Original Article

Comparison of predicted and measured levels of organic material input from a commercial cage farm in Western Turkey

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ABSTRACT

In this study, two different sediment trap trials were carried out to determine the deposition rate (flux) of particulate organic materials (POM) from marine cage farms. Flux predicted using a commercial software (Meramod), measured almost two-fold higher (1,355.5 g m^{-2} yr^{-1}) in 2009 compared to that in 2008 (765.0 g $m^{-2}yr^{-1}$). Predicted levels of flux were higher than measured values in all trials and ranged between 1,251.6 g m^{-2} yr^{-1} in 2008 and 1,811.9 g m^{-2} yr^{-1} in 2009. There were also considerable differences in measured and predicted rates of flux at each station. High variations of flux in repeated measures indicated the need for strict control of farm maintenance routines during long-term trap studies. Near bottom current speeds, periodic resuspension events and the presence of wild fish assemblages were considered as major factors that may have effects in predicting the accumulation rates of POM.

Keywords: Meramod, modeling, net-pens, particulate organic material, waste solid flux.

INTRODUCTION

Waste from marine cage farms is directly discharged into the environment in the form of dissolved and particulate organic material (POM) which, in turn, causes nutrient enrichment and eutrophication. Indicator parameters have potential drawbacks and no single indicator parameter conclusively describes the enrichment status of the farm sites. For example, concentrations of inorganic nutrients such as nitrogen, phosphate and other chemical parameters have short memories due to high flushing rates (Karakassis et al. 2005; Neofitou and Klaoudatos 2008) and may provide inconsistent data at low levels for site evaluation (Rapp et al. 2007) despite reported increased concentrations at farm sites with no signs of eutrophication (Karakassis et al. 2001; Mantzavrakos et al. 2007; Neofitou and Klaoudatos 2008). Biological parameters such as benthic faunal composition and succession, on the other hand, is a factor of complex interactions between depth, sediment type, current speed, farm capacity and also is subject to different conclusions (Kalantzi and Karakassis 2006).

Deposition of POM over the sediment derived from cage farms is considered as the major component of negative environmental impacts creating anoxic conditions that adversely affect the abundance and composition of benthic organisms (Pillay 1992; Troel and Norberg 1998; Read and Fernandes 2003; Gyllenhammar and Håkanson 2005). The particulate materials are primarily composed of waste solids originating from uneaten feed and fecal material (Holmer 1991; Iwama 1991) that can easily be collected by traps deployed underneath the cages.

Therefore, the rate at which POM accumulates is being increasingly used to determine the impacts of cage aquaculture (Dudley et al. 2000; Henderson et al. 2001; Cromey et al. 2002a,b; 2012). The large signal and traceability of POM accumulation over the sediment has also resulted in its use for modeling studies as an important component of aquaculture management processes (Henderson et al. 2001; Silvert and Cromey 2001; Pérez et al. 2002; Chamberlain and Stucchi 2007; Weise et al. 2009; Cromey et al. 2012). The current work was conducted to determine the accumulation rate of POM from a commercial cage farm using two different sediment traps and then evaluation of the usability of the software by comparing the accumulation models made using on-site measurements and cage farm technical information with real data.

An important aspect of this study is the ability to predict and verify the organic load accumulation of a commercial cage farm through computer simulations using a commercial software.

METHODS

Study Area

In the present study, the accumulation rate of organic materials underneath a commercial marine cage farm rearing European seabass, *Dicantarchus labrax*, and gilthead sea bream, *Sparus aurata* has been investigated using sediment traps. The representative fish farm was located in the Gulf of Gerence (Çeşme, İzmir, Turkey) an area characterized by intensive cage farming during the last two decades (Figure 1). Due to difficulties in isolating a single cage in a commercial farm, the whole cage system receiving solids from all directions was used as an experimental unit rather than a single cage.

