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RESEARCH PAPER

Numerical Investigation of the Impact of Onshore Fish Farming on the Western Coast of Algeria

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Abstract

A methodology for aquaculture site selection is presented using a combined hydrodynamic/nutritional model to predict fish farm wastes and dispersion, using the indirect fish waste estimation method, and the numerical model MIKE 21. This method can be used as a basis for assessment of the environmental impact of fish farms. The models were applied for a virtual inland fish farm to harvest 450 tons of sea bass in the west coast of Algeria. The results show that the fish farm effluents quantities and dispersion depends on the production cycle and size, the hydrodynamic parameters, as well as the food quantity and composition. The suspended waste, nitrogen and phosphorus are respectively the main contributors to the fish farm pollution. The current speed varies from 0.005 to 0.045 m/s, while the nitrogen and phosphorus concentrations reached 2.1 mg/L, and 0.03 mg/L respectively. This study allows the Algerian authorities to decide upon delivering fish farming permissions in the studied area, by identifying the suitability of the area for aquaculture, and predicting potential fish farm pollution. The use of numerical models in aquaculture could help reducing installation, water treatment costs and the environmental impact of fish farms by contributing to the sustainability of the activity.

Introduction

The global demand for fish has grown as the beneficial effects of seafood consumption are now proved (Lomolino et al., 2016). In general, seafood is appreciated for nutritional reasons due to high content of animal protein, low saturated fat concentration and the presence of omega3, and vitamins (USEPA) (2004). As fish represents 17% of the global population's intake of animal protein, aquaculture has been a fast-growing industry to fulfill an expanding sea food demand, particularly with the instabilities in catch proportion experienced this last decade (FAO, 2020).

With aquaculture's intensification, so-called "blue revolution", both its reliance and its impact on ocean are likely to increase, causing nutrient pollution near coastal fish ponds, water quality deterioration around sea-cages and the interaction with nutrient cycling in the underlying sediment (Wu, 2001).

Algeria has 1600 Km of coastline, which represents a tremendous potential for favorable fish farming sites. Nevertheless, some aquaculture systems, including sea cages, are difficult to implement due to the limited deep water sheltered bays, and the unstable character of the Algerian current (Arnone et al., 1990). The Algerian consumer trend shows a rising demand of sea bass which led the ministry in charge to provide incentives to aquaculture investors (MPRH, 2008). However, current regulations require a global economic, technical, and hydrodynamic study before fish farm implementation.

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Hence, selecting an appropriate site for the fish farm is the most important step in an aquaculture project. Moreover, recent advances in numerical modeling enabled the development of more sustainable designs and technologies for aquaculture.

Different models are used in aquaculture impact modeling (Kock Rasmussen et al., 2009). Cromey et al. (2009) studied the benthic effects of a large Atlantic cod farm in Shetland, UK, by using a model based on an existing salmon model. They found that the near-field sediments response to organic enrichment isn't excessive in terms of the biomass, and is comparable to salmon culture sites of similar scale in similar environments. Riera et al. (2017) developed a model using the particulate waste dispersion and benthic response to predict the environmental impact of offshore sea bream, sea bass and meager aquaculture in the north-eastern Atlantic. The results depicted a low percentage of lost pellets while a high rate of pellets was consumed by wild fishes and significant correlations between observed and predicted solid fluxes.

(Maar et al., 2018) used a 3D model to estimate spatiotemporal effects of two hypothetical offshore rainbow trout farms on water quality and sediments. The authors found that 21% of N and 16% P were transported to the surrounding water and the sediments were affected during the production period.

While nutritional models used in aquaculture are crucial in controlling farming operations, most studies concern rainbow trout, tilapia and offshore salmon farming. Modeling the environmental impact of both onshore and offshore farming starting from the feed process to the fish farm waste dispersion has gained interest among investors and decision makers all over the world. Several nutritional models have been proposed to estimate the fish farming waste and their environmental footprint (Bureau et al., 2003; Cho & Bureau, 1998; Davies, 2000; Hansen et al., 2001; Maar et al., 2018; Vaz et al., 2021). The use of combined nutritional and hydrodynamic models could provide an accurate feed management, improve the feed efficiency, and reduce feed waste in both onshore and offshore farming, thus improving fish farming sustainability.

The aim of this study is to assist aquaculture development in Algeria with proper site selection and farm size optimization using a predictive model able to simulate dispersion of fish farming effluents from a virtual farm. Coastal hydrodynamics modeling is carried out using MIKE 21 suites to estimate the dissolved wastes dispersion which leads to the prediction and the in-depth understanding of the interactions of aquaculture with local and regional environment hence, defining the scale and the quantitative and qualitative parameters for licensing new fish farms (Van Nes & Scheffer, 2005). In the present work, a complete description of the studied area including hydrodynamic data and boundary conditions and the virtual fish farm design including the biological fish cycle, the rearing tank characterization and the chosen fish species are given. The current nutritional model based on equations from literature using feed composition and quantity as inputs is presented (Papatryphon et al., 2005)

Materials and Methods

Site Selection

According to the Algerian ministry of fisheries and fishing resources, (MPRH, 2008) Ain Franin has been classified as an aquaculture activity area in 2008. It is located at 35°45'3'' N and 0°31'56.4'' W, near Oran on the western coast of Algeria (Figure 1). Its topography, type of soil (Boutiba, 2006) and the optimal physical and chemical parameters; temperature and acceptable pH, make it an appropriate site for fish farming.

Physical Parameters Data

Hydrodynamics farm simulation requires several physical parameters to properly assess the interaction between seawater hydrodynamic and aquaculture effluents. An annual collect of data is needed in order to generate the input files used in the simulation model. In this study, the hydrodynamic data was acquired from the Algerian Weather Center (L'office nationale de la météorologie) (ONM, 2015) (Figures 2,3,4).

Temperature

Temperature is a fundamental criterion in fish farm site selection because it affects the farmed species biological cycle and the environmental ecosystem (Valentini, 2016).The annual temperature of the studied area fluctuates between 15°C and 27°C, with a minimum annual temperature of 15.15°C, and a maximum of 27.2°C, with a pic registered in July 2016, these values correspond to the optimum temperatures for sea bass growth (Figure 2).

