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Effects of Different Current Speeds, Depths and Feeding Rates on Predicted Solid Fluxes Derived From Marine Cage Farms in the Eastern Mediterranean (North Aegean Sea, Turkey)

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Abstract

Determination of the deposition rate (flux) and deposition area (footprint) of particulate organic materials (POM) derived from marine cage farms is important for accurate assessment of environmental impacts. In the present study, the deposition rates and distribution area of POM derived from two different commercial marine cage farms located in the Northern Aegean Sea in Turkey have been predicted using a modeling software (Meramod, v.1.4). Deposition rates were predicted for a variety of hypothetical scenarios including different current speeds (Cs), depth (D) and feeding rates (FR). Simulations with real-time data indicated a solid flux of maximum was 891 g m^{-2} yr^{-1} in farm A and a solid flux of 2880.9 g m^{-2} yr^{-1} in farm B. Predictions indicated that an increase in mean current speed (C_s = 7.2 cm sec^{-1}) together with depth (D = 60 m) have resulted in highest surface areas of foot print and maximum flux zones corresponding to an increase of % 201 and % 145, respectively, compared to those of shallower site (20 m) with lower current speed (2.4 cm sec^{-1}). Representative, long-term surface and bottom current measurement underneath cages seems to be the key factor for determining ideal farm location. Deeper sites (≥60.0 m) with lower surface currents and higher bottom current speed that causes resuspension of the accumulated material will help maximize solid dispersion.

Key words: Deposition, fish farms, footprint, impact assessment, particulate organic materials

Farklı Akıntı Hızı, Derinlik ve Yemleme Oranlarının Doğu Akdeniz'deki (Kuzey Ege Denizi, Türkiye) Denizel Ağ-Kafes İşletmelerinden Kaynaklanan Tahmini Organik Birikim Değerleri Üzerine Etkileri

Özet

Denizel ağ-kafes işletmelerinden kaynaklanan partikül haldeki organik materyallerin birikim oranının ve birikim alanının belirlenmesi, çevresel etkilerin hassas bir şekilde değerlendirilmesi açısından oldukça önemlidir. Bu çalışmada, Türkiye'de Ege Denizinin kuzeyinde yer alan iki farklı ticari ağ-kafes işletmelerinden kaynaklanan partiküle organik maddelerin (POM) birikim oranları ve dağılım alanları hakkında, bir bilgisayar programı (Meramod, v.1.4) kullanılarak tahminler oluşturulmuştur. Farklı akıntı hızlarını (Cs), derinlikleri (D) ve yemleme oranlarını (FR) içeren kuramsal bir dizi senaryolar kullanılarak çeşitli tahminler ortaya konulmuştur. Gerçek zamanlı veriler kullanılarak yapılan simülasyonlar, A çiftliğinde katı madde birikiminin 891 g m^{-2} $yıl^{-1}$iken B çiftliğinde 2880.9 g m^{-2} $yıl^{-1}$olduğunu göstermiştir. Simülasyonlar, yüksek akıntı hızı(C_s = 7.2 cm sn^{-1}) ve derinlikteki (D= 60 m) değerler ile düşük akıntı hızı (2.4 cm sn^{-1}) ve düşük derinlikteki (20 m) değerler karşılaştırıldığında sırasıyla maksimum birikim konturunun % 201 ve % 145 oranlarında arttığını göstermiştir. Kafes sisteminin altında yapılacak uzun süreli yüzey ve dip akıntısı ölçümleri, ideal çiftlik yerinin belirlenmesinde önemli bir faktör olarak görülmektedir. Nispeten derin (≥60.0 m) düşük yüzey akıntısına ve birikmiş maddelerin asılı hale geçerek hareket etmesini sağlayacak daha yüksek dip akıntısına sahip lokasyonlar katı maddelerin en yüksek oranda dağılmasına yardımcı olacaktır.

