination. The results showed that seven fish farms are possible to integrate and operate without generating negative effects on the bay ecosystem. The allowed zone for aquaculture was around 84 ha, representing only 0.6% of the bay total area, with a maximum production level of 2,900 tonnes.

INTRODUCTION

Environmental protection has become one of the major concerns of the globe population. Thus, anthropic activities require the establishment and the implementation of sustainable principals and best practices' guides (**UNDP, 2011**; **Messerli *et al.*, 2019**).

Being one of the highly emerging activities with an accelerating expansion around the world over the last decades (**FAO, 2020**) and as an essential key to global food security **(Luca & Damvakeraki, 2015; Gimpel *et al.*, 2018)**, marine aquaculture has attracted researchers' attention to determine reference points and environmental criteria. This would subsequently allow determinating sustainability bases and monitoring procedures **(GESAMP, 2001)**. The assessment of aquaculture impacts provide an opportunity for sustainable exploitation avoiding irreversible negative scenarios. The application of geo-informatics may provide various tools that integrate multi-criteria evaluation system for optimal decision-making process boosting the sustainable aquaculture development **(Nayak *et al.*, 2014)**.

For developing aquaculture in a sustainable way, it needs to be embraced in an integrated coastal zone management (ICZM), where any proposed marine aquaculture concession should respond to an allocation system **(GESAMP, 1991, 1996)**. Such a system must select the most suitable sites for aquaculture based on environmental, economic and social factors, in other words, selecting sites with the least environmental stress, maximum potential for species growth, minimum production costs and the least conflicts with other users. Therefore, the carrying capacity concept in site selection process is used to optimise the definition of exploitable space and production's limits in coherence with the sustainability principles.

Thus, aquaculture carrying capacity could be defined as the maximum quantity to be sustainably produced by a given cultured species in a defined site. This term is composed of four types; namely, physical, productive, ecological and social ones **(Inglis *et al.*, 2000; Ross *et al.*, 2013; Cardia *et al.*, 2017)**. Furthermore, there are many carrying capacity models that have been used for aquaculture but they increased in complexity over the last decades **(Mckindsey, 2012)** such that they have been broadened to include ecological balance, social license, governance, and economic optimization.

In Morocco, marine spatial planning for aquaculture is implemented using integrated and participative procedure at regional level. However, marine aquaculture is still weakly developed; there are only two fish farms, two shellfish farms and one seaweed farm on the Mediterranean coast. Great prospects for the Moroccan aquaculture development have been recently revealed through many application forms for projects concessions.

Considering the need to increase aquaculture production to meet local and regional demands for food, and following FAO and GFCM recommendations for AZA and CC implementation **(Macias *et al.*, 2019)**, the present work aimed to contribute in the use of an integrated fish farming site selection methods, using AZA and CC concepts at a local scale. This work has been focused on the M'diq bay, which is a highly demanded space for aquaculture projects.
It is worthnoting that, since the eighties, more than twenty application forms have been submitted to Fishery Department for aquaculture projects to be implemented. This bay witnesses various activities, such as artisanal fishing, sport fishing, nautical activity, navigation, etc. It represents a very important case study for an integrated marine

aquaculture spatial planning implementation. The identification of suitable sites was performed using a combination of remote sensing data and field data. Three main fish species have been selected, sea bass (*Dicentrarchus labrax*), sea bream (*Sparus aurata*) and common meagre (*Argyrosomus regius*), since they are traditionally cultured in the Mediterranean countries and both exist naturally in national and regional marine waters and are highly demanded on market.

MATERIALS AND METHODS

1. Study Area

This study was conducted in the M'diq bay located in the west part of the Moroccan Mediterranean coast. It is an east opened bay-oriented North-South with a mountainous hinterland. The sea space is around 13,000 hectares and about 23km in length; the maximum width is around 7km. It is limited by Ceuta Cape in the North (35°54'N, 5°17'10''W), and Negro Cape in the South (35°40'N, 5°16'40''W). The bay coastline is around 33km, with an alternation of rocky cliffs (in the North, central and the South of the bay) and sandy beaches (along the west side). There is strong urbanization over the coast, especially with marinas and tourist complexes.

The bay is exposed, totally to east-to-south-east winds and partially to west-to-north-west winds. In general, east winds are most critical and have a high velocity speed during winter storms. The bay oceanographic conditions are influenced by its proximity to the Strait of Gibraltar. Main currents flow from south to north, except in summer season, where a predominant south-southeast direction current is observed with a velocity up to 0.68m/s **(Orbi *et al.*, 1997**; **Lakhdar *et al.*, 2001)**. Tidal current directions are northwest during the flow and southeast for the ebb tide **(Orbi *et al.*, 1997)**.

2. Site selection methodology

An integrated approach based on spatial multi-criteria evaluation (SMCE) was adopted using analytic hierarchy process (AHP) and weighted linear combination (WLC) to select suitable polygons for fish farming **(Pérez *et al.*, 2003; Pérez *et al.*, 2005; Dapueto *et al.*, 2015; Aguilar-Manjarrez, *et al.*, 2017; Shih, 2017)**. Then, the carrying capacity concept was used to determine the most suitable fish farm number.

2.1. Spatial multi-criteria evaluation method

Spatial multi-criteria evaluation (SMCE) is a process allowing the combination and transformation of multiple geographic data (input) into a resulting decision (output) **(Malczewski *et al.*, 1999)**. Initially developed for complex business decisions, SMCE is used in different domains and applied on spatial matters **(Carver, 1991; Rahman & Saha , 2008; Zucca *et al.*, 2008; Van Haaren & Fthenakis, 2011)** to surpass Boolean results.

A list of required factors, commonly used in marine fish farming site selection, have been established **(Pérez *et al.*, 2003; Pérez *et al.*, 2005; Szuster & Hatim., 2010; Dapueto *et al.*, 2015; Micael *et al.*, 2015; Aguilar-Manjarrez, *et al.*, 2017; Shih, 2017;**

Gimpel *et al.*, 2018) in addition to the national technical documents implemented for aquaculture planning. Then, significant factors were selected according to their suitability to cage culture, mainly related to the three target fish species (seabass, seabream and common meagre) in M'diq bay according to local conditions, and in compliance with national legislation and local rules in force.

Following the breaking down process into a hierarchy of objectives, twenty-six factors have been selected and divided in criteria units and constraints. Acceptance or exclusion limits was defined for each parameter. Digitalized data were divided in five groups, including major physical parameters criterion, optimal conditions for Fish "OCF" (i.e.: species required parameters) criterion, technical parameters criterion, environmental parameters (that may affect survival or well-being of fish) criterion and constraints (Tables 1, 2, 3, 4, 5).

Table 1. Major physical parameters criterion

Factor	Data source	Selection threshold	Threshold references
Bathymetry (B)	Digitalization of bathymetric map established by INRH and also through the current study	20 to 50 m	**Falconer *et al. (*2013)** **Cardia and Lovatelli, (2015)** **Cardia *et al. (*2017)**
Seabed substrate type (SbSt)	INRH sampling campaigns Current study, particle size analysis following **Environment Canada, (2002)** Guide and **Blair and McPherson, (1999**) classification	Rocky and irregularly seabed excluded	**Cardia and Lovatelli, (2015)** **Dapueto *et al. (*2015)**

Table 2. Optimal conditions for fish "OCF" criterion

	Parameter	Data source	Selection interval	References
- *Dicentrarchus labrax* - *Sparus aurata* - *Argyrosomus regius*	Temperature (T)	CMEMS	≥ 15 & ≤ 25 ≥ 15 & ≤ 27 ≥ 13 & ≤ 28	FAO Cultured Aquatic Species Fact Sheet **Barnabé,** (1**980**) **Claireaux and Lagardère,** (**1999**)
	Salinity (S)		≥ 8.8 & ≤ 39 ≥ 8.8 & ≤ 38 ≥ 5 & ≤ 39	**Hernández *et al. (*2003**) **Ibarz *et al. (*2003**)
	Dissolved oxygen (O_2)		≥ 6 ≥ 5 ≥ 6	**Roque d'Orbcastel *et al. (*2004**) **Fountoulaki *et al. (*2017**) **Ruiz-Jarabo *et al. (*2019**)

Table 3. Technical parameters criterion

Factor	Data source	Selection Threshold	Threshold references
Slope (Slp)	Isobaths processing	< 2%	**Aguilar-Manjarrez *et al. (*2017**)

Seawater Velocity (current) (U_v)	Satellite data CMEMS http://marine.copernicus.eu	0.05 to 0.8 m/s	**Cardia et Lovatelli, (2015)** **Cardia *et al.* (2017)** **Shih, (2017)**
Sea Surface Height (wave) (SSH)		< 3 m	
Wind speed (Ws)	Weather data www.meteoblue.com https://fr.climate-data.org http://www.puertos.es	< 30 km.h^{-1}	**Espeut *et al.* (1993)**
Tidal range (Tr)	Based on national records and **El Mrini *et al.* (2012)**	< 5 m	**Espeut *et al.* (1993)** **Prema, (2013)**

