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RESEARCH ARTICLE

Physical carrying capacity of a potential aquaculture site in the Mediterranean: the case of Sigacik Bay, Turkey

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Abstract

The aim of the present study was to evaluate physical carrying capacity of a potential cage aquaculture site near a Cittaslow area in the northern part of the Mediterranean (Sigacik Bay, Turkey). Developing tools for timely management of marine aquaculture facilities are important to minimize harmful influences of fish farming. The physical carrying capacity was estimated by mathematical formulations previously developed for the same area, using data of topographical characteristics of the site, production capacities, and leased area information of fish farms in total. Based on the findings of the present study, estimated physical carrying capacity of the potential aquaculture site with a total area of 38.9 ha near the Cittaslow residential area of "Sigacik Bay" was found as 27,694 tons of fish production which is more than 2-fold of the present production level that is around 11,800 tons in the area. Therefore, it might be concluded from a physical point of view that the production level of the present cage farms in Sigacik Bay is below risk levels.

Keywords Aquaculture management · Cage aquaculture · Physical carrying capacity · Cage farming · Cittaslow

Introduction

The world aquaculture industry is providing high-quality food for the increasing world population expected to reach nearly 10 billion in 2050 and 11.2 billion in 2100 (UN-WPP 2017). Hence, meeting the demand for food fish of the increasing human population with food security is an important challenge for the aquaculture industry. Conflicts of coastal zone users and environmental concerns triggered the move of cage farms to exposed offshore areas with more extension opportunities in terms of surface area lease. As a reliable food sector providing high-quality protein for human consumption, fish farms are facing new challenges in terms of social and environmental pressure. Conflicts between fish farms and other coastal zone users such as the tourism sector evoke further considerations of "site selection", "carrying capacity assessment" and "administrative bureaucracy". Site selection for aquaculture is dependent on many factors such as water quality standards for fisheries, sea water quality standards, environmental influences from coastal sources such as agricultural effluents or touristic facility wastes, water drainage and discharge standards for marine aquaculture, marine-protected areas, and environmental impact assessment (Ross et al. 2013; Zhu and Dong 2013). Therefore, it is important to understand the ecosystem approach to aquaculture while managing the demands for production. For ensuring sustainable aquaculture, ecological and social interactions are to be considered and analyzed carefully. Thus, carrying capacity of a specific marine site has become an important concept for ecosystem-based management since 1960s (Weitzman and Filgueira 2019). While early studies have focused on increasing the production capacity at maximum levels, ecological capacity has started taken attention after 1980s (Weitzman and Filgueira 2019). As McKindsey et al. (2006) stated,

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carrying capacity concept can be divided into four types. Namely, (a) physical carrying capacity considers water quality and availability, hydrography, and water access; (b) production carrying capacity deals with optimization of production yield and species growth; (c) ecological carrying capacity tries to minimize environmental impacts, while (d) social carrying capacity aims to reduce social conflicts and tries to measure social acceptance (Ross et al. 2013; Weitzman and Filgueira 2019).

Not only economic benefits but also environmental risks are to be considered by decision makers for new site selection, approval of new farm deployments, or eventually reducing the number of fish farms in a certain area for meeting social concerns. Hence, sustainable development of cage aquaculture can be implemented only through the control of farm loads. The term "carrying capacity" can be explained as the assessment of production potential without significant impacts on the aquatic environment (Beveridge and Phillips 1993; Beveridge 1996; Kautsky et al. 1997). As a matter of fact, "how far can cage farms extend their operations without significant impacts on the marine environment?" This is a prediction that needs long-term measurements and environmental monitoring of the marine area. However, when necessary measures are to be taken in rather short time frame, practical reliable tools may help to evaluate the potential culture area in terms of maximum production capacity with minimum influences. This may help timely management of marine cage farms in locations with relatively higher concerns and social pressures due to both slow philosophy and tourism.