Anahtar kelimeler: Birikim, balık çiftlikleri, ayak izi, etki değerlendirme, partiküle organik maddeler

Introduction

Advances in the field of aquaculture has resulted in increased production during the last two decades and today aquaculture produces 50% of the world's seafood (FAO, 2014). A considerable portion of this production comes from marine cage (net pen) aquaculture in coastal areas. However, the rapid development of marine aquaculture along the coastal areas has raised concerns about their impact on the natural environment. Fecal waste and uneaten food particles are continuously formed as a result of fish feeding and this material is then deposited over the over the sediment in the form of particulate organic materials (POM) which is considered as the major component of negative environmental impacts. Overtime, POM accumulation creates anoxic conditions that adversely affect the abundance and composition of benthic organisms in the vicinity of cage farms (Pillay, 1992; Troel and Norberg, 1998; Read and Fernandes, 2003; Gyllenhammar and Håkanson, 2005; Cromey et al., 2009). On the other hand, traceability and long-term memory of POM accumulation have resulted in its use in impact studies (Henderson et al., 2001; Silvert and Cromey, 2001; Pérez et al., 2002; Chamberlain and Stucchi, 2007; Weise et al., 2009; Cromey et al., 2012). In recent years, the extensive use of POM accumulation for modeling purposes (Henderson et al., 2001; Silvert and Cromey, 2001; Pérez et al., 2002; Chamberlain and Stucchi, 2007; Weise et al., 2009; Cromey et al., 2012) has emerged as a potential tool for better management of marine cage farm operations. Determination of POM accumulation rate allows prediction of deposition area (foot print) underneath the cage farm which, in turn, is a factor of other on site parameters such as cage characteristics, farm plan, current speed, fish biomass, feeding rate, depth and resuspension of deposited material on the seabed for more accurate impact assessment of marine fish farms. The use of computer modeling allows systematical analysis of the effects of combination of these factors on the deposition area under site-specific conditions.

In this study, POM accumulation rate (solid flux) and deposition area (footprint) from two different commercial cage farms have been predicted using hydrodynamic and production data. In addition, the effects of different scenarios on solid flux and footprint were predicted by changing variables including depth, current speed and feeding rate. For this purpose, a modeling software (Meramod v.1.4) that is developed for predicting impact assessment of marine cage farms have been used. Modeling POM deposition allows making predictions on the impact of existing or future farms which in turn, can be used for determining carrying capacity of an area.

Materials and Methods

Data were collected from two different established commercial fish farms located in the Aegean Sea (Eastern Mediterranean, İzmir, Turkey; Figure 1). One of these farms was located in the Gulf of Gerence (Çeşme, İzmir, Turkey) while the other one was located in Sığacık Bay (Çeşme, İzmir, Turkey). Data on farms characteristics (number of cages, farm layout, total biomass, feeding rates) were obtained from farm managers and hydrodynamic data on current speed and direction were measured on site (Table I). All data were then used to predict accumulation and deposition area of POM under the cages for existing (real-time) conditions. In addition, accumulation and deposition area (footprint) of POM were predicted for 3 different scenarios by changing critical variables that affect solid flux. For this purpose, the effects of current speed (2.4 vs 7.2 cm sec^{-1}), depth (20 m vs 60 m) and feeding rate (62.5 vs 125, 250, 500 kg $cage^{-1}day^{-1}$) on solid flux were assessed. A list of tested current speed, feeding rate and depth scenarios are given in Table II. While current speed and depth simulations were run for Farm A in Gerence Bay, biomass simulations were run for Farm B in Sığacık Bay. For scenarios with higher current speeds and depth in Farm A, all measured data was multiplied by a factor of 3. The effects of different feed input in Farm B were predicted for feeding rates of 62.5, 125, 250 and 500 kg $cage^{-1}$ day^{-1}. Surface areas of flux zones were determined using an image analysis program (Rasband, 1997-2014).

Measurement of current speed

Current speed and direction underneath the commercial farms were measured using an acoustic doppler current profiler (Teledyne RD Instruments, USA). The current meter was deployed on the mooring system 50-70 m away from the cage site and 1 m below surface. The measurement interval was 20 min. in all trials and the measurement period was 3 days.