Table 4. Environmental parameters criterion

Factor	Data source	Selection Threshold	Threshold references
Turbidity (Tu)	INRH results and **Arid *et al.* (2005)**	< 10 mg/l	**Cardia and Lovatelli, (2015)**
pH Nitrogen (NO_3) Phosphorus (PO_4)	Satellite data http://marine.copernicus.eu	7.5 to 8.5 < 0.1 mg/L < 0,015 mg/L	**Prema, (2013)**
Chlorophyll a (Chl-a)	Satellite data http://marine.copernicus.eu, INRH data	No frequently blooms and same as near geographical farming site (< 2 µg/g)	**Price *et al.* (2015)**

Table 5. Constraints

Factor	Data source	Selection Threshold	Threshold references
Sewage Discharge Point (SDP)	Satellite image https://www.copernicus.eu	500 m	**Perez *et al.* (2005)** Current study Satellite imagery assessment results
Bathing Area and Marine Leisure Activities (BAMLA)		500 m	
Artificial Reef (AR)	**El Mdari *et al.* (2018)** National data	Excluded zone	Adapted from **Dapueto *et al.* (2015)** and through the current study conditions
Fishing Area • Seiner Area (SA) • Trawling Area (TA) • Fishing Dredge Area (FDA)	https://globalfishingwatch.org/map/ INRH data		
Navigation Area (NA)	www.vesselfinder.com et www.marinetraffic.com		
Diving area (DA)	Scuba diving companies and professional divers		
Aquaculture Activity Area (AAA)	Google earth pro		
Forbidden Areas (FA) • Specially restricted zone • Submarine cables	National data https://www.submarinecablemap.com/		

2.2. Major physical parameters criterion

Two factors were retained as pertinent for this criterion. Suitable bathymetry range for fish farming is selected from 20 to 50m; areas outside this range were excluded. Suitable seabed type is substrate, excluding the rocky ones.

2.3. Optimal conditions for fish (OCF) criterion

Three factors have been adopted as they were considered as mostly and directly affecting the survival and the growth of the target cultured fish species. Notably, the selected species are eurythermal and euryhaline but in culture condition, animal welfare and optimal mass production require specific conditions. Selected areas should then show a range matching with the species' optimal farming conditions.

2.4. Technical parameters criterion

Five factors were considered as pertinent; slope, seawater velocity (current), sea surface height (wave height), wind speed and tidal range. Slope and current are among the key factors used in aquaculture planning and determining conditions for siting, stabilising and operating fish cage farm. Current is a basic factor for seawater exchange in fish farms for it determines the setting up of fish farms (high current speed increases the loading forces on the mooring system), ensures sufficient water exchange in fish cages to provide and re-establish depleted dissolved oxygen, and disperses away particulate and dissolved waste materials from farmed fish in order to avoid environmental consequences and farm self-pollution risk.

Sea surface height (or wave) represents a moving mass that could generate elongation stress on the mooring components. Reflected wave or "return wave", amplified by strong winds could happen in coastal area near the shore and in deep sites, producing destructive effects on fish farm, especially cages and nets. Remarkably, the selected lowest depth is a practical siting choice as it is far from the coast by 1.3km (expect near to the caps).

M'diq bay is characterised by its exposure to winds, mainly from the East and the West. Besides its major contribution to wave production, wind action on exposed parts of the farming equipment could increase farming structures abrasion and destruction, particularly between fish nets and their supporting components. Winds can hinder the husbandry operations and the daily work.

Tidal range takes place every week in general in the Mediterranean Sea and in M'diq bay in particular; its local maximum value does not exceed 80cm.

2.5. Environmental parameters criterion

Environmental quality of marine ecosystems is a large concept and extremely difficult to be thoroughly evaluated. Nevertheless, since farmed fishes depend only on composed food (supplied by farmers), only factors related to their interaction with ecological status have taken into consideration. Consequently, five factors were retained as pertinent for environmental criterion, including turbidity, pH, nitrogen, phosphorus and chlorophyll-a. These factors may not affect fish survival, but are able to impact the ecological integration success of fish culture.

Turbidity can be generated both by phytoplankton and zooplankton blooms, fish farm waste (cultured fish faeces and eaten feed) and also resuspension of deposed fine materials from the sea bottom. In a high turbidity score that lasts for a long duration, this may impact the fish respiration process. The pH variations due to rivers flow may affect the fish health.

Fish farms release can increase the productivity in the framing area, such as algal massive proliferation. It is reported that an area with a higher nitrogen and phosphorus concentration has more chance to lead to a potential environmental risk, essentially characterized by eutrophication **(Jessen *et al.,* 2015)**. Phytoplankton blooms, and assessed trough chlorophyll-a content can affect dissolved oxygen in seawater. According to local data, the M'diq bay did not had algal blooms outbreaks.

2.6. Constraints

Eight factors were selected as constraints for fish farming in M'diq bay, since they represent conditions that make an area unsuitable for fish farm siting in the study area.

In general, suitable areas to be selected for fish farming should not overlap with used, occupied or exploited zones by others activities, or closely juxtaposed to them in order to avoid conflicts.

3. Data collection and database generation

Data and information of selected factors have been collected from two sources: satellite and field data.

Remotely sensed data were provided for nine factors (temperature (SST), salinity (S), potential of hydrogen (pH), dissolved oxygen (DO), current (seawater velocity (Uv)), wave (sea surface height (SSH)), Nitrogen (NO3), Phosphorus (PO4) and Chlorophyll a (Chl-a)). They were downloaded during 10 years' period (2009-2018) from Copernicus Marine Environmental Monitoring Service (CMEMS) Portal (http://marine.copernicus.eu/faq/cite-cmems-products-cmems-credit/?idpage=169). Eminently, these data were collected from feature grid maps (0.042 x 0.042 degrees) and used to generate database for the whole M'diq bay.

Satellite images were also collected and used to generate values for four factors: sewage discharge point (SDP), bathing area and marine leisure activities (BAMLA), navigation area (NA) and sewage discharge point (SDP).

On the other hand, field data were collected from the National Institute of Fisheries Research (INRH) marine study campaigns reports. Additional studies were carried out within the present study framework. They focused on some supplement sampling points coordinates.

All data and information were elaborated with GIS software "ArcGis 10.3" in order to combine factors obtaining criterion and constraints' maps.

4. Site selection procedure

The process followed for suitable site selection for fish farming in M'diq bay is showed in Fig. (1). Selection was performed in five steps. Zoning was progressively established using selected factors following the method of **Dapueto *et al.* (2015)**.

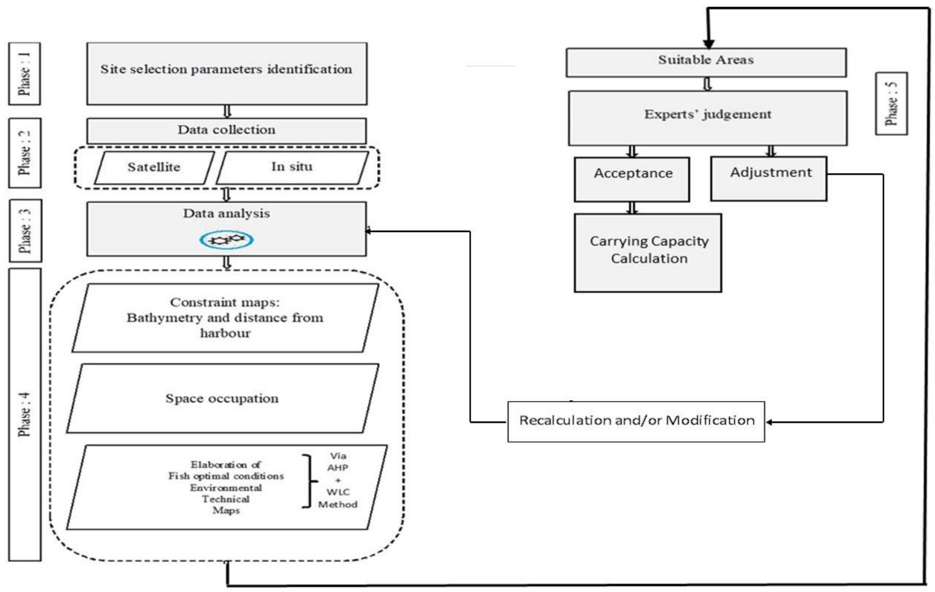

Fig. 1. SMCE methodology

In this study, selected criteria for fish farming site selection in M'diq bay were assessed and thematic maps (base layers) were designed for each criterion. First zoning was established based on the major physical parameters using Boolean method.

Second zoning was made based on the three allowance criteria; namely, optimal conditions for fish" (OCF), and technical and environmental quality criteria. These criteria were first classified and scored through literature reviewing **(Halide *et al.*, 2009; Falconer *et al.*, 2016; Shih, 2017; Wang *et al.*, 2017; Gimpel *et al.*, 2018; Gonson *et al.*, 2018; Vianna & Filho, 2018; Laama & Bachari, 2019; Henríquez-Antipa & Cárcamo, 2019)** and aquaculture experts' consultations (collected from personal communications and surveys). Then, thematic zoning was established using relevant rating scale by AHP method **(Saaty, 1990)**. AHP was applied to extract a multiplying factor of each parameter processed via WLC method **(Malczewski, 2000)**.