The present study deals with the physical carrying capacity of a potential aquaculture site allocated for cage farming off the coast of a Cittaslow area in the Mediterranean, which can be a good example for marine sites with similar conditions in the whole Mediterranean region in terms of harmony and consensus of cage farms with well-informed social awareness.

Materials and methods

Study area and coordinates of fish farms

The "Potential Aquaculture Site No: 9" (PAS-9) allocated for cage farming in Sigacik Bay by the Ministry of Environment and Urban Development has been selected as the study area as an example site with rapid growth of cage farming activities in the Mediterranean. Geographical locations with coordinates for the cage farms deployed in the area have been given in Fig. 1. Annual production capacities along with leased surface area for each fish farm are shown in Table 1.

Specific conditions of the study area

Sigacık Bay, located near the Cittasflow town of Sigacik (Izmir-Turkey), is known as the first coastal town in the Cittaslow movement opposing from look-alike cities of globalization in the Mediterranean. The residential area is well known with its touristic reputation, slow philosophy, and home-made local food production. The so-called ecological life-trend in the area remarkably increases social pressure on cage aquaculture activities in this region. The study was carried out during the summer period in Sigacik Bay, off the Cittaslow area of Sigacik town, and water quality parameters of temperature, salinity, dissolved oxygen (DO), and pH were measured as 24.29 ± 0.47 °C, 31.29 ± 0.08‰, 7.20 mg/L (98.3%), and 8.20 ± 0.02, respectively, in August 2018.

Production systems and capacities in the aquaculture area

There are totally seven fish farms active in the bay, among them "Farm 1" is a Bluefin tuna (*Thunnus thynnus*) fattening farm, whereas remaining six farms (farms 2, 3, 4, 5, 6, and 7) gilthead seabream (*Sparus aurata*), and European seabass (*Dicentrarchus labrax*) producers. Water depth of the marine area where cage farms are deployed outstretches from 40 to 80 m with a gentle slope. Gravity-type cage systems constructed by high-density polyethylene (HDPE) pipes as main floatation rims are used in the area. Each cage is secured with 8 bridle lines connected to 4- to 8-m submerged grid systems. All cage farms producing seabream and seabass use double floatation pipes as the main floating rim, except the Tuna cages which consist of single pipe floatation as the main upper rim, connected to submerged grid collectors anchored to sea ground with deadweights.

Estimation of physical carrying capacity

The physical carrying capacity of the potential aquaculture site No: 9 in Sigacik Bay (PAS-9) was estimated using mathematical formulations provided by Karakassis et al. (2013), as also reported by MEUP (2015) and Macias et al. (2019) as a rapid model that can be applied for estimating the physical carrying capacity in marine sites of the Mediterranean with similar water conditions and production managements of similar fish species such as gilthead seabream or European seabass. Both Greek (Karakassis et al. 2013; Macias et al. 2019) and Turkish legislations (MEUP 2015) set for fish farming in the Mediterranean follow similar parameters for the estimation of physical or production carrying capacity in allocated aquaculture sites in the Mediterranean Sea. These parameters are water currents, water depth under the cage systems, distance from the shore, the exposure of the farm site, or the current speed along with the total area that allocate for aquaculture in the area with cage farm systems.

The distance of the bay-opening with basic topographical axes and dimensions of Sigacik Bay used for physical carrying capacity estimations are presented in Fig. 1.

Table 1 Annual production capacities and operation surface area in the potential aquaculture site No: 9 of Sigacik Bay with four-point coordinates of each cage farm