Table 1. Summary of farm characteristics

Farm Characteristics	Farm A (Gerence Bay)	Farm B (Sığacık Bay)
Number of cages	20	20
Cage shape	Circular	Circular
Length/diameter (m)	24	24
Depth of nets (m)	8	8
Fish species	Seabass – Seabream	Seabass – Seabream
Fish stocking rate (kg m^{-3})	5	5-15
Production capacity (tonnes yr^{-1})	300	1850
FCR	1:2	1:2

Table 2. Summary of tested scenarios for Farm A and B

Tested Scenarios for Farm A and Farm B	Depth (m)	Feeding Rate (kg $cage^{-1}$ day^{-1})	Current Speed (cm sec^{-1})
Depth and current speed (Farm A)	60*	62.5	2.4
	60*	62.5	7.2*
Current speed (Farm A)	20	62,5	2.4
	20	62,5	7.2*
Biomass (Farm B)	66	62.5*	4.5
	66	125*	4.5
	66	250	4.5
	66	500*	4.5

* indicates hypothetical data

Model description

MERAMOD consists of four modules including, grid generation, particle tracking, resuspension and benthic impact modules. Briefly, in the grid generation module, a scaled map of the farm site with 5-25 m resolution is generated using bathymetric data and farm layout. In the particle tracking module, the trajectory of settling solid particles from the point of discharge to the seabed is calculated (g m^{-2} yr^{-1}) taking into account current speed direction and feeding rate. This information is then used to estimate the footprint underneath the farm site. In the resuspension module, total flux is recalculated by taking into account data on near bottom current speeds that exceed 9.5 cm sec^{-1}. Benthic module estimates changes in species composition based on flux, but was out of the scope of the present study.

Hydrographic data indicated current residuals were to the north (118.3 magnetic degree) in farm A and to the north east (218.8 magnetic degree) in farm B. In farm A, the mean current speed was 2.4 cm sec^{-1}, with a maximum of 7.4 cm $sec^{-1}$and minimum of 0.1 cm sec^{-1}. In farm B, the mean current speed was 4.5 cm sec^{-1} with a maximum of 9.7 cm sec^{-1} and a minimum of 2.2 cm sec^{-1}.

Results

Effects of current speed and depth on predicted accumulation rate and deposition area

In Gerence Bay, two depth scenarios (20 and 60 m with flat bathymetry) with two different current speeds were (2.4 and 7.2 cm sec^{-1}) tested to estimate changes in accumulation of POM (solid flux) and deposition area underneath the cages. Using measured data (depth = 20 m; C_s= 2.4 cm sec^{-1}; FR =62.5 kg $cage^{-1}$ day^{-1}) mean solid flux was 891 g m^{-2} yr^{-1} with a total deposition area of 27.693 m^2. The total deposition area and the maximum flux zone were not affected by the residual current as there was no obvious displacement towards any direction. The deposition area of maximum flux (Figure 2) was directly beneath the center of the cages with a total area of 1416 m^2 corresponding to an accumulation rate of 1150 g m^{-2} yr^{-1}. However, flux zones between 115-920 g m^{-2} yr^{-1} were slightly towards the north due to the residual current from the south. The sphere of the lowest flux zone extended to 30.8 m to the south and 67.4 m to the north. Increased mean current speed (7.2cm sec^{-1}) did not have an effect on total deposition area (31.220 m^2; Figure 3) but slightly affected the magnitude of the maximum flux area (437 m^2) corresponding to an increase of 12.7% compared to that of maximum flux zone when the mean current speed was 2.4 cm sec^{-1}. In addition, when the mean current speed was 7.2 cm sec^{-1}, flux simulation indicated that there was a displacement of footprint towards the north due to increased southerly residual current (Figure 3).

With a hypothetical depth of 60 m (C_s= 2.4 cm sec^{-1}; FR= 62.5kg $cage^{-1}$ day^{-1}), the total flux was 1100g m^{-2} yr^{-1} corresponding to a foot print of 31124 m² which was 12.4% higher than that of 20 m (Figure 4). The maximum flux zone covered an area of 1682 m^2. The footprint was slightly towards the north as a result of the residual current. The sphere of the lowest flux zone lays 63.6 m to the north and 34.5 m to the south from the outer edge of the cages. At a depth of 60 m, when the current speed was increased to 7.2 cm sec^{-1} (FR= 62.5kg $cage^{-1}$ day^{-1}) predicted mean solid accumulation rate was 821g m^{-2} yr^{-1}, resulting in larger distribution areas (Figure 5). The maximum flux zone was located towards the north as a result of the southerly residual current direction with an area of 2051 m^2. The footprint covered an area of 55818 m^2 which was two folds higher than that at a mean current speed of 2.4 cm sec^{-1}. The sphere of predicted deposition as defined by the lowest flux zone (0-700 g m^{-2} yr^{-1} contour) extended 30.3 m to the south and 170.1 m to the north of the cages.