In this logic and following WLC method, OCF parameters, four technical parameters (Slp, U_v, SSH and Ws) and four environmental parameters (pH, NO_3, PO_4 and Chl-a) were reclassified following standardized scores from 0 to 10 **(Dapueto *et al.*, 2015)**. Tr and Tu were discarded because of their weak scores. The standardization of parameters was established by giving a higher score to the most suitable condition for each parameter.

AHP results in terms of weights for each parameter and criterion are shown in Fig. (2). These results showed that, among the three allowance criteria, the OCF has the highest weight (0.525). Among OCF factors, temperature has the highest value (0.682), while among technical parameters, current speed has the highest value (0.549). Concerning environmental parameters, NO_3 has the highest weight (0.358).

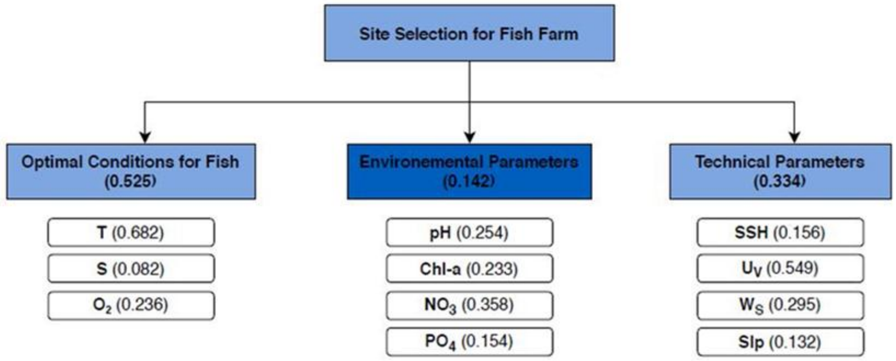

Fig. 2. Weights of parameters assessed by AHP method

Temperature (T), Salinity (S), Dissolved oxygen (O_2)
Chlorophyll a (Chl-a), Nitrogen (NO_3), Phosphorus (PO_4)
Sea surface height (SSH), Seawater Velocity (U_v), Wind speed (Ws), Slope (Slp)

Third zoning was based on constraints criterion using Boolean method to exclude areas which are object of others conflicting coastal activities. Then, suitable site selection map was established by superposition of the previous three kind maps.

5. Carrying capacity

The previous selected site was submitted to carrying capacity process through its four types (physical, productive, ecological and social). These carrying capacity dimensions were evaluated following key elements described in the studies of **Ross *et al.* (2013)** and **Cardia *et al.* (2017)**.

5.1. Physical carrying capacity:

Physical carrying capacity (PhCC) was assessed using Percentile method, based on some pertinent factors to allow the elimination of eventual risks that may cause unacceptable damage to fish farms in the studied area. Percentile method is a statistical methodology used in several scientific papers in multiple ways **(Salako & Hopke, 2012; Soepyan *et al.*, 2016; Smith, 2017; Feng *et al.*, 2018; Scholz, 2019)**.

In the present study, this method was used in its simple way, based on the calculation of yearly days' percentage, considered as a tolerated limit of unfavourable values of some pertinent factors used in site selection process (Uv, SSH, Ws, T, S and DO). Percentile tolerance thresholds of these factors, shown in Table (6), were determined based on some references.

Table 6 . Percentile tolerance threshold

Parameter	Percentile tolerance threshold	Reference
Current speed (Uv)	3%	**Huang *et al.* (2008)**
Significant wave Height (SSH)	2%	**Cardia et Lovatelli, (2015)** **Aguilar-Manjarrez *et al.* (2017)**
Wind speed (Ws)	2%	**Faltinsen et Shen, (2018)**
Temperature (T)	16%	**Dalla Via *et al.* (1998)**

Salinity (S)	49%	**Pichavant *et al. (*2001)**
	49%	**Lanari *et al. (*2002)** **Dülger *et al. (*2012)** **Ercan and Tarkan, (2015)**
Dissolved Oxygen (DO)		**Remen *et al. (*2015)** **Kır *et al. (*2017)** **Kır et Demirci, (2018)** **Makridis *et al. (*2018)**

Moreover, the percentile tolerance thresholds of Uv, SSH and Ws, factors affecting the fish farm structure, were verified by correlating them with the yearly number of days showing values beyond the site selection limits that caused damage to a marine fish farm located in the studied bay.

These tolerance percentages were calculated with RStudio 1.2.1335 simple script **(RStudio Team, 2018)**, where areas displaying percentages above the unacceptable limits were excluded.

5.2. Productive carrying capacity:

The selected fish farming area by PhCC was submitted to productive carrying capacity (PrCC) process based on two typical offshore fish cages farms structures, small and medium production, respectively, are accommodated in 20-30m strata and 30-50m strata. Siting assessments can be based on physical environmental factors related to manufacturers' specific cage designs **(Hunter, 2009)**. Circular C250 and C315 fish cages are designed for on-growing in semi-exposed sea conditions; they are chosen as fish farming facilities based on their physical suitability (resistance, floatability, flexibility, etc.) and their high-performance ability in this area (Table 7). Currently, C250 cages have been used in M'diq bay since 1998 for seabass, and sometimes for seabream and meagre culture in the local fish farm. Moreover, these two types are largely used in the Mediterranean Sea **(Trujillo *et al.*, 2012; FAO, 2016)** and, therefore, they are adopted as a structural tool for fish farming site selection.

In this study, the small fish farm was composed of 14 C250 floating cages of 12m in diameter and 9m in net depth. Its annual production was estimated at 200 tons (7 cages), with a sea surface occupation estimated at 8.76ha (365 x 240 m). The medium fish farm was composed of 12 C315 floating cages of 25m in diameter and 10m in net depth. Its annual production was estimated at 500 tons (5 cages), with a sea surface area estimated at 13.33ha (430 x 310 m). For both fish farm scales, separating distance between two neighbouring farms was kept at 500 m **(Trujillo *et al.*, 2012; FAO, 2016; Arechavala-Lopez *et al.*, 2018)**.

Table 7. Threshold values locally used for circular C250 and C315 cages **(Hunter, 2009)**

Cage Type	Standard Net Depth (m)	Rearing volume (m^3)	Wave Height (m)	Currents (kn)
C250 Designed for semi-exposed Environments	6 – 9	600 - 1,000	3.5	1.6
C315 Designed for exposed Environments	10	3000 -17000	6	1.8

PrCC was estimated based on the number of concessions suitable for fish farming in M’diq bay.

5.3. Ecological carrying capacity:

Following PrCC results, ecological carrying capacity (EcCC) was evaluated based on some indicators to define the suitable production amount without causing significant negative effect on the local environment. Dissolved oxygen consumption, wasted feed and fish faeces were considered depending on the R package of aquaculture (RAC) **(Baldan *et al.*, 2018)** in Rstudio 1.2.1335 **(RStudio Team, 2018)**; this model provides the output for two fish species, *Sparus aurata* and *Dicentrarchus labrax*. The faeces and wasted feed were transformed into carbon following **Brigolin *et al. (*2014)** methodology to estimate wasted feed carbon flux and faeces carbon flux. The dispersion of organic waste in seawater column was assessed following the method of **Bravo and Grant (2018)**, and the **d**uration to **m**eet the **f**ish **o**xygen **d**emand (**DMFOD)** was calculated based on the following formula, where oxygen demand was provided by RAC **(Baldan *et al.*, 2018)**:

$$\text{DMFOD}=\frac{\text{Maximum Oxygen demand}}{\text{Water flow in a cage}\times\text{Average Oxygen concentration in water}}$$

The ecosystem potential to reuse wasted feed, as a by-product for other species or a primary source, was considered through the evaluation of wasted feed consumption by wild fish around the existing marine fish farm situated in the South of the studied area, following the methodology of **Riera *et al.* (2017)**. Furthermore, several experimental fishing operations were conducted on the site by using fish feed to prove the species response "Taxis" to it. In addition, their stomach contents were examined to confirm fish feed consumption. Moreover, a formula was proposed to assess the **t**heoretical **s**pecies’ **c**ontribution to **r**emove the **u**neaten **f**eed and fish **f**aeces (TSCRUFF); the presence frequency notation used in the formula was deduced from the study of **Parreira and Silva (2016)**.

Table 8. The presence frequency scale

Presence Frequency	Always	Almost always	Very frequently	Often	Sometime	Rarely
Notation	1	0,9	0,75	0,5	0,25	0,1

$$\text{TSCRUF}=\text{RA}\times\text{PF}\times\text{PBSEFF}$$

With:

- RA: Relative abundance
- PF: Presence frequency
- PBSEFF: Percentage to be seen eaten the uneaten feed or fish faeces

Moreover, species present around the fish farm that benefit from the farm services, like protection "shelter", feeding on other species or the use of organic/inorganic waste, were evaluated by scuba diving.