Wind

As Wind is a generator of waves and superficial currents, it represents an important parameter in coastal hydrodynamic studies. According to the ONM compass rose (1990 - 2010) (Figure 3), the winds blow in different directions with a prevalence of west, north/east and southwest wind directions, namely: 1) West with 37% frequency, 2) Northeast with 27% frequency, 3) Southwest with 16% frequency. (ONM, 2015).

Sea Surface Elevation

Sea surface elevation, also called Sea Surface height (SSH) is affected by moon tidal and sun forces. The SSH used in this study corresponds to the period from January 2016 to June 2017 (Figure 4). Water level, ranging from - 0.50 to - 0.20 m, is used as a boundary condition for the hydrodynamic model. Tidal water level variations are low in Oran bay. The astronomical tide is microtidal and semi-diurnal.

Species Selection

European sea bass (*Dicentrarchus labrax*), stands among the most fished and farmed species in the Mediterranean Sea (Lomolino et al., 2016). In Algeria, sea bass farming have been successfully experimented in the early nineties (Lacroix, 1996). In order to model farm effluents and study their impact on the environment, it is necessary to understand fish metabolism and fish excretion quantity. Fish is an ammoniotelic organism as it excretes nitrogenous wastes primarily as ammonia while consuming oxygen and food.

Farm Design

In the nutritional analysis, all stages of farming have been taken into account. A farm with a base intensive production rate of a 450 tons / year, is

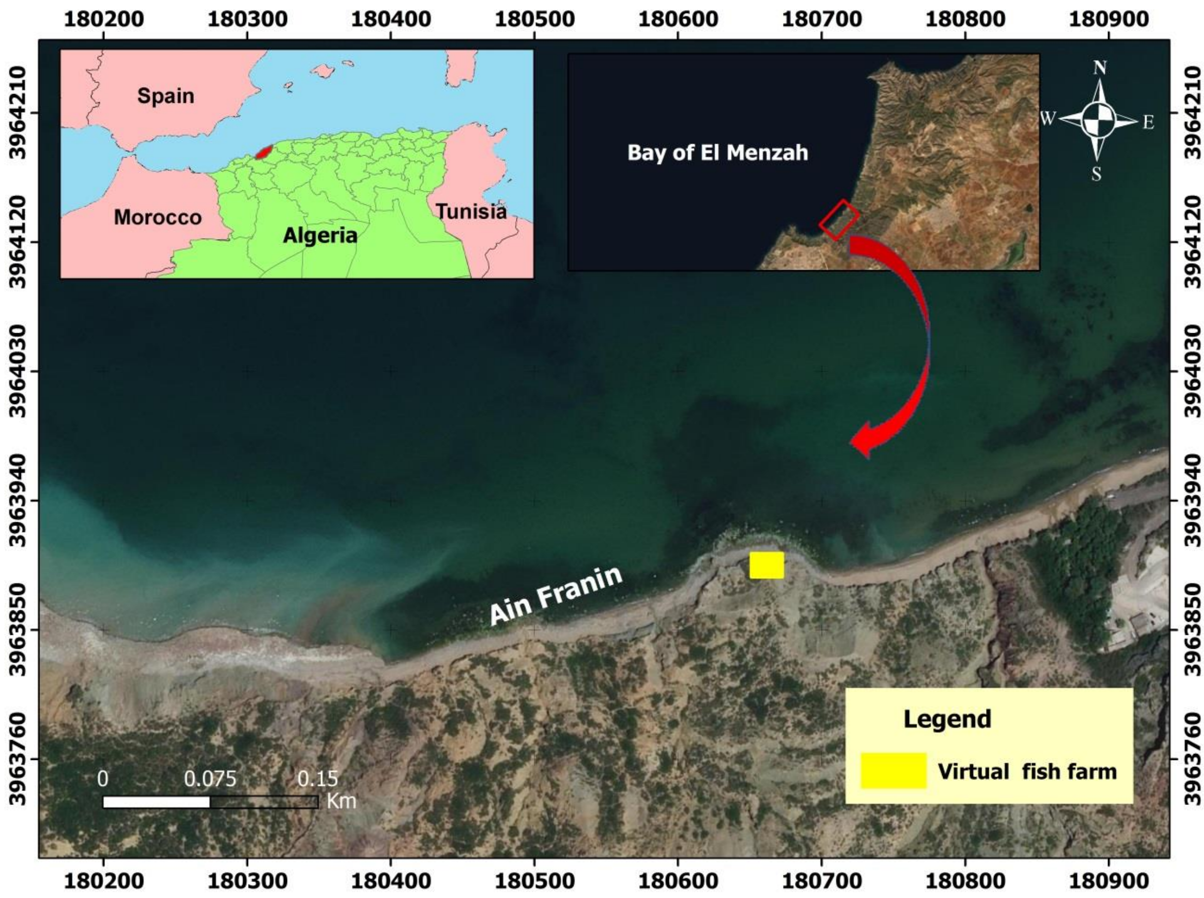

Figure 1. Location of the study area.

Figure 2. Temperature range of the studied area (April 2016-June 2017). (ONM, 2015).

considered using onshore Foster-Lucas tanks (Burrows & E. Chenoweth, 1955) in order to maximize fish production (Table 1). The tank choice is based on the quantity of harvested fish and resources availability. The complete fish farm design is shown in Figure 5. Fish tank dimensions were estimated according to the FAO (Food Agriculture Organization) norms, wish recommends a depth greater than 1.2 m, and a length / width ratio greater than 5 (Seltz, 1986) with a maximum biomass charge of 25 kg/m^3. Therefore, a production of 450 tons requires 27 tanks, the outlet water is evacuated to the sea after being filtered using a sand filter (30% efficiency rate).

Feeding and Nutritional Data

The nutrient load from the fish farm to the seawater was estimated using an in-house code based on the indirect method elaborated by (Papatryphon et al., 2005) Papatryphon et al. (2005) and simplified by Emmanuelle Roque Orbcastel et al (Emmanuelle Roque d'Orbcastel & Yves Moutounet, 2008). The simulated fish farm is assumed to use the Gouessant® fish feed (Legouessant, 2019). This extruded food, which is considered for its higher digestibility and stability, also provides an important reduction of extracted nutrients in the water column (Lazzari & Baldisserotto, 2008).