Effects of biomass

In farm B, the model predicted a flux of 2880.9 g m^{-2} yr^{-1} when measured data was used as input (C_s= 4.5 cm sec^{-1}; Depth: 66 m; FR= 250 kg $cage^{-1}$ day^{-1}; Figure 8) with a total footprint of 37646 m^2 and a maximum flux zone of 3516 m^2. Predictions based on different feed inputs resulted in relatively similar foot prints with the main difference being the rate of POM accumulation. When the biomass was reduced, corresponding to a feeding rate of 62.5 kg $cage^{-1}$and a production capacity of about 300 tones, solid flux was 714.5 g m^{-2} yr^{-1} with the maximum flux zone covering an area of 2594m^2 (Figure 6). Predictions indicated that maximum flux zones covered an area of 3243 and 3126 m^2 for feeding rates of 125 (Figure 7) and 500 kg $cage^{-1}$ day^{-1} (Figure 9), respectively. With a feeding rate of 500kg $cage^{-1}$ day^{-1}, the mean flux was predicted as 5761.5 g m^{-2} yr^{-1}. The total deposition zones were similar in all simulations and the sphere of the lowest flux zone extending to a minimum of 23.3 m and a maximum of 77.5 m on the north axes, and to 35 and 58.4 m on the south axis indicating the effect of residual current from southwest.

Conclusions

Measured values of POM accumulation rates underneath cage farms have been reported to range between 133.6 - 46355 g m^{-2} yr^{-1} (Gowen and Bradbury, 1987; Kalantzi and Karakassis, 2006; Kutti et al, 2007). In the present study, simulations with real-time data indicated a solid flux of maximum was 891 g m^{-2} yr^{-1} in farm A and a solid flux of 2880.9 g m^{-2} yr^{-1} in farm B and these values were within reported values. Although no critical level of solid accumulation has been reported in the literature or there exists any threshold by the local regulatory framework, higher solid accumulation beneath cage farms should be avoided to minimize potential impacts. For a given cage farm location, high accumulation rates can be avoided by taking into consideration of factors that have major influence on solid flux such as current speed, depth and production capacity. In the present study, predictions based on these critical factors provided important insights on the potential for reducing solid accumulation underneath the cages.

Simulations indicated that at a depth of 20 m, increased current rate (7.2 cm sec^{-1}) alone had only a slightly positive effect by increasing the area of footprint. Larger distribution areas of organic materials will result in higher oxygen concentrations in the sediment which in turn, will create better conditions for assimilation by the local fauna. In this study, the effects of current speeds >7.2 cm sec^{-1} on footprint were not estimated as it was unrealistic to assume a sustained mean current speed more than 3 fold of the measured value (2.4 cm sec^{-1}). Sustained higher current speeds may also have some potential negative impacts on fish growth. For example, although swimming at a moderate speed corresponding to 1-1.5 BL s^{-1} resulted in higher weight gain in salmonids (Davison, 1989; Jobling et al., 1993), lower growth rates were achieved when fish were exposed either to still water or strong currents (Jobling et al., 1993). Therefore, sustained surface current speeds higher than >10.0 cm sec^{-1} may compromise fish growth particularly for those <10-15 cm in length. On the other hand, an increased near bottom current is potentially desirable for its flushing effect. The positive impact of resuspension as a result of increased bottom currents has been reported in other studies (Findlay et al., 1995; Cromey et al., 2002) but reported values of current speeds at which resuspension generated is contradictory with a range of 9.5-66 cm sec^{-1} (Cromey et al., 2002; Dudley et al., 2000; Tengberg et al., 2003). Such differences in resuspension speed may possibly be due to differences in bottom topography and substrate composition of farm sites. Based on reported values, relatively higher near bottom currents (i.e. >10.0 cm sec^{-1}) will potentially increase deposition area by increasing dispersion of settling particles and resuspension of the sediment thus reducing environmental impact.