	ED50-UTM 6°					
	UTM-E (Y)	UTM-N (X)	Distance from shore (m)	APC (ton/year)	TLSA (m^2–ha)	Cultured fish species
Farm 1	469046.600	4226410.100	4255	2000	52,200–5.22	SBR + SB
	469387.300	4226526.300				
	469434.100	4226389.000				
	469093.400	4226272.800				
Farm 2	468978.600	4227231.500	1240	950–2000	40,000–4.00	SBR + SB
	469151.100	4227536.000				
	469241.700	4227466.800				
	469072.700	4227161.000				
Farm 3	469246.700	4225402.700	1281	2000	64,000–6.40	SBR + SB
	469700.600	4225621.950				
	469755.400	4225508.300				
	469301.500	4225289.300				
Farm 4	469861.400	4227105.700	3846	950	33,800–3.38	SBR + SB
	470098.000	4227213.400				
	47051.900	4227095.100				
	469915.557	4226987.128				
Farm 5	471110.500	4224508.700	1226	900	39,200–3.92	BFT
	471189.400	4224777.400				
	471323.700	4224737.900				
	471244.800	4224469.300				
Farm 6	467390.500	4220416.200	1150	2500	91,785–9.18	SBR + SB
	467848.500	4220416.100				
	467851.300	4220216.100				
	467392.900	4220216.100				
Farm 7	469273.200	4222566.500	1240	2500	68,000–6.80	SBR + SB
	469473.200	4222568.900				
	469477.300	4222228.900				
	469277.300	4222226.500				
Total farms (1 to 7)			2034 (*average*)	11,800	388,985–38.90	∑(SBR + SB + BFT)

The environmental legislations in Turkey do not allow deployment of cage farms in a distance less than 0.6 nautical miles (1.11 km) from the shore

UTM Universal Transverse Mercator coordinate system, *UTM-E* UTM easting, *UTM-N* UTM northing, *APC* annual production capacity, *TSA* total surface area, *SBR* seabream, *SB* seabass, *BFT* Bluefin tuna

The physical carrying capacity as tons per hectar (t/ha) was estimated according to:

(a) Distance from shore
(b) Water depth (between cage bottom and seabed) and
(c) Exposure of the farm site using the following equations:

$$\text{Estimated physical carrying capacity (EPCC)} = [(150 + 80) \times (S{-}1)] \times [\text{disC} \times \text{depC} \times \text{expC}] \quad (1)$$

where

S	surface area (ha) of the cage farm site
disC	distance coefficient
depC	depth coefficient
expC	exposure coefficient or topographical openness factor

Since the distance to shore and depth under the fish farms in the study area were more than 1000 m (> 1000 m) and 50 m in average (> 50 m), respectively, the distance coefficient (disC) and depth coefficient (depC) were used as 4.2 and 3.96, respectively, as specified for the specific conditions in the formula of Karakassis et al. (2013). The openness coefficient (expC), also known as topographical openness factor (TOF), has been calculated according to the following formulation:

$$\text{The topographical openness factor (TOF)} = [\text{OD}/(\text{A1} + \text{A2})] \times [\text{OD}/(\text{L1} + \text{L2})] \quad (2)$$

where

OD	opening distance, the narrowest opening distance of the bay towards the open sea area
A1 + A2	sum of the basic topographical axes of the designated bay
L1 + L2	sum of distances from two points of bay-opening straight forward to the center point of cage farms