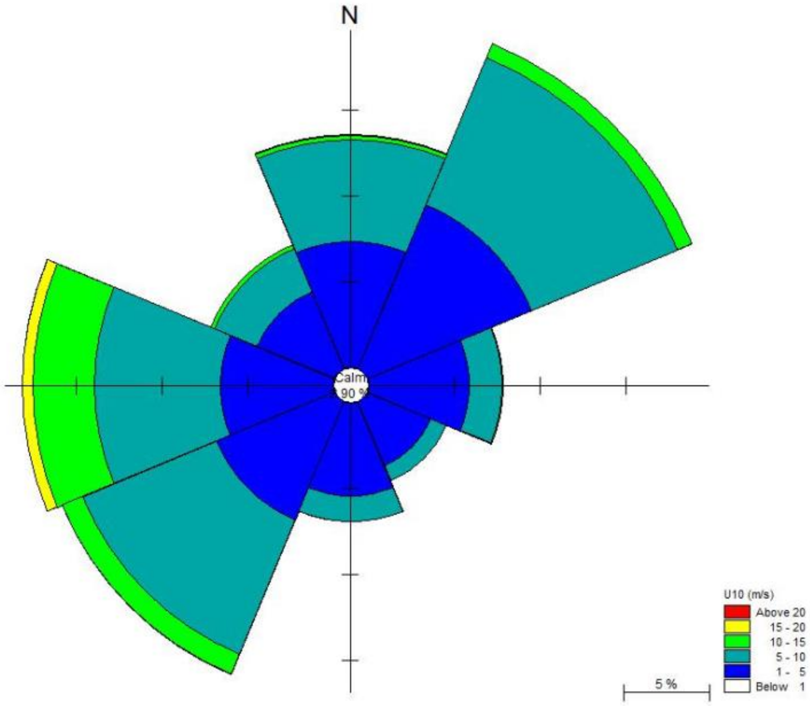

Figure 3. Compass rose (1990 - 2010) of the studied area. (ONM, 2015).

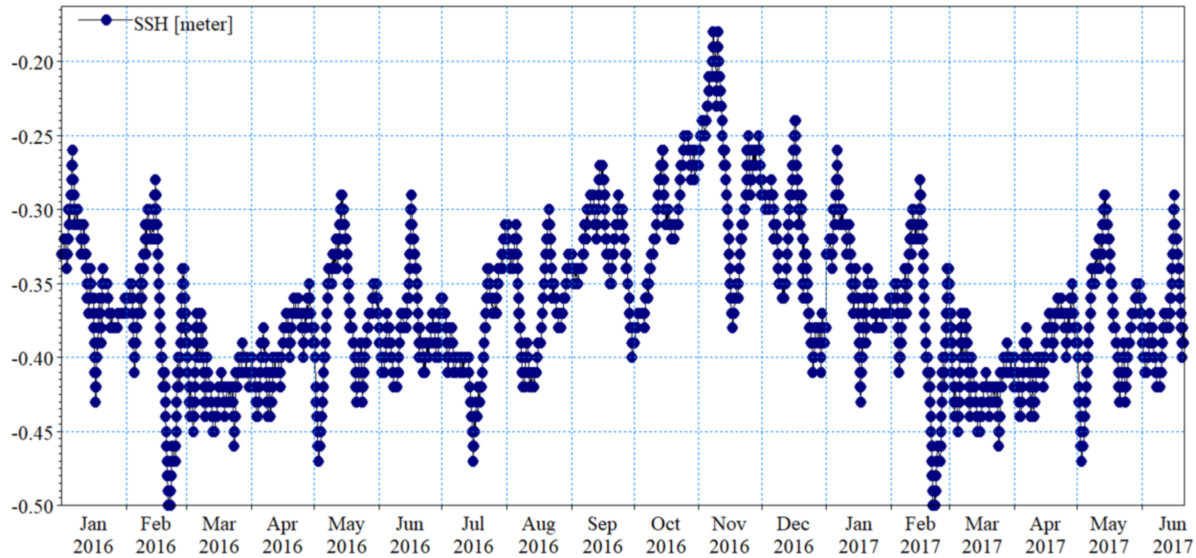

Figure 4. SSH range of the studied area (April 2016-June 2017). (ONM, 2015).

Food quantity is calculated according to the feeding tables provided by the manufacturer. The average temperature and the fish weight defining the rearing phase is considered. The food distributed quantity increase with the temperature and depends on the fish weight.

The feed composition and digestibility coefficient provided by the manufacturer are shown in Figure 6a, Figure 6b) (Legouessant, 2019). Comparing to conventional foods, this food contains less cellulose and ash, while it remains rich in proteins, with 47% and 43% for the early-growing and the on-growing fish respectively. The apparent digestibility coefficients used in the effluent estimation suggest that fat has the highest digestibility coefficient (95%) followed by proteins with 90%, while cellulose and ash are the less digestible by sea bass. In this study, feed ratio and uneaten food percentage are theoretically assumed to be 1.9 and 5% respectively. The biological cycle of the selected species is required to understand the food metabolism, including consumption and excretion (Table 2).

Hydrodynamic Model

MIKE 21 Flow Model is a numerical code developed by DHI (The Danish Hydraulic Institute's) (DHI, 2013)®, it has been used in a large number of studies; (Liang et al., 2017; Pritchard et al., 2013; Zavattero et al., 2016; Zhang et al., 2017). As MIKE 21 is a set of different modules simulating hydraulic and environmental phenomena in different area, the integrated modeling of hydrodynamics, transport and spectral waves are performed in the studied area using the numerical model MIKE 21/3 Coupled Model. The latter was chosen because the study area is relatively shallow.

Model Setup and Boundary Conditions

MIKE 21 HD accounts for two types of primary boundary conditions, namely; surface elevations and flux densities (Table 3). The studied area encompasses the Ain Franin near shore zone and has one open boundary, where the effect of earth rotation hasn't been included and the Coriolis parameter has been switched off in the numerical model.