Our predictions indicated that an increase in current speed together with depth have resulted in highest surface areas of foot print and maximum flux zones corresponding to an increase of %201 and %145, respectively, compared to those of shallower site (20 m) with lower current speed (2.4 cm sec^{-1}). Predictions indicate the importance of depth for minimizing POM accumulation rates and favor deeper sites with higher current rates (≥7.2 cm sec^{-1}). With detailed bathymetric data and long-term current measurements, the optimum cage farm locations can be determined in a given area so that POM accumulation rates can be minimized.

An increased organic material accumulation on the seabed directly beneath the cages in relation to increased feed input was expected but provided insight on the extent of solid deposition rate as a factor of biomass. When feeding rate was increased to 500 kg $cage^{-1}$ day^{-1}, solid accumulation rate in the maximum flux zone reached 8500 g m^{-2} yr^{-1} with a mean flux of 5761.5 g m^{-2} yr^{-1}. Such feeding rates with existing current speeds can be prohibitive for sustainability and result in excessive nutrient enrichment and solid accumulation in this particular location.

This study demonstrates the importance of current speed, depth and feeding rates (fish biomass) that have major effects on solid deposition rates derived from marine cage farms. In addition, although it is impractical to verify the outcomes of all possible model input parameters due to the diversity of farm sites with respect to physical, chemical and biological parameters, this study further illustrates the need for more concentrated efforts on validation studies to effectively use modeling software in impact assessment studies. In particular, comprehensive work should be carried out on determining long-term variability in current speeds throughout the water column and on-site solid accumulation rates using sediment traps to be able to compare predicted vs solid fluxes in a given location. Once validation studies prove successful, it is in the interest of governmental agencies to integrate modeling tools as part of their decision making processes to reevaluate impact status of existing farms or to determine optimal locations for future cage farms.

Acknowledgements

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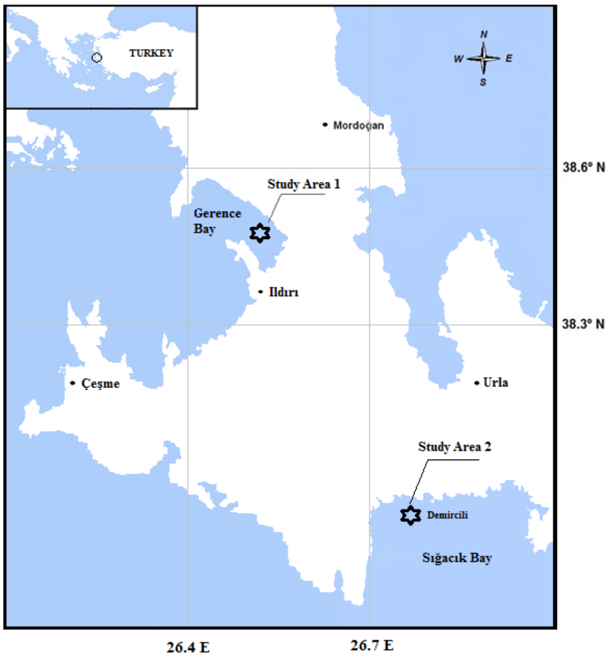

Figure 1. Study areas (○) in Gerence Bay (Farm A) and Sığacık Bay (Farm B) in the Aegean Sea, Western Turkey

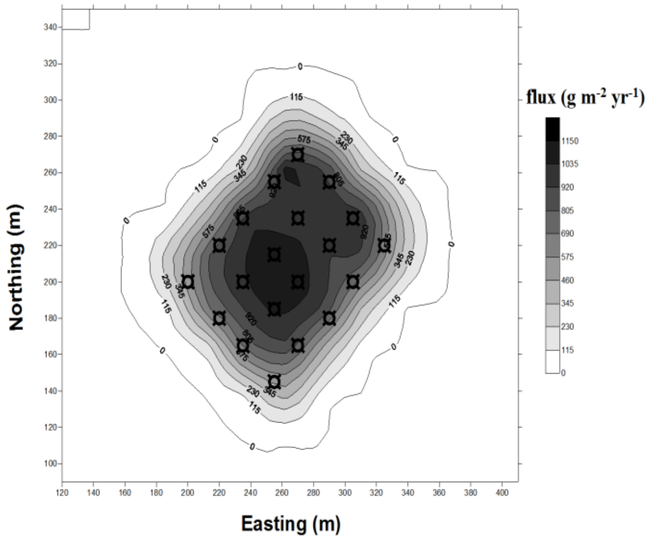

Figure 2. Predicted solid flux with measured data from farm A in Gerence Bay. Depth: 20 m; current speed: 2.4 cm sec^{-1}; feeding rate: 62.5 kg $cage^{-1}$ day^{-1}