The ecological stability in the bay was estimated to predict the acceptability and the interaction with other trophic levels; this was performed using ecopath (www.ecopath.org). Notably, this software was used to evaluate carrying capacity in bivalve farming **(Jiang & Gibbs, 2005; Byron *et al.*, 2010; Byron *et al.*, 2011a, 2011b; Kluger *et al.*, 2015)**. However, in the present study, it was used to evaluate eventual weak trophic levels, and determine the impact of this fish farm on those levels. Data of fish production biomass in the habitat were collected from INRH and ONP, and those related to the consumption biomass were estimated **(Jiang & Gibbs, 2005; Byron *et al.*, 2010; Byron *et al.*, 2011a, 2011b; Kluger *et al.*, 2015)**.

In addition, seabed component was assessed via three indicators. First, the evaluation of the studied bay benthos organic enrichment tolerance was performed by AMBI software **(Borja *et al.*, 2000)**. Infauna species data in the studied area were collected by using Van Veen Grab sampler of 250 cm^2 **(PSEP, 1987; Kelly *et al.*, 2002)** and scuba diving sampling of sediment using 15cm deep sampling core. Sediment samples were first sieved through a screen of 1mm mesh; and then, the organisms were categorized into different groups and observed under a stereomicroscope or Leica DMLB microscope or profile projector depending on the species size, then the species taxonomy were determinate.

In order to understand the local dispersion mechanism and the organic waste behavior, they were assessed following **Cromey *et al.* (2002)** and **Bravo and Grant (2018)** functions (supplementary material) to characterize if they have a gross deposition or an erosion mode.

Furthermore, sediment capacity to assimilate organic matter has been considered as a function of the granule size (**Burdige, 2007**; **Pusceddu *et al.*, 2009**; **Serrano *et al.*, 2016**), where the more the sediment particle is smaller, the more the sediment can assimilate organic matter. In the present studied area, the seabed substrate type has three sizes (sandy, muddy sand and slightly gravelly sand to gravelly sand) for which a notation has attributed in each cage points based on its beneath particle size sediment (Table 9).

Table 9. Sediment Notation.

Sediment type	Notation
Muddy sand	1
Sand	1.25
Slightly gravelly sand to gravelly sand	1.5

Then, an ecological pertinence map was established applying AHP principle to get a score for each indicator. AHP scoring results (Table 10) showed that fish faeces and feed dispersion areas (FFFDA) have the highest score (0.547), followed by the feed loss quantity (FLQ) (0.397); these two indicators could directly affect the ability of the environment to return to the equilibrium line and not cross the line beyond unacceptable ecological limits.

Table 10. Indicators' scores

Indicator	Abbreviation	Score
Fish **F**aeces and **F**eed **D**ispersion **A**rea	FFFDA	0.547
Oxygen **C**onsumption	OC	0.122
Feed **L**oss **Q**uantity	FLQ	0.397
Fish **C**apacity to **R**emove **L**oss **F**eed	FCRLF	0.228
Species **P**rotection	SP	0.101
Influence of **F**ish **F**arm on the **U**nstable **G**roups	IFFUG	0.192
Seabed **E**ndobenthos **S**tate	SES	0.290
Deposition **C**haracterisation	DC	0.242
Seabed **P**otentiality to **S**tore **O**rganic **M**atter	SPSOM	0.059

5.4. Social carrying capacity:

Following the same previous process, the result of EcCCA was submitted to social carrying capacity (SoCC) evaluation using limitative and regulatory constraints. **Angel and Freeman (2009)** referred to SoCC as the concept that reflects the trade-offs between all stakeholders using common property resources, and which the most critical to evaluate.

First, in order to assess SoCC in terms of concessions relevance, four factors were considered (current, temperature, depth and distance from harbour). The adopted method depended on the cumulative temperature and current speed values, with regards to the depth in the area and the distance to the nearest harbour. The temperature is one of the key elements influencing the production cycle time and cultured fish performances. The current speed has a great effect on the anchoring system, the floating part of the fish farm system, and may cause severe risk on farming structures generating fish losses. A bigger depth may cause supplementary cost of the anchoring systems to guarantee better stability and may need more financial cost for the scuba divers. A more important distance to the harbor may cause additional charges **(Person-Le Ruyet *et al.*, 2004; Falconer *et al.*, 2013; Remen *et al.*, 2015; Cardia *et al.*, 2017; Faltinsen & Shen, 2018)**. These factors could therefore have some economic repercussions affecting, among others, the social aspects, mainly in terms of employment and remuneration. Therefore, concessions classifications, through their suitability ranking, were achieved using multiplication factors calculated by AHP methods (Table 11).

In addition, market limits were processed, using surveys results for local market that were conducted over three years 2017-2019 (unpublished data) and national and international (European and Mediterranean) markets data of the three targeted species and others species that could replace them in the market or play the same role in the consumer's habits **(Monfort, 2010; DEPF, 2018)**. Thus, selected fish farms concessions were evaluated through five scenarios, based on the commercialization strategy in terms of the destination of their products sales. (i) 100% of sale to the national market "100L", and (ii) 100% of sale to the international market "100 IN, (iii) 75% to the international market and 25% to the national market "75IN25L", (iv) 50% to the international market and 50% to the national market "50IN50L", and (v) 75% of the production destined to the national market and 25% to the international market "75L25IN".

Table 11. Economic parameters multiplication factors

Factors	Results
Current	0.35
Temperature	0.53
Depth	0.06
Distance from Harbour	0;07

To choose the appropriate scenario, an evaluation of the optimal production matrix was elaborated to calculate the commercial value, the price stability, the freshness introduced to the consumers, the tax value, the possible quantity absorbed by the market and the competition **(Monfort, 2010; EUMOFA, 2014, 2015, 2016, 2017, 2018, 2019; DEPF, 2018; FAOSTAT, 2019; ONPstatistics, 2019; FENIP, 2020**) in addition to other fish selling websites.

Table 12. Evaluated factors to assess market potentiality

Market name						
Impact Factors coefficient (IFC)	**5**	**4**	**3**	**2**	**1**	**Sum**
Factor Description	High	Medium to high	Medium	Medium to Low	Low	
Price						
Price stability						
Freshness to the consumers						
Taxes						
Quantity						
Column sum (CS)	X_1	X_2	X_3	X_4	X_5	
IFC*CS	$5 * X_1$	$4*X_2$	$3*X_3$	$2*X_4$	$1*X_5$	$=\sum IFC*X_iCS$
Competition (C)			N			= IFC*N
Results (%)	$= (1 - \frac{(\sum IFC \times XiCS) - (IFC \times N)}{(\sum IFC \times XiCS})\times 100$					

Moreover, as a part of SoCC evaluation, several surveys were conducted focusing on social activity acceptance, willingness to consume aquaculture products, visual nuisance by the presence of the fish farms, impacts on other coastal activities, job generation and contribution to the national economy. The support of the government and policy maker's for the development of fish farming activity was also evaluated based on national reports **(MMAMF, 2009; Nguyen *et al.*, 2016)**.

RESULTS

1. Site Selection results

1.1. Zoning based on major physical parameters

Results shown in Figs. (3a, b) indicate that M'diq bay has a large physical potential area suitable for fish farming in terms of required bathymetry (more than 50% of the total bay surface) and suitable seabed type (more than 90% of the total bay surface). The overlaying of these two major physical parameters results led to obtain a very important area situated along the entire coast and occupies the entire central part of the bay (less than 50%) (Fig. 3c).

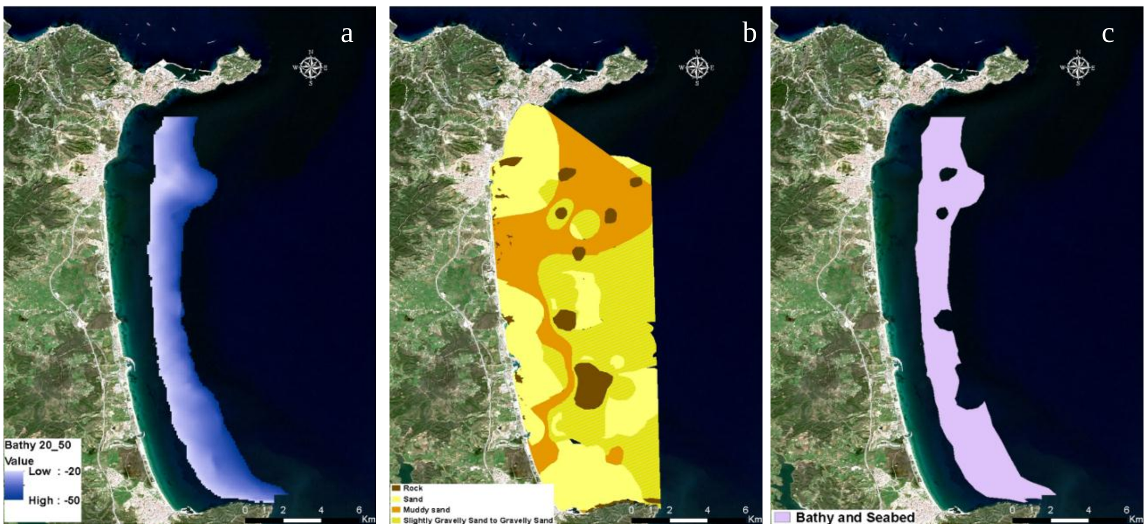

Fig. 3. Zoning maps for fish farming in M'diq bay based on major physical parameters showing: **(a)** Bathymetry; **(b)** Seabed type, and **(c)** Both bathymetry and seabed type.