Table 1. Characteristics of a FOSTER-LUCAS tank

Tank	
Length	70 m
Width	7 m (L/W>5)
Water flow (inlet)	45L/s
Water renewal	200%
Filtration efficiency	30 % (theoretical)

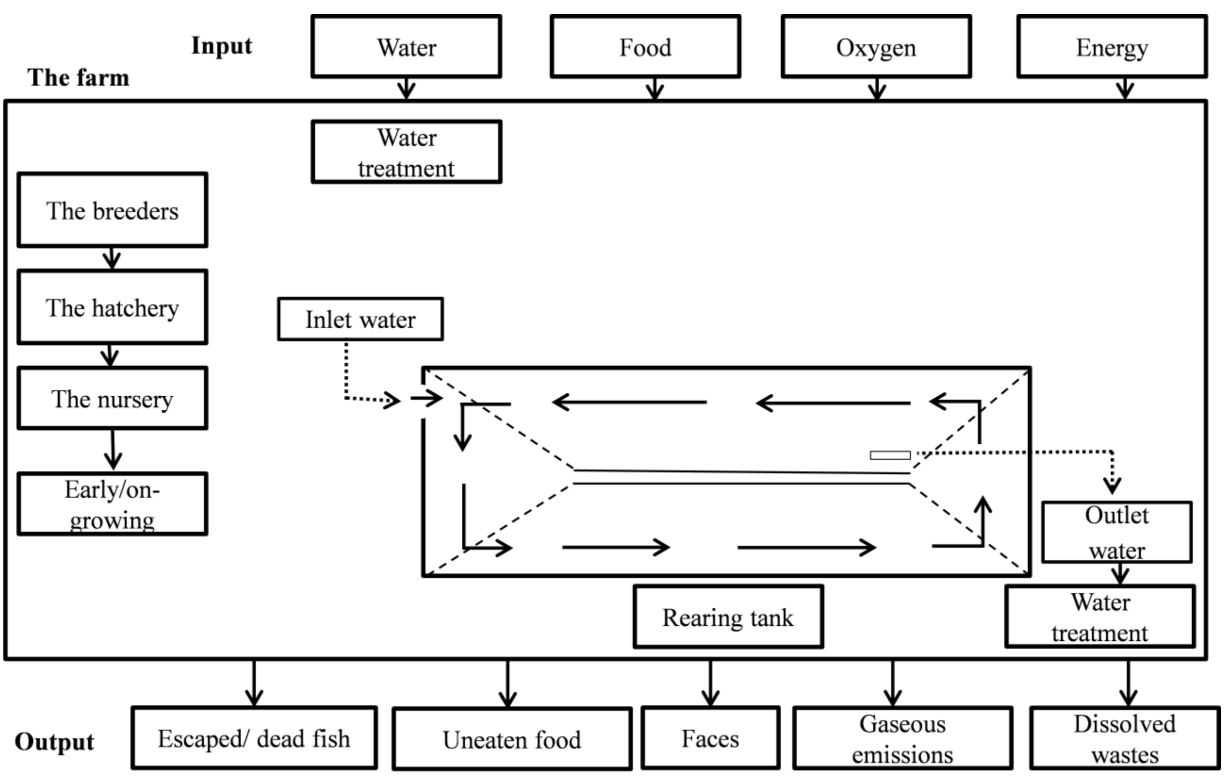

Figure 5. Farm dynamics system adapted to the studied farm.

Mesh Generation

The simulation domain was divided into regional and local areas, in order to refine the mesh in the vicinity of the farm discharge thus alleviating the computational burden. Georeferencing of the area chart and the bathymetries were defined by using the geodetic coordinate system UTM 30. The simulation model was run for 15 months, which covers the early and on-growing fish production cycle (with different fish feed composition and quantities), with a time step Δt = 3 h, based essentially on the hydrodynamic data interval at the studied area.

MIKE 21 uses triangulation for mesh generation (DHI, 2013), resulting in 3294 elements and 1762 nodes. A sigma vertical coordinate system with 10 layers' equidistant distribution (1 m) was used. The progressive mesh refinement from the far field to the shore is depicted in (Figure 7). Further refinement is carried out close to the farm in order to capture the effluent dispersion.

Validation Data

Hydrodynamic and nutritional results were validated against satellite altimetry data, downloaded from the E.U. Copernicus Marine Service Information; <https://doi.org/10.48670/moi-00141, https://doi.org/10.25423/cmcc/medsea_multiyear_bgc_006_008_medbfm3>. These values are the initials nutrients concentrations in the seawater and correspond to the modeling period under investigation. The simulation nutritional results were also validated against *in-situ* measurements from the literature.

Inputs and Outputs

The inputs and outputs of the model are summarized in Table 3. For the scalar model, settling velocity and the horizontal/vertical dispersion were taken from the literature (Asunción Piedecausa et al., 2009; Magill et al., 2006; Riera et al., 2017). The spectral waves (SW) model is using the hydrodynamic results as inputs to provide the different wave parameters.

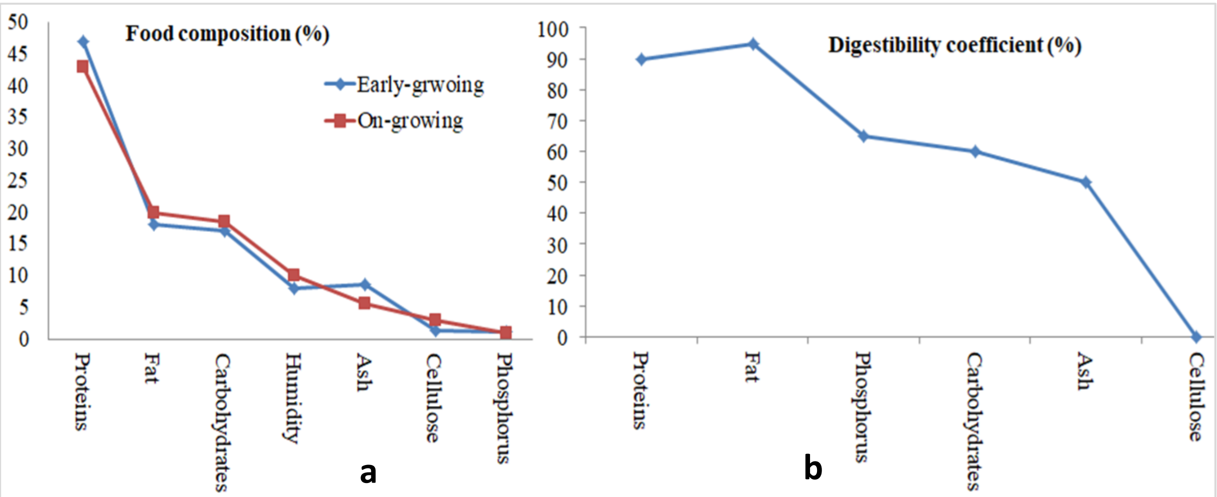

Figure 6. Nutritional data (a): Food composition, (b): Digestibility coefficient. Legouessant (2019).