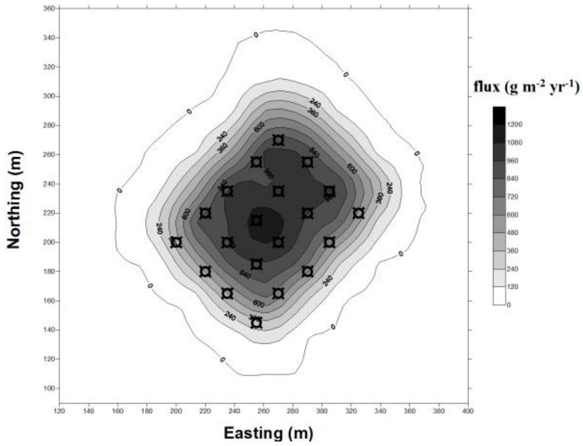

Figure 3. Predicted solid flux with hypothetical current (7.2 cm sec^{-1}) from farm A in Gerence Bay. Depth: 20 m; feeding rate: 62.5 $cage^{-1}$ day^{-1}

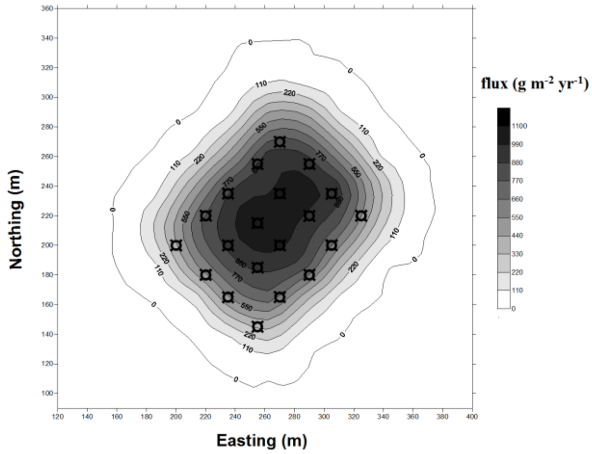

Figure 4. Predicted solid flux with measured current (2.4 cm sec^{-1}), from farm A in Gerence Bay. Depth: 60m, feeding rate: 62.5 $cage^{-1}$ day^{-1}

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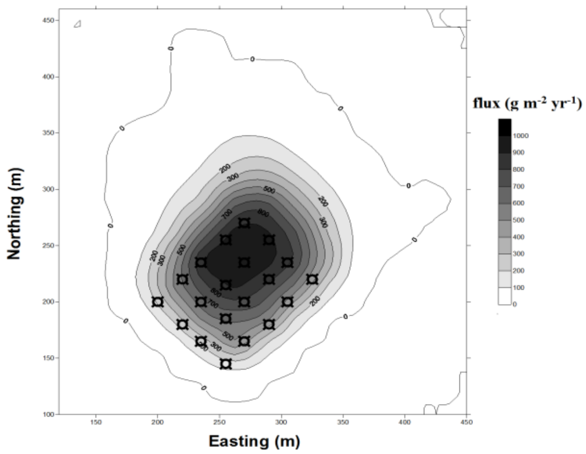

Figure 5. Predicted solid flux with hypothetical current (7.2 cm sec^{-1}) and depth 60m, from farm A in Gerence Bay. Feeding rate: 62.5$cage^{-1}$ day^{-1}

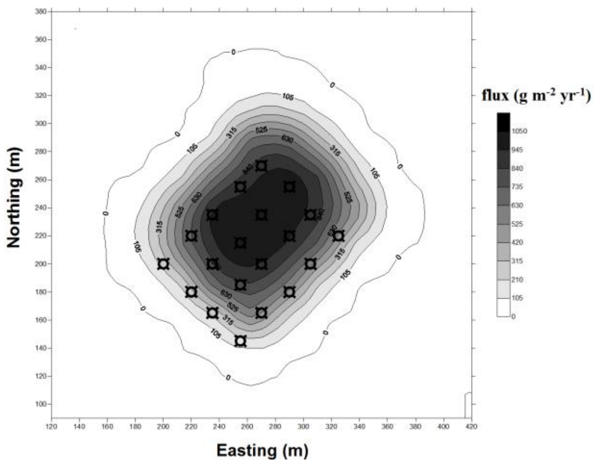

Figure 6. Predicted solid flux with hypothetical feeding rate (62.5 kg $cage^{-1}$ day^{-1}) from farm B in Sığacık Bay. Depth: 66m; Current speed: 4.5 cm sec^{-1}