Husbandry Data

The farm site was comprised of 20 circular cages with a diameter of 24 m and a net depth of 8 m corresponding to a volume of 3617 m^3 cage^{-1}. The reported production capacities of the farm were 184 and 100 t in 2008 and 2009, respectively (Table 1). The reduction in reported total biomass was due to relocation of the farm from near-shore site to the off-shore site in late 2008. The biomass corresponds to a stocking density of 2.5 kg m^{-3} in 2008 and 1.3 kg m^{-3} in 2009. However, due to uncertainties in total biomass as a result of unreported capacity increases, routine fish stocking, and mortality and harvesting, simulations on accumulation of organic load were based on monthly husbandry logs for each cage provided by the farm management. All of these data were entered in the modelling software.

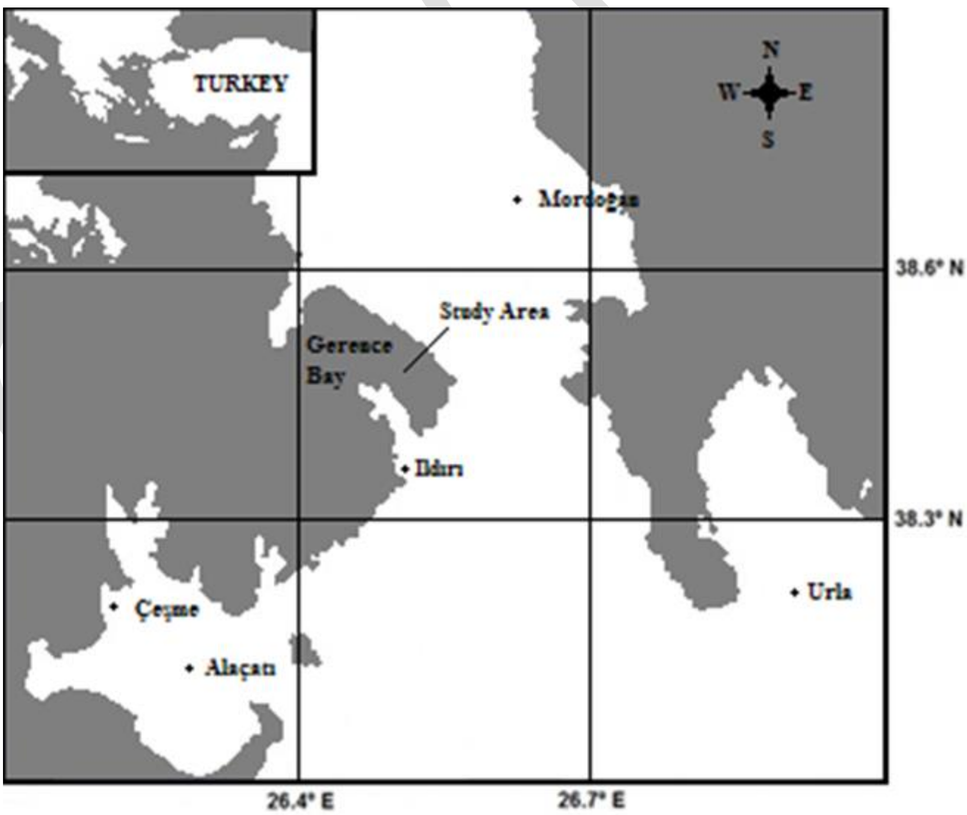

Figure 1. Study area in Gerence Bay (Aegean Sea, Western Turkey).

Table 1. Summary of fish farm characteristics in 2008 and 2009.

Year	Total Number of Cages	Total biomass (tons yr^{-1})	Feeding rate (tons yr^{-1})	FCR (Feed Conversion Rate)	Stocking rate
2008	20	184	387	2.10	2.5 kg m^{-3}
2009	20	100	184	1.84	1.3 kg m^{-3}

Hydrographic Measurements

The current speed and direction were measured monthly (for periods ranging from 2 hours to 3 days) and during sediment trap trials (28-33 days). For this purpose, an acoustic doppler current profiler (Teledyne RD Instruments, USA) was deployed on the mooring system 70 m away from the cage site and 1 m below surface. The measurement interval was 20 min in all trials. Current speeds and direction throughout the Gerence Bay were also measured (data not given) along predetermined transects using a current meter (Workhorse Sentinel; Teledyne RD Instruments, USA) attached to a fishing boat to characterize major hydrodynamic behavior of water masses.