Table 2. Biological cycle of the selected farmed fish

Phase evolutionary stage	Timing	Weight/size	Food quantity	Rearing tank/storage density
Artificial breeding Hormonal injection (HCG)	Mid-December	♀ 30.1 cm ♂ 23.5 cm ♀ 1.3-6 kg ♂ 0.7-2.5 kg	/	Tank (20m³) 3 kg/m³
Incubation Hatching	End December	/	/	Cylindro-conical tank (40L) 6000Ø/L
Nursery	January-March (3 months)	1g - 5 g to weaning	Rotifers/nauplii (5prey/ml)	Cylindro conical tank (50 m³) 10 kg/m³
Early-growing	April-January (10 months)	10g - 30 g 30g- 50 g 50g - 150 g	14,7 kg/day 23.1 kg/day 49.8 kg/day (per tank)	Foster-Lucas 25kg/m³
On-growing	February- June (5 months)	150g- 300 g	147 kg/day (per tank)	

Results and Discussion

The studied area bathymetry was generated by the MIKE Zero module. The local bathymetry indicates that the isobaths are relatively regular with a smooth slope in the west toward - 72 m (Figure 8a), the extended bathymetries show an increasing depth layers from the coastline to the open sea, bathymetry in (Figure 8b) ranges from 0m to - 2100 m.

Hydrodynamic Results

The MIKE 21 Hydrodynamic monthly outputs (Figure 9) show the influence of the hydrodynamic parameters on the effluents dispersion. Clearly, the dissolved effluents follow the current speed and direction which depends on local wind speed and SSH. The initial fish farm waste dilution manner is regulated by hydrodynamic conditions at the farm site in

Table 3. Numerical model inputs and outputs

MIKE 21/3 Coupled model		
Model	Inputs	Outputs
Hydrodynamic	Mesh data: triangulated Bathymetric data: digitalized chart Boundary conditions: sea surface elevation Wind data: speed and direction Source parameter: location, source type and discharge (m^3/s)	Current (speed, direction) Water lever variation and fluxes
Spectral waves	Wind data: speed and direction Wave breaking Boundary condition: spreading factor; n, mean wave direction, wave period; TP, Hs	Wave outputs (energy, action, period) Significant wave height Peak wave period
Transport	Component specification Horizontal/ vertical dispersion (literature) Source discharge: In-house program	Dissolved effluents (concentrations, dispersions)

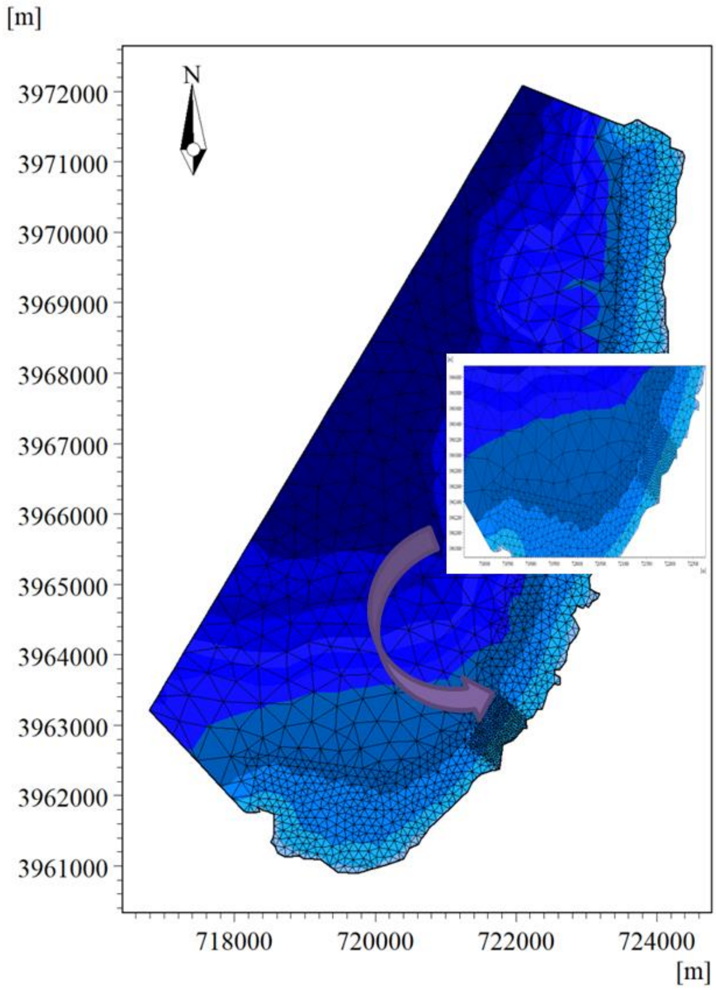

Figure 7. Mesh generation of the studied area with progressive mesh refinement.

accordance with other studies (Wang et al., 2020), hence the current speed and direction should be considered when investigating for aquaculture site selection. The studied area is characterized by low speed current with an East North and West dominant direction, theses velocities increased gradually from the bottom to the surface, this weak current speed caused a reduction in waste dispersion from the fish farm and an absence of resuspension as confirmed by (Porrello et al., 2005), whereas, high current speed reduces waste accumulation and increases the oxygen supply, which enables the aerobic decomposition of organic substances (Yokoyama, 2003). The evolution of the current speed at the farm location during the whole farming cycle (April 2016-June 2017) compared to the satellite data are shown in Figure 10 where the predicted velocities ranged from 0.005 m/s to 0.45 m/s, the meseaured data were higher than the predicted ones, (maximum velocity:0.48 m/s, min velocity: 0.98 m/s). The local fish farm area is characterized by lower current speed. The predicted results depicted a spatial and temporal variability in the simulated current speed arround the fish farm thus improving the benthic environment below which is in agreement with previous works (Norði & Patursson, 2012).