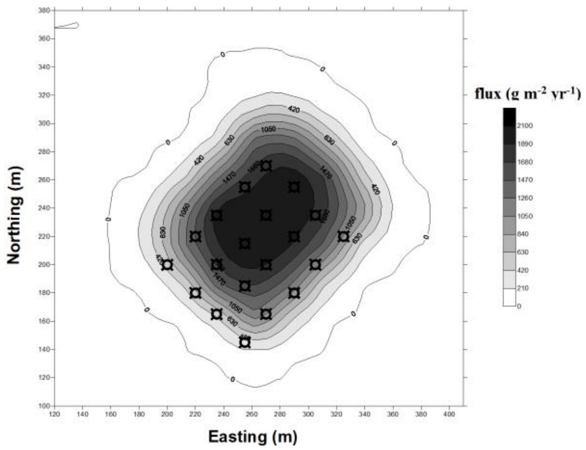

Figure 7. Predicted solid flux with hypothetical feeding rate (125 kg $cage^{-1}$ day^{-1}) from farm B in Sığacık Bay. Depth: 66m, Current speed: 4.5 cm sec^{-1}

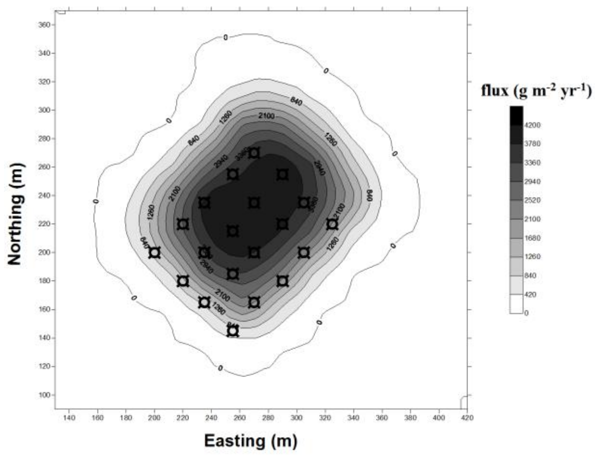

Figure 8. Predicted solid flux with measured feeding rate (250 kg $cage^{-1}$ day^{-1}) from farm B in Sığacık Bay. Depth: 66m, Current speed: 4.5 cm sec^{-1}

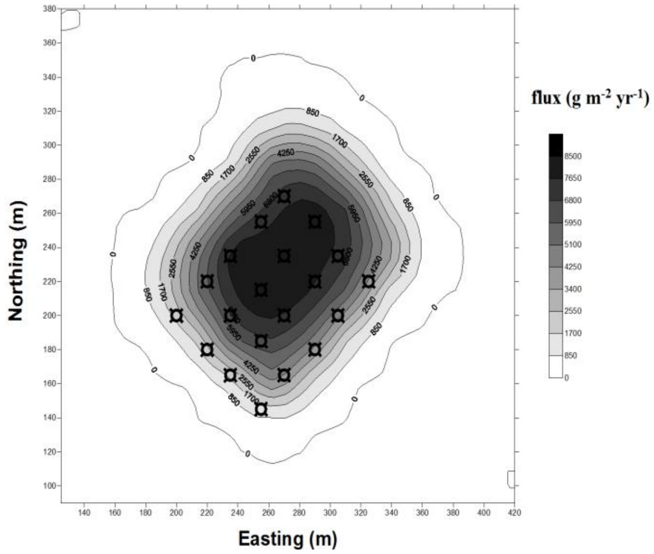

Figure 9. Predicted solid flux with hypothetical feeding rate (500 kg cage^{-1} day^{-1}) from farm B in Sığacık Bay. Depth: 66 m, Current speed: 4.5 cm sec^{-1}

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