Deployment of Sediment Traps

In order to determine onsite accumulation rate of organic load and for validation, five separate sediment trap studies were conducted in April-August 2008 and also one in September 2009 to symbolize the autumn period when the fish harvest has not yet taken place during the said dates. Sedimentation rates of solids (organic waste input) from cages were determined for a period 28-33 days and at the end of each trial, the contents of the traps were collected and the traps were redeployed. Different trap designs were used in two experiments; in 2008, traps were made up of polyvinyl chloride (PVC) pipes with a diameter of 12.5 cm and consisted of a main body and a removable collector. The main body of trap was 75 cm long and was cylindro-conical in shape. The aspect ratio was 6.00. In the first trial, each trap was fixed to a rope at 3 m above the seabed and only one trap was deployed to each predetermined station. The rope was attached to a concrete weight in one end and to a buoy at the other end. The buoy was kept 2 m below surface in order to minimize the effects of waves. Sampling stations were established at 0 (center), 50, and 100 m intervals along two perpendicular transects on the North to South (NS) and West to East (WE) axis. A total of 9 traps were deployed at each trial. Two different control traps were established at 1 km on the WE and NS axes to determine the background levels of organic material accumulation (Figure 2).

In 2009, relatively smaller-sized traps were used and each sediment trap was consisted of a main body, a collector and a holder in order to evaluate the resuspension event more realistically. The main body of each trap was constructed out of a PVC pipe 7 cm in diameter and 60 cm in length. The aspect ratio was 8.57. A removable collector made of a PVC pipe 5 cm in diameter and 30 cm in length was attached at the bottom of the main body. A single unit contained 4 PVC pipes (4 replicates) connected to a 120 cm long metal bar (holder) using brackets. When the traps were deployed, the mouth of each trap was 110 cm above the sea floor. A semi-circular metal ring was welded on the upper end of each metal bar for rope attachment. Each trap unit was deployed at a predetermined sampling station using ropes and the location of each station was marked with plastic buoys attached to ropes. Sampling stations were established at 0 (center), 25, 50, 75, 100 and 200 m intervals along two perpendicular transects on the NS and WE axis. A total of 21 traps were deployed for a period of 28 days. Two different control traps were established at 1 km (Figure 3).

Data Collection and Modeling

At the end of each trial all traps were manually removed. Accumulated material in each trap was sieved to remove particles > 500 µm and the amount of material collected was determined gravimetrically. Deposition obtained over the study period was then scaled up to obtain flux. Flux was expressed in terms of ash free dry weight (AFDW) as g m^{-2} yr^{-1}.

The solid accumulation over the sea bed was predicted using a computer model, Meramod, that was developed to predict the waste solids flux of sea bass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus auratus*) cage farms (Cromey et al. 2012) considering hydrodynamic conditions in the Mediterranean. General model set up was similar to earlier studies reported by others (Cromey et al. 2002a; Cromey and Black 2005; Cromey et al. 2012). The model is composed of four different subsequent modules: grid generation module, particle tracking module, resuspension module and the benthic impact module. Briefly, the grid generation module generates a map of the farm area using data from bathymetric measurements and farm layout (orientation, number and dimensions of cages). Particle tracking module then, calculates total flux of solids (g m^{-2} yr^{-1}) by taking into consideration current speed and direction, as well as feed input. Resuspension module recalculates total flux based on near bottom current speeds that exceed 9.5 cm sec^{-1}. The benthic impact module which is used to establish relationships between modeled solid flux and benthic fauna was not employed in the present study.

The modeling results were compared with the real data of organic material accumulation obtained in the last stage of the study.

RESULTS

Current Speed and Direction

Data indicate current speeds ranging between a minimum of 0.5 cm s^{-1} (August 2008; June 2008; May 2009; June 2009) and a maximum of 10.5 cm s^{-1} (November 2008) throughout the water column. The mean current speed over the 3-year period was 2.6 cm s^{-1}. Monthly changes in current speed and direction in 2008-2009 are given in Table 2. In general, the residual current direction was southerly except in November 2008 when the residual current direction was easterly (Table 2).