Nutritional Results

The effluent load calculated using the in-house program to solve the nutrients balance equations is given in Figure 11. Effluents from the on growing fish are higher than the excretion of the early growing ones. The high quantity of suspended solids corresponds to the high food quantity distributed and to the last rearing month. The total nitrogen loads from the early growing and the on-growing fish are 90 and 199 kg/day respectively, however the phosphorus effluents are the smallest fluxes, ranging from 2.18 kg/day for the early growing fish to 4.19 kg/day for the on growing one, these results are consistent with distributed food composition and digestibility (Figure 6) and in agreement with previous works (Brigolin et al., 2014; Emmanuelle Roque d'Orbcastel & Yves Moutounet, 2008). Emmanuelle Roque d'Orbcastel et.al. used a fresh water brook trout produced in a fish farm of 600 tons/year with a fish stocking density of 58 kg/m^3. Brigolin et al. (2014) used satellite's remotely sensed data and an integrated aquaculture impact assessment model on an Algerian coastal area near the town of Bejaia for a sea cage fish farm with a total biomass of 23.541 tons of sea bass with a fish stocking density of

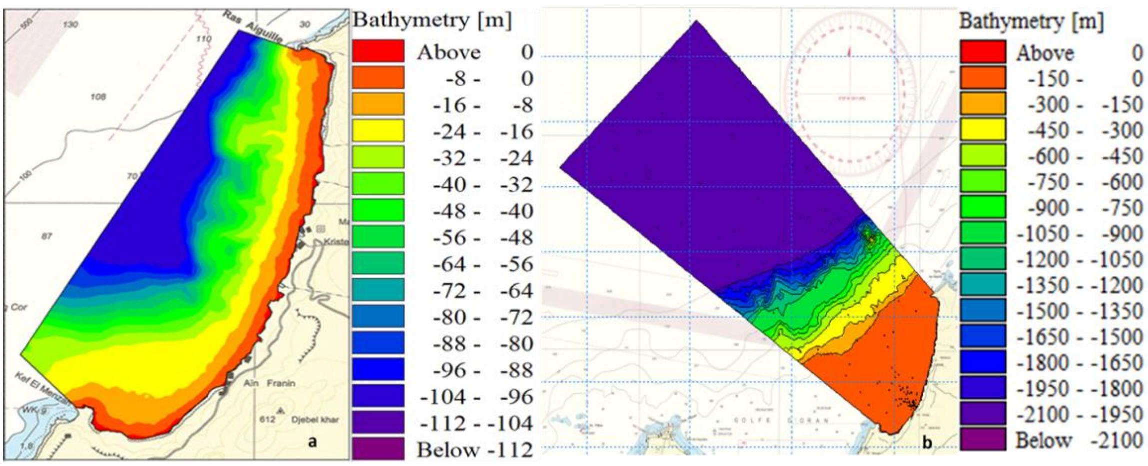

Figure 8. Bathymetry model (a): Local bathymetry, (b): Extended bathymetry.

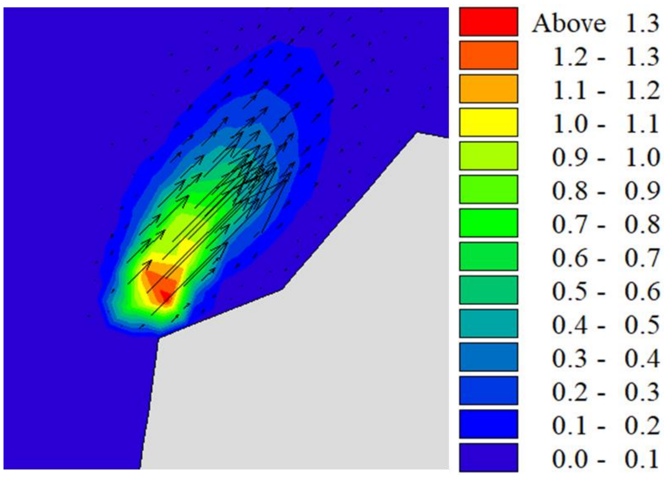

Figure 9. Nitrogen effluent dispersion following the current direction.

13.3 kg/m^3 (10 months stocking). The latter found a 315.5 mole/day average daily cage emission of organic N and 13.3 mole/day average daily cage emission of organic P. The slight difference between these results and ours may be attributed to the difference in harvested species physiology, production size, production system, food quantity and the investigation period.

The current results of effluent prediction suggest that the suspended waste is the main contributor to near shore water pollution. A portion of feed wastes is removed by wild fish and associated ichtyophauna (Fernandez-Jover et al., 2011; Fernandez-Jover et al., 2007; Fernandez-Jover et al., 2009).

Water depth (represented in this study by layers) seems to play an important role in reducing or increasing the environment impact of the simulated fish farm (Figure 12, Figure 13). Indeed, the effluents concentrations at the farm location vary considerably between the first layer (farm location) and last layer.

The nitrogenous concentrations were higher than the phosphorus ones, this is justified by the food composition, (higher proteins, less phosphorus), the nitrogen effluents at the farm localization vary from 0.1 to 2.1 mg/L at the first layer during the early and on-growing phase, while it did not reach the last layer. As shown in Figure 13, the phosphorus concentrations range between 0.002 mg/L and 0.03 mg/L at the first layer, where the fish farm is located, and decreases to reach 0 mg/L at the last layer. According to the environmental standards of aquaculture effluents in Algeria these values are located in the tolerated effluent