1.2. Zoning based on allowance criteria

Zoning based on allowance criteria in Fig. (4) shows that the higher OCF score is located in the south part of M'diq bay (Fig. 4a), and the score rating based on environmental conditions is higher in its west part along the whole coastline (Fig. 4b). According to these two criteria, the north area, near to Ceuta, has lower suitability regarding both score ratings results. For technical AHP treatment results (Fig. 4c), it is highly influenced by the slope shape, where the lower scores are generally around rock seabed resulted in an irregular seabed form.

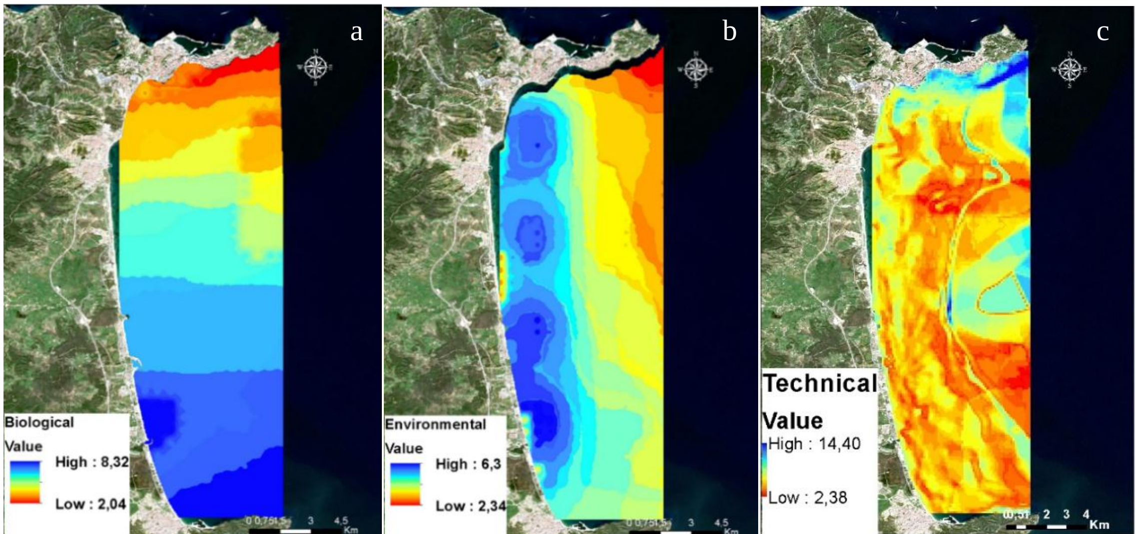

Fig. 4. Zoning maps based on allowance criteria showing: **(a)** Optimal conditions for fish; **(b)** Environmental parameters, and **(c)** Technical parameters

1.3. Zoning based on constraints criterion

Results in terms of spatial occupation in M'diq bay are presented in Fig. (5a) and the excluded areas within the bay are shown in Fig. (5b) These results are compatible with those of bathymetry, where area with less than 20m of depth shows conflicts with coastal activities.

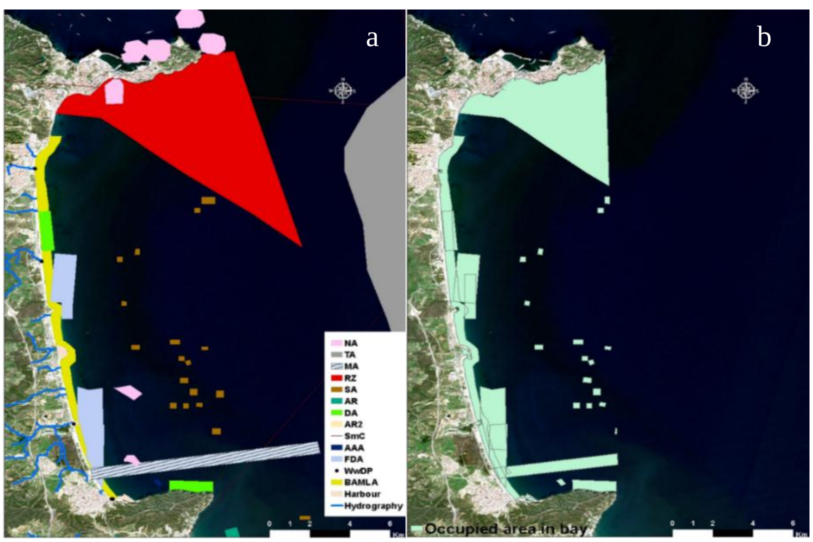

Fig. 5. Zoning maps based on constraints criteria showing: **(a)** Spatial occupation of constraints components and **(b)** Excluded areas

1.2. Suitable site selection map

Results on zoning in terms of site selection is required to determine the result of overlaying all previous zoning maps. The suitable site selection map is shown in Fig. (6). It represents 15% of the whole bay surface. It provides an overview of potential exploitable area that could be allowed for fish farming in M'diq bay, where the highest scoring areas are localized in its southern part and the lowest scoring areas in its north part (Fig. 6).

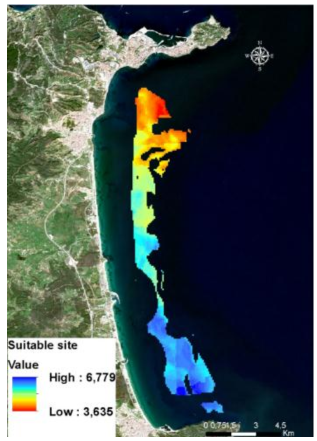

Fig. 6. Site selection for fish farming in M'diq bay

2. Carrying capacity results in terms of site selection finalization

2.1. Physical carrying capacity results

The implementation of percentile concept has led to determine an area to be excluded (Fig. 7b). This excluded area represents 8.56% of the total suitable site selection surface. After eliminating this area, suitable area for fish farming (Fig. 7c) became 14% of the whole bay surface.

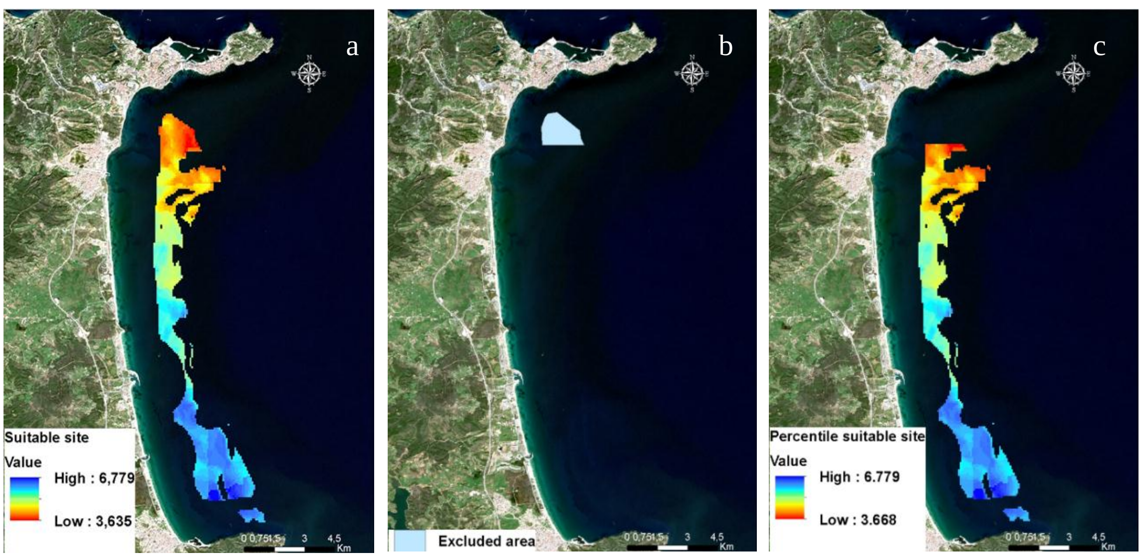

Fig. 7. Physical carrying capacity results showing: **(a)** Last suitable site selection map; **(b)** Excluded area based on physical carrying capacity approach, and **(c)** Resulted site selection

2.2. Productive carrying capacity results

The productive carrying capacity results of both bathymetric strata 20- 30m and 30 50m (Fig. 8a) were conducted to eliminate two 200 tons' fish farms concessions overlapping with two 500 tons' fish farms concessions (Fig. 8b). Therefore, the outcome is 18 fish farm concession of 200 tons and 11 fish farm concessions of 500 tons (Fig. 8c).

Then, the total bay productive carrying capacity was estimated as 9,100 tons, representing about 14.6% of the suitable selected zone surface and 2.2% of the whole bay surface. This can be translated as 41 kg/ha compared to the suitable area surface and 7 kg/ha next to the whole bay surface.