Comparison of Measurement and Prediction

In 2008, mean observed deposition values per trap ranged between 163.0 and 1663.0 g m^{-2} yr^{-1} whereas predicted deposition values ranged between 25.0 and 3179.0 g m^{-2} yr^{-1} (Table 3). Table 4 shows predicted and observed solid fluxes for the farm site in 2008 and 2009. There were considerable differences (0 -4133 g m^{-2} yr^{-1}) in accumulated material collected from the same traps deployed at different times through March-August 2008 (Table 3). In addition,

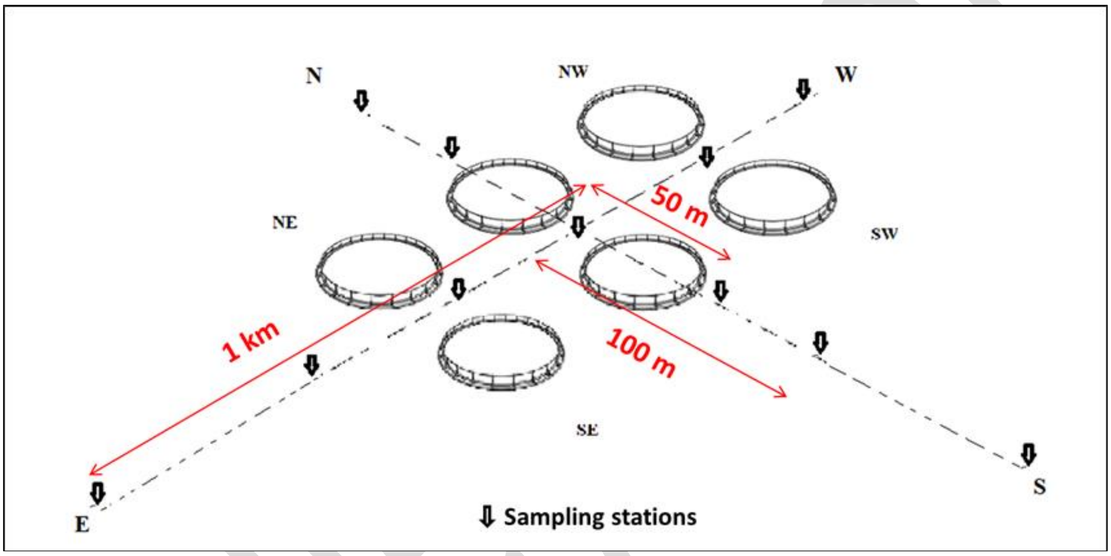

Figure 2. Schematic representation of station locations in 2008.

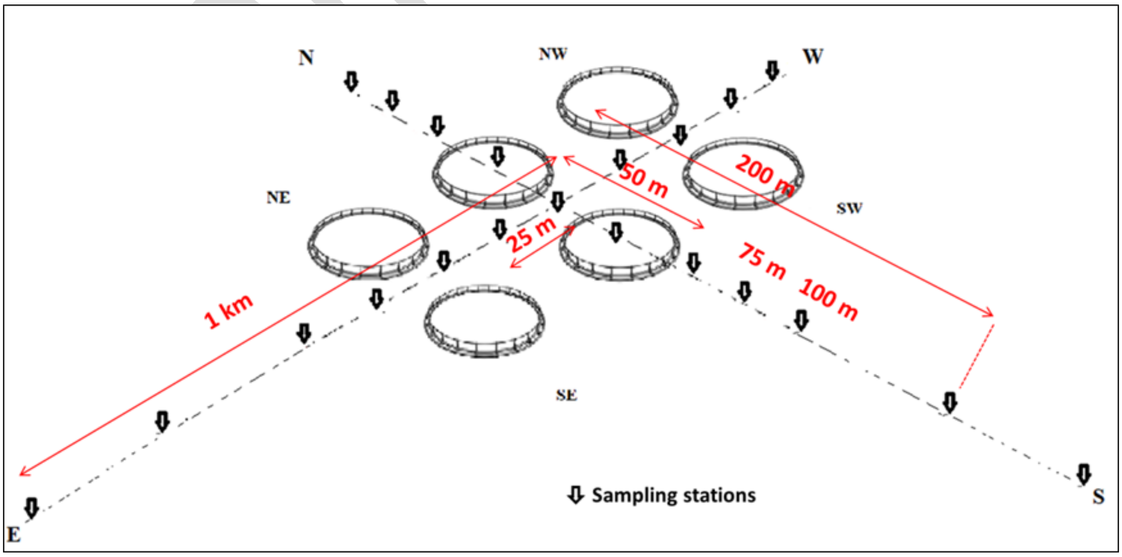

Figure 3. Schematic representation of station locations in 2009.