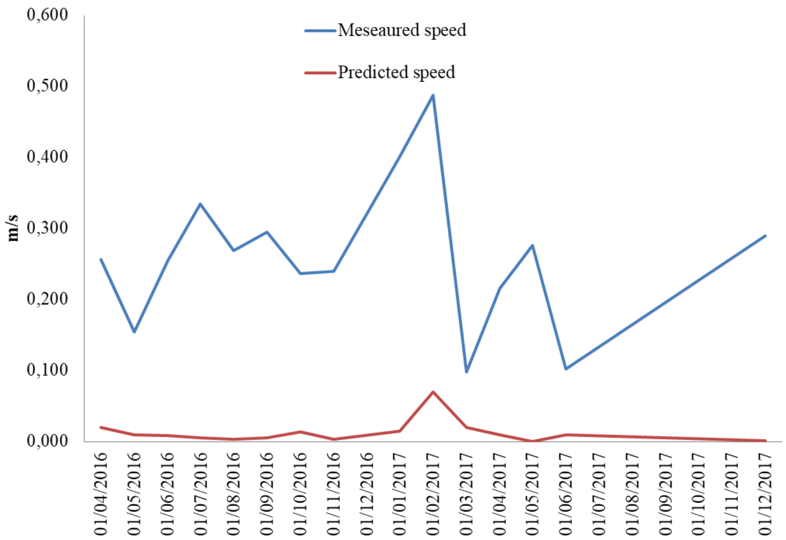

Figure 10. Measured and predicted current speed (April 2016-June 2017).

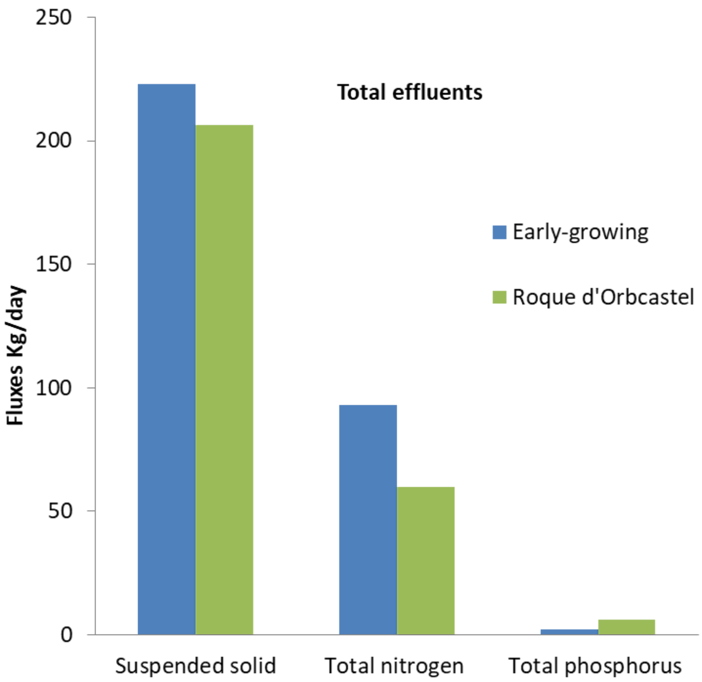

Figure 11. Fish excretion data compared to Emmanuelle Roque d'Orbcastel et. al. results.

concentrations (JORA, 2006). The fish farm effluents dispertion did not exeed 300 m which agrees with previous studies (Chelossi et al., 2003; Porrello et al., 2003; Sarà et al., 2004). As shown on Figures 12, 13, 14, the highest values of nitrogenous and phosphorus effluents are 1.8 mg/L and 0.05 mg/L respectively corresponding to the highest quantities of distributed food during the last month of the on-growing phase, where the fish weight reaches 300 g, hence, the dissolved effluents of the fish farm correlate with the quantity of distributed feed.

The satellite data are measured at ~ 1m and correspond to the initial nutrients concentrations in the seawater. Once added to the simulated results ([N], [P] at layer 01), following the equations developed by Papatryphon et al. (Papatryphon et al., 2005), they completed the virtual fish farm environmental impact, showing that the total nutrients remain under the standard limits (maximum 10 mg/l for phosphorus and 30 mg/l for nitrogen). Furthermore, the simulation results are in accordance with the results reported by Tayeb et al. (Tayeb et al., 2015), where the *in-situ* samples collected from 2013 to 2014 in the Ain Franin region showed that NO_2 concentrations didn't exceed 0.2 mg/l, $NO_3 \leq$ 10 mg/l, NH_4^+ fluctuated between 1–10 mg/l and phosphorus ranged between 0.5 and 1.5 mg/l. Moreover, Taghezout (Taghezout, 2015) measured the sea water nutrients in 13/12/2013, 03/03/2014 and in 26/05/2014, showing that the average of total N concentration was 6.242 mg/l, while the average P concentration was 1.43 mg/l.

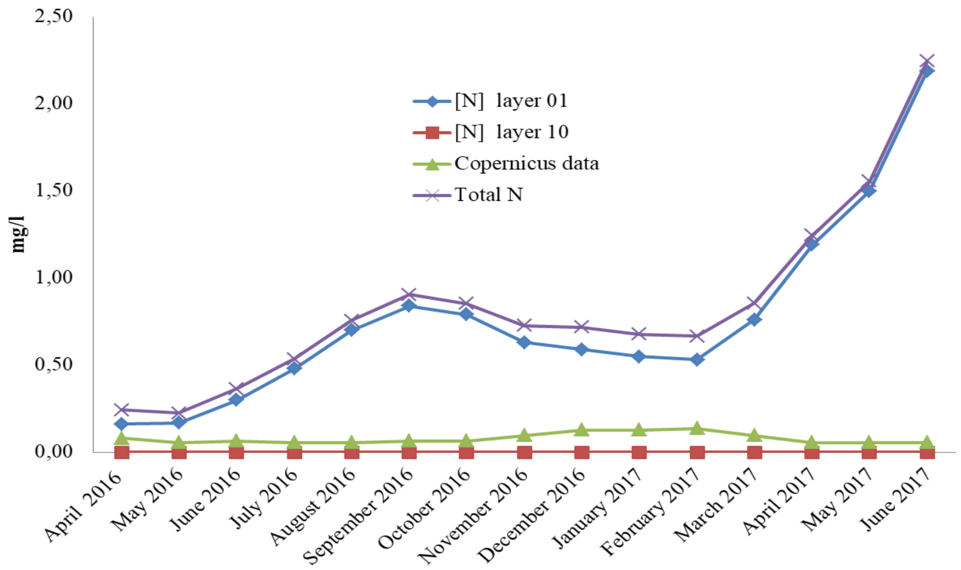

Figure 12. Nitrogenous concentrations at the farm location, copernicus data.