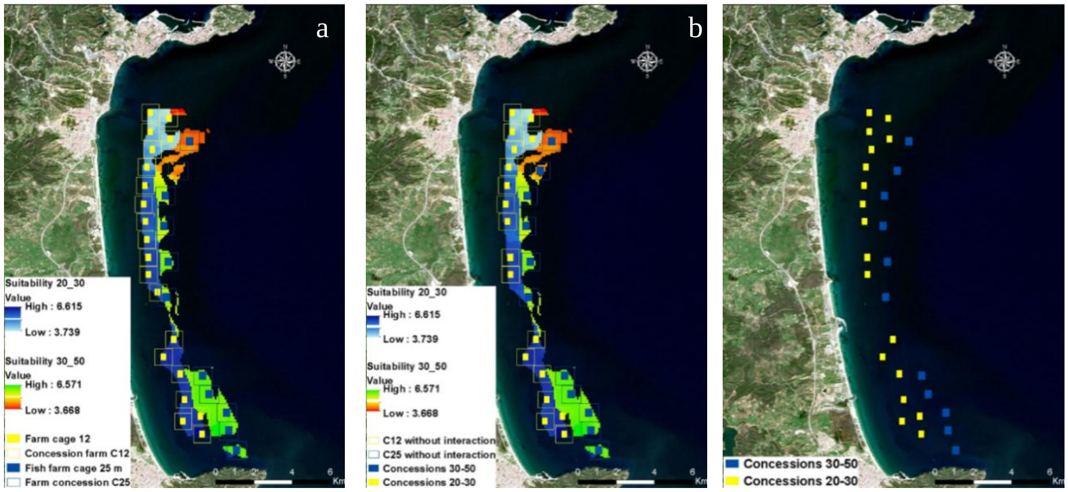

Fig. 8. Productive carrying capacity suitability rating results showing: **(a)** Overlaying results of both bathymetric strata 20-30 m and 30-50 m; **(b)** Elimination of overlapping concessions, and **(c)** Resulting concessions maps

2.3. Ecological carrying capacity:

The ecological carrying capacity of the selected environment in terms of dissolved oxygen is largely sufficient to cover farmed fish mean consumption. Markedly, the mean dissolved oxygen content in local seawater is 7.41 mg/l, which is much higher than the required minimum limit (5 mg/l). Geographical position ensures a continuous renewable seawater and wasted feed and faeces flux with values suggested to be, respectively, 11.1 and 1.5 g of carbon/m^3/d (Table 13). Moreover, this quantity could be less important if we take into account the dispersion area (Fig. 9 & Table 14), which could reach an extent more than 460m in case of farmed meagre faeces, 96m in case of farmed seabream faeces, 47m in case of seabass faeces and 42 m for their wasted feed.

Table 13. Oxygen consumption, wasted feed and faeces flux (per cage 25m)

Parameter	Value	Unit
Maximum total daily oxygen consumption	580	kg/d
Duration to meet oxygen consumption	32.42	S
Daily oxygen renewable rate	2665	%
Wasted feed flux (in terms of carbon)	11.08	g/m^3/d
Faeces flux (in terms of carbon)	1.50	g/m^3/d
Depth under fish net	9 to 20	M
Cage volume	4,906	m^3

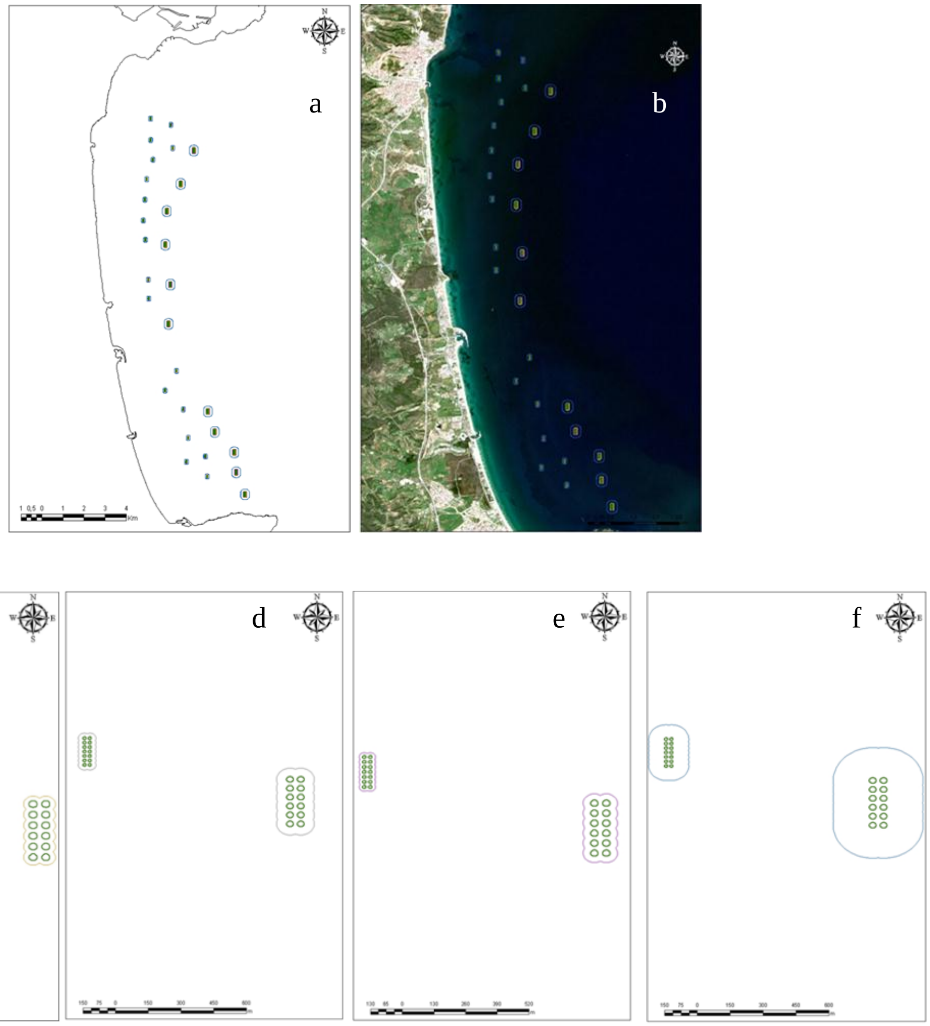

Fig. 9. (a&b) Farm waste dispersion area pattern, **(c)** Dispersion area pattern of waste feed and faeces of studied fish species: **(d)** Seabream, **(e)** Seabass and **(f)** Meagre

Table 14. Waste dispersion area

Dispersion area of		**Meagre Faeces**	**Sea bream faeces**	**Sea bass Faeces**	**Feed**
Most frequent current condition	Max	134.77	27.87	13.60	12.19
	Min	50.15	10.37	5.06	2.48
	Mean	74.80	15.47	7.55	5.46
Max Current condition		468.99	96.98	47.33	42.44
Min current condition		59.30	12.26	5.98	5.37

Furthermore, the studied zone is characterized by an organic wastes gross deposition (τ_u=0.01 < τ_{cd}=0.1), as mentioned by **Bravo and Grant, (2018)**. A gross organic carbon deposition can prevent sulphide concentration above a certain limit in certain hydrodynamic conditions.

In order to have an idea about the natural bioremediation of the environment and its biological tolerance in terms of organic waste the AMBI test showed a biotic index equal to one with a biotic coefficient of 1.038, where it was described in **Borja *et al*, (2000)** as an impoverished group which is indifferent to enrich.

Similarly, eco-efficiency of groups in this bay was found quietly balanced for almost all groups, except crustacean class, which is composed essentially of shrimp, crabs and mantis shrimp. In addition, mollusc shell passes through the same situation (supplementary material). So, fish farming could be seen as an activity with no direct negative effect on the group's subject to unbalanced ecological efficiency because of overfishing or other effects on the ecological system. However, those groups can survive inside the ecosystem created by the implantation of the fish farms in the studied area the same as other species.

In the current study, species that could live inside fish farming areas were separated into two groups. The first group consists of species which have been recorded to benefit from the uneaten feed as an alternative source in a local poor food generator environment, as it is the case for the Bogue (*Boops boops*) or mullet fish species (*Mugil cephalus*, *Chelon labrosus*, *Liza ramada*) (Table 15). These species were permanently present in the studied area with an important frequency and contribution in the uneaten fish feed removal process by 85% to 100%.