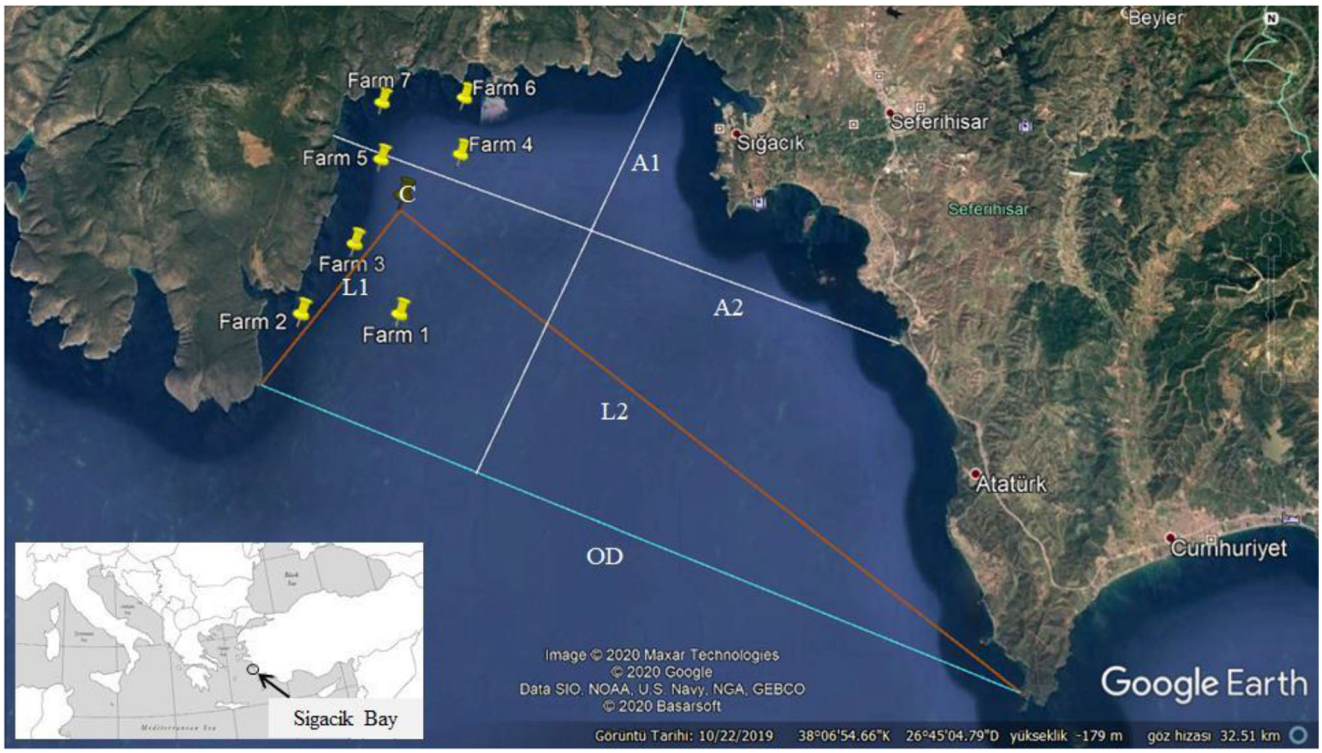

Fig. 1 Locations of cage farms in the potential aquaculture site No: 9 of Sigacik Bay, Turkey. OD: narrowest opening distance of the bay towards the open sea area; A1 and A2: basic topographical axes of the bay; L1 and L2: span from two points of bay-opening to center point of the cage farms. Coordinates in UTM (Universal Transverse Mercator coordinate system), farm 1: 470116.0838 E–4220210.9259 N; farm 2: 467122.2940 E–4220184.5466 N; farm 3: 468532.5407 E–4222534.3679 N; farm 4: 471619.8786 E–4225680.9486 N; farm 5: 469096.8257 E–4225476.9129 N; farm 6: 471612.0547 E–4227747.5706 N; farm 7: 468950.2435 E–4227545.8488 N

Results

All cage farms within the potential aquaculture site of Sigacik Bay (PAS-9) were located in a distance of over 1150 m from shore. More than 71 % of these farms were deployed between 1100 and 2100 m off the coast, while around 14% were located between 2100 and 4100 m, and the rest over 4100 m off the coast line. Total area leased was 388,985 m^2 (38.90 ha) with a minimum lease of 3.38 ha in PAS-9 of Sigacik Bay. Over 57% of total cage farms in the bay expanded in a marine area of 3–6 ha, whereas 28.57% of the farms outstretched in an area of 6–8 ha. The rest operated within 9–10 ha of marine surface. All farms in PAS-9 presented an annual production capacity of over 900 tons per year. Around 28% of the total cage farms presented capacities between 900 and 1000 tons per year, whereas 42.86% showed a production capacity between 1000 and 2500 tons and the remaining 28.57% between 2500 and 3000 tons per year.

Based on topographical characteristics, production capacities, leased area data for the Mediterranean aquaculture site PAS-9 in Sigacik Bay, topographical openness factor (F) was estimated as 0.5233 and physical carrying capacity for the total maximum production was found as 27,694.62 tons/year (Table 2).