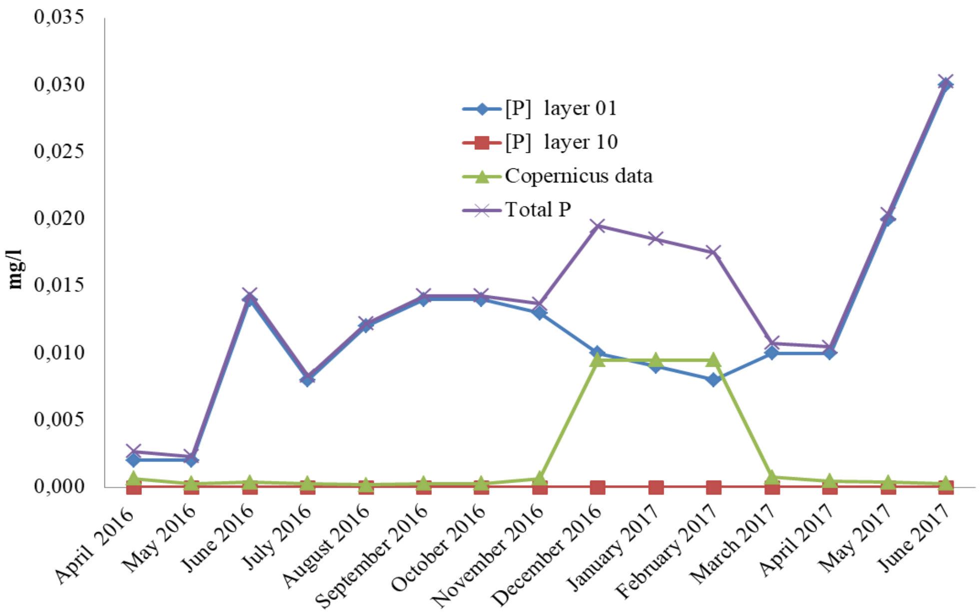

Figure 13. Phosphorus concentrations at the farm location, copernicus data.

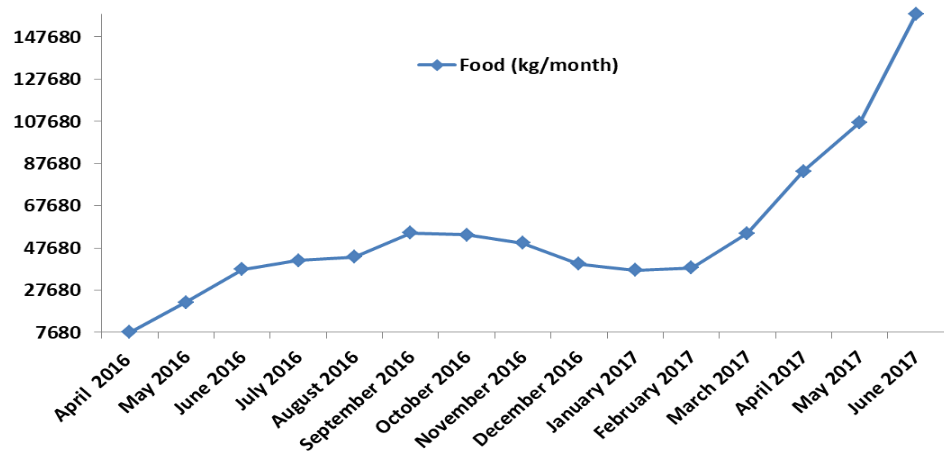

Figure 14. Food distributed quantity (kg/month).

As depicted in Figures 12, 13, the effluents dispersion decreases with layers following the current direction, suggesting that the environmental impact of an onshore fish farm depends on the vertical position and location of its outlet water (Figure 10). Therefore, the layering parameter must be considered when investigating a fish farm project (Yeo et al., 2004). Previous works suggest that the most relevant factors for reducing the fish farm environmental impact are an improvement in feed and feedings (Antoine, 2000) and the consideration of hydrodynamic parameters (Wang et al., 2012).

Conclusion

The studied area appears as favorable site for aquaculture. In this study, the fish farm effluents dispersion is more apparent and the nitrogen values are higher than the phosphorous values. Their dispersion depends on: a) the region hydrodynamics since the current velocity changes values and direction seasonally and b) the fish metabolism which depends on the feed distributed quantity and quality.

At the farm level (internal impact), the fish production is the major contributor to eutrophication (91-93%) (Aubin et al., 2009). Likewise, the degree of water pollution caused by the fish farm effluents must be defined according to the carrying capacity of the local environment, which makes the comparison between different studied areas less accurate. Furthermore, fecal effluents and settling velocities are hard to be generalized because of the variability between the parameters of each experience (Cromey et al., 2009). The selling weights is also an important factor in nutrient loading (Aubin et al., 2009). Moreover, the Mediterranean Sea is described as an oligotrophic sea, leading to a high sensitivity to eutrophication.

All these factors must be taken in consideration when estimating a fish farm impact on the environment, the wild fish consumption and reduction of the fish farm effluents should be regarded too. Further studies are required to collect data related to the near shore growing wild species of the Algerian coast, for example by using the MERAMED model which includes the wild fish as feed removers (Fernandez-Jover et al., 2007).

The results obtained in this study may help to develop more accurate models to estimate the environmental impacts by including wild fish, zooplankton nutrients consumption and the existing concentrations of nutrients in sea water, these models will predict the exact aquaculture farms effluents and help in aquaculture site selection. Predicting the local and regional impact of fish farms on the ecosystems is crucial for a sustainable aquaculture.

Ethical Statement

Not applicable.

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Author Contribution

Conceptualization: YIA, SS, Data Curation: YIA, DMS, KM, SS, Formal Analysis: YIA, DMS, KM, SS, Investigation: Y IA, Methodology: YIA, SS, Supervision: DMS, SS, KM, Writing – Original Draft Preparation: Y IA, Writing – Review & Editing: YIA, DMS, KM, SS.

Conflict of Interest

The authors assert that they have no conflict of interest.

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