Table 15. Fish species contributing to uneaten feed removal

Species	Number	Presence frequency	PBSEFF	TSCRUF	Abundance
▪ *Boops boops*	90 000	1	1	81,390%	74.340%
▪ *Scomber scombrus and Scomber japonicas*	10 000	0.5 Pf	1	4,522%	8.260%
▪ *Sardina pilchardus, Sardinella aurita and Madeiran sardinella*	10 000	0.5 Pf	0.5	2,261%	8.260%
▪ *Mugil cephalus, Chelon labrosus Liza ramada*	7 250	1	1	6,556%	5.989%
▪ *Pagellus acarne*	1 544	0.75	1	1,047%	1.275%
▪ *Trachinotus ovatus*	1 500	1	1	1,356%	1.239%
▪ *Trachinus draco*	300	1	0.5	0,136%	0.248%
▪ *Coris Julius*	275	1	1	0,249%	0.227%
▪ *Diplodus sargus*	98	0.5	1	0,044%	0.081%
▪ *Scorpaena notate*	40	0.75	1	0,027%	0.033%
▪ *Mullus barbatus*	17	0.25	0.5	0,002%	0.014%
▪ *Diplodus cervinus*	13	0.25	1	0,003%	0.011%
▪ *Sparus aurata*	13	0.25	1	0,003%	0.011%
▪ *Conger*	5	0.75	0.5	0,002%	0.004%
▪ *Pagrus pagrus*	6	0.25	1	0,001%	0.005%
▪ *Dentex dentex*	4	0.25	1	0,001%	0.003%
Total number of individuals	**121 065**				

Mf = Migratory fish

The second group is composed of species that profit indirectly from fish farms services (Table 16). These species take advantage under different ways such as feeding on species attached to farming structures, or using these structures as shelter or breeding ground. Fish farms can provide indirect ecological services, mainly in environment characterised as poor or restricted food generator systems, such as those described by **Powley *et al.* *(*2017)** as desert sea areas.

Table 16. Species benefiting from fish farming services

Species	Number	Presence frequency	Relative Abundance
Citharus linguatula	15	0.5	38.46%
Bothus podas	8	0.5	20.51%
Mola Mola	2	0.1 Pf	5.13%
Thunnus thynnus	5	0.25 Mf	12.82%
Muraena Helena	4	0.25	10.26%
Zeus faber	5	0.25	12.82%
Total fish individuals		**39**	
Mytilus galloprovincialis	38 400	1	98.84%
Perna perna	384	1	0.99%
Octopus vulgaris	11	0.5	0.03%
Total mollusc individuals		**38 795**	
Astropecten sp	8	0.9	0.02%
Total starfish individuals		**8**	
Holothuria tubulosa	4	0.25	0.01%
Total sea cucumber species		**4**	
Carcinus maenas *Liocarcinus marmoreus*	30	0.9	0.08%
Total crab species		**30**	
Parapenaeus longirostris *Plesionika martia*	12	0.25	0.03%
Total shrimp species		**12**	
Total individuals		**38 849**	

Mf = Migratory fish

According to these results, the selected zone for fish farming could be sustainably exploited on ecological level. Furthermore, fish farms could provide positive ecological services to species living in their surrounding areas. Thus, the result will be as a multiplication factor of the productive carrying capacity to one.

Moreover, the ecological suitability shows that the area with highest depth is more suitable, highlighting the fact that more farmed fish species faeces-sinking speed are low, more these species ecological pertinence is higher. Therefore, as a general layout, the most suitable fish farms are those situated in the east (Fig. 10).

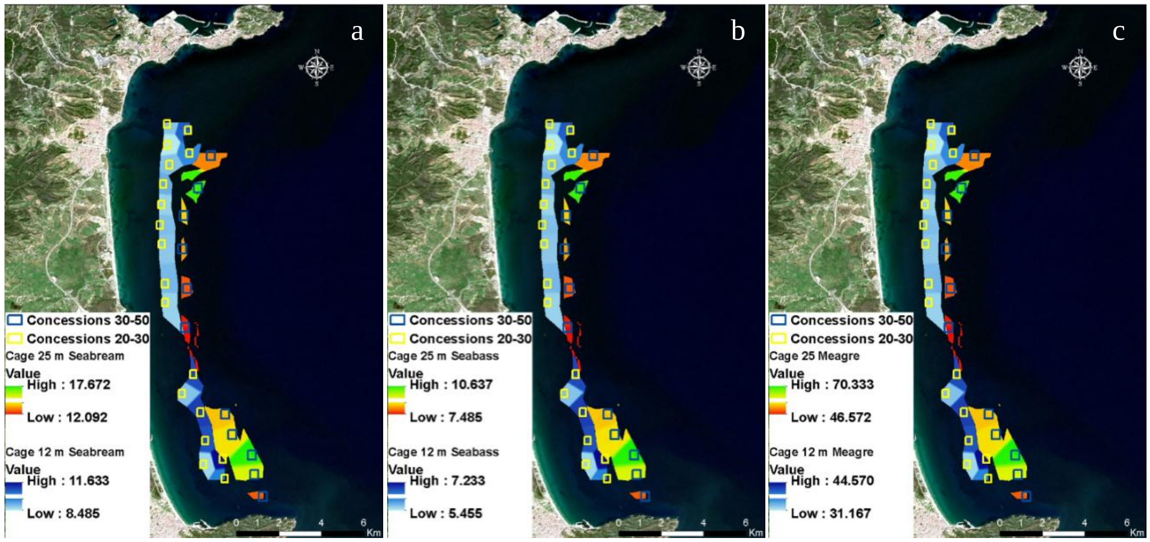

Fig. 10. Ecological carrying capacity suitability rating results: seabream farming (a), seabass farming (b) and meagre farming (c).

2.4. Social Carrying Capacity:

Classification based on used criteria (Table 11), provided suitability concessions ranking as shown in the Fig. 11. According to these results, the lowest suitable concessions are in the far north of the bay and the highest suitable fish farms concessions are all located in central and the south parts of the bay.

Based on these results, the assessment of the five considered scenarios in terms of market limits has defined production quantities levels from 3,000 to 6,000 tons where the minimum case is composed of 5 concessions for farms producing 200 tons and 4 concessions for farms producing 500 tons (Fig. 12a) and the maximum case composed of 10 concessions of 200 tons and 8 concessions of 500 tons (Fig. 12b). These two cases represent in terms of space exploitation respectively 0.67% and 1.41% of the whole bay surface and about 4.15% and 8.67% of the selected suitable area.

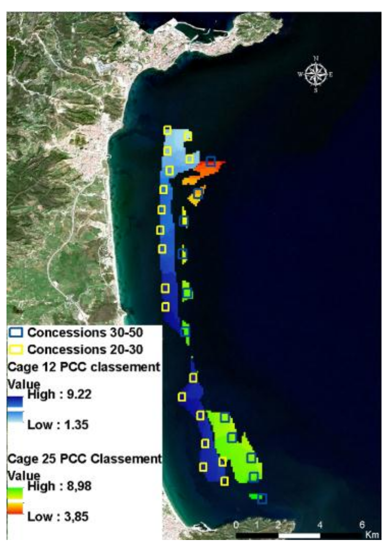

Fig. 11. Social aspect level concessions classifications.

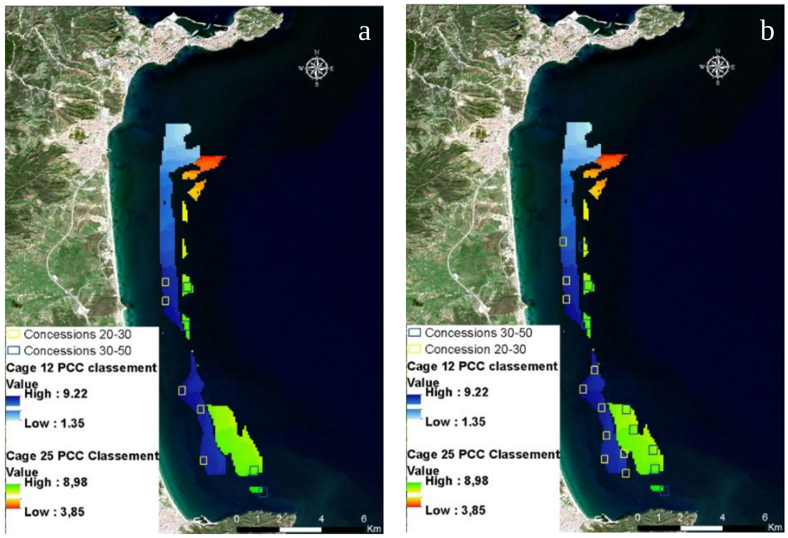

Fig. 12. Minimum (a) and maximum (b) economic (market) limit in terms of suitable fish farming concessions that could be supported by the bay characteristics.

Moreover, considering the socio-economic characteristic, the area extended from the central part of the bay to its almost all south part was judged as not potential for fish farming purposes, particularly for being considered a specific restricted area by local authorities in which allowed activities are strictly limited to nautical tourism, water sport activities and artisanal and sport fishing. Basing on these considerations, all corresponded concessions are cutting off and the resulting suitable fish farming concessions map is illustrated in the Fig. 13.