Estimated physical carrying capacity of 27,694.62 ton/year represents the maximum production limit possibly without potential risks caused by farm activities in the allocated aquaculture site No: 9 in the Mediterranean (Sigacik Bay). In terms of physical carrying capacity estimations, it could be noted that the fish farms outstretched in an area of 38.9 ha are operating below the estimated annual production level of 27,694 tons per year, which in fact is twice than the present annual production of 11,800 tons for the seven commercial cage farms operating in the area.

Discussion

Estimations for physical carrying capacity of the investigated potential aquaculture site in the northern outreach of the Mediterranean (Sigacik Bay) followed the mathematical model provided earlier by Karakassis et al. (2013), MEUP (2015), and Macias et al. (2019), an extrapolative intuitive estimation method based on a system of factors that calculates the maximum allowable production level depending on characteristics such as water depth below cage farms, distance from shore, and exposure specifications of the designated marine environment of the production area.

Table 2 Parameters and estimated physical carrying capacity in Sigacik Bay (potential aquaculture site No: 9)

Parameter	Value
∑S Total surface area leased (ha)	38.9
DFS Distance from shore (m)	> 1000
AvD Average depth (m)	60
disC[a] Distance coefficient	4.2
depC[a] Depth coefficient	3.96
OD Narrowest opening distance of the bay towards the open sea area (m)	23,588
A1 Basic topographical axes of the designated bay (m)	16,013
A2 Basic topographical axes of the designated bay (m)	19,160
L1 Distances from two points of bay opening to left point of farm site (m)	6906
L2 Distances from two points of bay opening to left point of farm site (m)	23,321
APC Annual production capacity (∑farms 1–7, tons/year)	11,800
TOF[a] Topographical openness factor (exposure or openness coefficient, expC)	0.5233
Present production capacity (tons/year)	11,800.00
Estimated physical carrying capacity (tons/year)	27,694.62

[a] According to Karakassis et al. (2013), calculated as TOF (exC) = [23,588 m / (16,013 m + 19,160 m)] × [23,588 m / (6906 m + 23,321 m)] = 0.5233; estimated physical carrying capacity (tons/year) = [150 + 80 × (38.9 ha^{-1})] × (4.2 × 3.96 × 0.5233) = 27,694.62 ton/year

Environmental legislations for cage farming can vary among countries all over the world (Henderson and Davies 2000; Hansen et al. 2001; Pulatsü 2003; Nguyen et al. 2013a, b; Zhu and Dong 2013; Campuzano et al. 2015; Neto et al. 2016; Bueno et al. 2017; Rahman et al. 2017; Budiasa et al. 2018; Simanjuntak and Muhammad 2018). Official rules in Europe require "Environmental Impact Assessment (EIA)" reports (Macias et al. 2019) for receiving license approval for aquaculture business; however, it seems that ecosystem quality standards are still not well established (Karakassis et al. 2013). Further, different estimation methods are used for maximum production levels in different marine sites and tools for environmental monitoring also differ between countries or even different regions within countries (Yokoyama et al. 2004; Cai and Sun 2007; Holmer et al. 2008; Karakassis et al. 2013; Neto et al. 2016; Bueno et al. 2017).

Considering the physical carrying capacity findings of the present study, increasing aquaculture production in the area from its present annual yield of 11,800 tons to 27,694 tons is likely not to pose any significant difference in the aquaculture allocated site of Sigacik Bay off the Cittaslow residential area. This corresponds to an increase of around 2.35-fold for the total of seven commercial farms in the allocated cage aquaculture area of PAS-9 and designates an estimated potential productivity possibly with no risks on the marine environment. However, this is an estimation that needs to be spelled cautiously, since a more explanatory assessment could only be made upon long-term measurements of the aquatic ecosystem including sea bottom sediment analyses and long-term monitoring of the marine environment. Nevertheless, the findings in the present study provide a quick estimation for farm managers or regional decision makers based on a rapid mathematical model. Earlier studies on fish production capacities in different regions in the world reported that even in the worst situations, water quality conditions were in a better status compared with legislative upper limits enforced in different marine systems of the world, for example in Scotland (Henderson and Davies 2000) or Japan (Yokoyama et al. 2004), and consequently, production levels of fish farms were far below environmental risks and did not seem to have exceeded the capacity of the marine ecosystem. Similarly, Nguyen et al. (2013b) also reported that increasing production to 2-fold over the present level for the fish cage site in Vietnam (Phu Quoc Island) would not reveal any environmental risk in terms of water quality.

Even though the physical carrying capacity estimation applied as a practical model in this study refers to a production level below limits and the bay still might tolerate a certain increase in production level. However, the area allocated for cage farming would benefit from further experimentations with long-term monitoring of water conditions along with biological parameters, and bottom sediment analyses in the specific aquaculture-allocated zone as well as the entire bay area. In a long-term monitoring study, Gürses et al. (2019) reported an "Eutrophication Risk Scala" less than four ($T <$ 4) around an intensive Bluefin tuna cage farm deployed within the borders of the potential aquaculture site of Sigacik Bay, that is the same area investigated in the preset study. Even though Gürses et al. (2019) concentrated on the specific area within the bay, namely a tuna cage farm, their findings in terms of biological evaluation in the potential aquaculture site PAS-9 support our findings for the physical carrying capacity

indicating that the production capacity is still below limits of environmental tolerance.

However, when necessary measures are to be taken in rather short time frame, practical and reliable tools may help to evaluate the potential culture area in terms of production capacity with reduced influences on the aquatic environment. This may help timely management of marine cage farming activities, especially near Cittaslow areas with remarkable social pressure on fish farms. Most residents in Cittaslow towns may quickly get into provoked anti-aquaculture protests, possibly because of the slow philosophy and influence of tourism activities. Hence, reliable and quick assessment of production capacities and ecological accordance is highly valuable for cage farms in order to show that these co-occurrences can be combined in harmony with common benefits following appropriate farm management. Therefore, the present study can be a good example for marine areas with similar conditions in the Mediterranean, when quick but reliable decisions are to be considered in order to calm social concerns and reduce anti-aquaculture acts against cage farms with good aquaculture practice in Cittaslow residential areas such as Sigacik Bay.

Conclusion

Based on the results of the present study, the total production capacity of fish farms in the allocated potential aquaculture site off the Cittaslow town-Sigacik is below acceptable limits according to physical carrying capacity estimations for the study area. Even though physical carrying capacity model applied in this study ratifies an increase of the production capacity to around 2-fold over the present level for the aquaculture-allocated potential production site in Sigacik bay without possible environmental risks in terms of water quality. However, long-term monitoring with biological investigation of water column and bottom sediments is encouraged to evaluate eutrophication risks through nutrient inputs from fish farms for a comprehensive assessment prior to capacity increase or expansion of fish farms with new cage deployments in the aquaculture-allocated marine sites for the sustainable and environment-friendly Mediterranean aquaculture industry.

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Authors' contributions Murat Yigit: Designed study, analyzed data, field experimentations, drafted paper (conceptualization, methodology, ınvestigation, experiment set-up and coordination, environmental and geographical data analyses, data curation, writing - review & editing, visualization, supervision)

Sebahattin Ergun: Designed study, analyzed data, field experimentations (resources, ınvestigation, experimental organization, environmental and geographical data analyses, project administration, funding acquisition)

Yesim Buyukates: Designed study, analyzed data, field experimentations, drafted paper (validation, methodology, environmental data analyses, resources, data curation, writing - review & editing)

Abdullah Suat ATES: Designed study, analzsed data, field experimentations (conceptualization, methodology, validation, data curation, field experimentations)

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request to authors with approval of funding organizations.

Compliance with ethical standards

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

Ethics statement No ethical committee approval is required for this study, since no experimental living organisms were used.

Informed consent Informed consent was obtained from all individual participants included in the study.

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