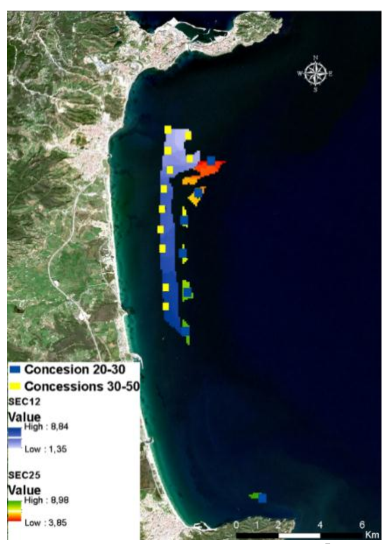

Fig. 13. Suitable fish farming concessions potential on socioeconomic level

These latest results were assessed in terms of likely marketing risks following the said five scenarios. As shown in Table 17, the lowest risk value (5.88%) was presented by the scenario based on the whole sale to the domestic market (100L) while the highest risk (35.71%) was shoed by the scenario wholly based on international market (100IN).

Table 17. Market Risk Results

Scenario	Results
100 L	5.88%
100 IN	35.71%
75IN50L	23.53%
50IN50L	26.67%
25IN75L	13.33%

So, targeting domestic market seemed to offer appropriate conditions to not affect investment and sustainability. Farmed fish production driven by 100L scenario could be suitable to mitigate market risks and presents appropriate opportunity to enhance sustainably local marine fish farm. When suitable marketing is established, farmed fish production could increase in a mastered way to explore other possible markets without generating significant risks and without being under the pressure of similar product at lower prices.

Moreover, policymakers and government support to fish farming development was evaluated as positive. In fact, some pertinent strategies were adopted by the government, such as the Halieutis Plan **(MMAMF, 2009)** and the Blue Belt Initiative **(Nguyen *et al.*, 2016)**.

Social perception of fish farming is adequate as indicated in Table 18. So, to enhance fish farming development as a potential activity suitable to help increase fish supply and relieve fishing pressure on natural resources, authorities support is highly needed, particularly by creating the optimal condition to support the investment in fish farming in this area.

Table 18. Social indicators results

Factors	Positive	Neutral	Negative
Activity acceptance	87%	8%	5%
Consumption willingness	44%	50%	6%
Visual impact	6%	75%	19%
Impact to other activity	10%	63%	27%
Respond to job demand	90%	10%	0%
Contribution to national economy	85%	15%	0%
Sum	53.66%	36.83%	8.33%

Regarding these previous results, the final carrying capacity could be resulted to be the one obtained in the case of the100L scenario taking into account all considered aspects. So, final carrying capacity in terms of fish farming is estimated to be composed of for 2 fish concessions farms producing 200 tons and 5 fish concessions farms producing 500 tons with a total annual production capacity reaching 2,900 tons (Fig. 14).

These concessions have a total occupied space of 84 ha, representing almost 0.6% of the whole M’diq bay area.

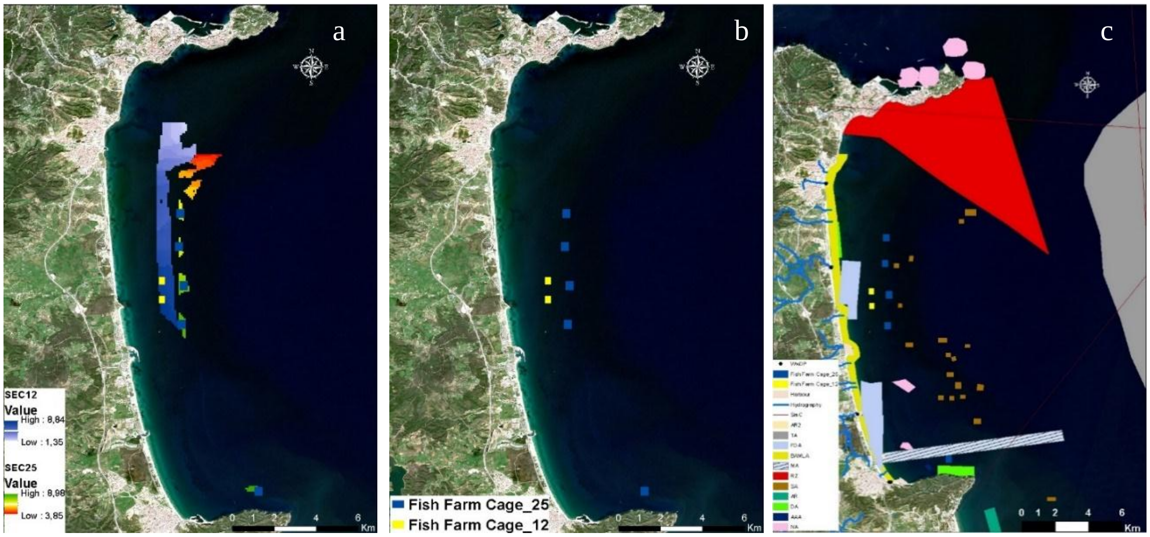

Fig. 14. Selected concessions next to Social Carrying capacity (a), Selected concessions in the bay (b), Selected concessions next to other activities spatial occupations.

DISCUSSION

The results obtained by this study, using GIS tool and SMCE combined with AHP, WLC and Percentile method, is very important. It represents an integrated way to contribute in local marine spatial planning to identify suitable areas with their carrying capacity assessment. Several studies used the same concept of site selection implementing different parameters and criteria (**Perez *et al.*, 2005**; **Nayak *et al.*, 2014**; **Dapueto *et al.*, 2015**; **Brigolin *et al.*, 2017**; **Gimpel *et al.*, 2018**;). Then, the selected suitable areas were submitted to carrying capacity concept through its four dimensions evaluation following some key indicators described in **Byron and Costa-Pierce, (2013)** and **L.G. Ross et al, (2013)**. In fact, fish farming carrying capacity at the local level is not widely studied in the Mediterranean Sea.

One the most important aspect of the present study is the use of satellite and field data. Moreover, we found a very high correlation between these two types of data. So, in case of lack of field availability data, it could be very suitable to use Remotely sensed data. However, more work in needed in terms of comparison and correlation between these two types of data, particularly at local level and high resolution of satellite data and very deep sampling network of oceanographic data.

The present study focused on site selection for fish farming in M’diq bay and carrying capacity evaluation through different ways according to each of its four dimensions. The application of the percentile concept is a new way to assess the physical risk that can affect negatively the sustainability of fish farms while the ecological carrying capacity was based on multiple tools to estimate the environmental acceptance of fish biomass that can be produced. There are surely many methods to assess the ecological carrying capacity based on multiple integrated tools to calculate the environmental limits **(Stigebrandt, 2011; Tett *et al.*, 2011; Ibarra *et al.*, 2014; Middleton *et al.*, 2014; David *et al.*, 2015)**, basically because of the existence of a high pressure exercised on the marine ecosystem. The distribution of waste feed and faeces are generally more considered in fish farming and they can be approved by more performed suitable software (which are generally are not open access). Furthermore, the study of the sediment assimilative capacity as it was described in **Bravo and Grant, (2018)** will be useful support to the carrying capacity evaluation, particularly in the case of the increase of the farmed fish production amount from the lowest limit (3,000 tons) to the highest limit (6,000 tons) in selected concessions in the M’diq bay.

The social carrying capacity (SoCC) is the most delicate one comparing to the other three carrying capacity dimensions as it depends on other limitative and regulatory constraints such as population acceptance and the need to find a compromise between stakeholders, decision-makers and the environment. Moreover, many authors reported that SoCC is the most complicated carrying capacity type comparing with the others three types; it should highlight the social issues which prevail on the others carrying capacity dimensions (**Dempster and Sanchez-Jerez, 2007; Mckindsey, 2012**).

In general, aquaculture is seen as an activity that could realize many achievements for humanity as the positive contribution for achieving food security, guaranty a sustainable economic growth and participate in the conservation and the sustainable use of marine resources (**KATRANIDIS *et al.*, 2003; Brugère *et al.*, 2019; Smaal and van Duren, 2019**). The funding of this study is on the same direction with this concept, where fish farming activity is locally seen as a promising activity that can generate beneficial energy to the studied region.

The implementation of the four carrying capacity components in fish farming sites selection has then strengthen the integration of selected sites and allowed to define limits of sustainable exploitable area between 97,12 ha (almost 100 ha) as a minimum limit and 194,24 ha (almost 200 ha) as a maximum limit that can be accepted in M’diq bay under the current local conditions. These both fish farming area limits represent respectively 0.7% and 1.4% of the whole bay surface. These sea space exploitation ratios are very weak and then very interesting keys to emphasize local aquaculture development. It is important to note that the adopted approach for site selection in the present study was very limitative and then includes many restrictive considerations to ensure fish farming sustainability and local environmental preservation. However, the finding in terms of fish farming exploitable area could be increased if some of the considered parameters will change, mainly regarding two essential aspects, the local market demand which could increase and the position of the stakeholders who could make some compromises in terms of reconciliation between socio-economic development and environmental preservation.

CONCLUSION

The present study has shown that it is possible to use satellite data as useful and key elements in aquaculture planning as emphasized by many studies **(Longdill *et al.*, 2008; Aguilar Manjarrez *et al.*, 2010).** Remote sensing is an important approach for developing countries and data-poor regions, which promote more logical decision-making. Coupling GIS tools with Carrying capacity approaches can offer a more acceptable activity and a better-integrated practice, guaranteeing the balance between profitability and the ecosystem without forgetting the social concept.

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