monthly mean fluxes ranged from a minimum of 336.7 ± 317 g m^{-2} yr^{-1} in April to a maximum of 1598.1 ± 1593 g m^{-2} yr^{-1} in June with an average of 845.0 ± 491 g m^{-2} yr^{-1} month. In 2008, due to limited number of traps, there was no data available on solid flux beyond 100 m from the center of the farm. However, flux simulation was indicated in 2008, the sphere of predicted deposition as defined by the 340 g m^{-2} yr^{-1} contour extends 110 m to the SSE and 120 m to the NW of the cages. There was no significant displacement of footprint due to lack of residual current in any direction (Figure 4) with no significant differences in observed solid flux among 4 different axes. Although the center traps received the highest deposition (1662.9 ± 1173 g m^{-2} yr^{-1}), there was no deposition gradient towards the periphery of the cages between 50 m (646.2 ± 363) and 100 m (660.3 ± 327). Control traps located 1 km away had a mean flux of 452.1 g m^{-2} yr^{-1}.

In 2009, the total mean of observed deposition rate was almost two-fold higher than that in 2008 (Table 4). Observed mean flux from 21 traps ranged from a minimum of 467.3 to a maximum of 4754.6 g m^{-2} yr^{-1} (Table 4). Deposition predictions were also higher and ranged between 9 to 4763 g m^{-2} yr^{-1}. In 2009, the sphere of predicted deposition as defined by the 400 g m^{-2} yr^{-1} contour extended 90 m to the SSE and 180 m to the NW of the cages indicated a slight displacement of the footprint due to southerly residual current (Figure 5).

Observed solid accumulation was considerably higher on the west axis (mean: 2148.48 g m^{-2} yr^{-1}) followed by the east (mean: 1334.85 g m^{-2} yr^{-1}), north (mean: 963.07 g m^{-2} yr^{-1}) and south (mean: 878.98 g m^{-2} yr^{-1}) axes. The observed deposition gradient from the center to the periphery of the cages along each transect reduced as indicated by the mean deposition rates except at 200 m. The observed deposition at the center trap was 1825.7 g m^{-2} yr^{-1} and was the third highest deposition rate after trap W1 (4754.6 g m^{-2} yr^{-1}) and E2 (1922.9 g m^{-2} yr^{-1}). Control traps located 1 km away from the cages had a mean deposition rates of 916.0 g m^{-2} yr^{-1}.

Table 2. Hydrographic data between 2007-2009. * Indicates period when sediment trap trials were carried out.

Month/Year	Mean current (cm s^{-1})	Min-max current (cm s^{-1})	Residual current direction
July/07	2.0	1.5-5.8	135.0
August/07	1.9	0.5-6.4	177.3
September/07	1.7	1.3-4.4	170.2
October/07	2.1	1.6-4.5	137.1
November/07	2.9	2.7-10.5	47.8
December/07	2.7	2.0-6.1	131.7
January/08	2.6	2.4-5.9	161.1
February/08	3.4	2.2-6.0	176.1
*March/08	2.3	2.2-4.5	179.7
*April/08	3.1	1.8-7.7	143.9
*May/08	3.6	1.7-9.5	179.3
*June/08	1.7	0.5-4.5	176.9
*August/08	4.3	1.7-6.8	191.2
September/08	3.1	1.9-7.0	133.7
January/09	3.3	3.1-5.4	177.8
March/09	1.9	1.5-2.1	142.7
April/09	1.9	1.8-7.7	158.6
May/09	2.3	0.5-5.9	130.4
June/09	1.9	0.5-2.9	131.0
*September/09	3.0	1.9-7.0	129.3
October/09	2.5	0.8-6.4	139.4

Table 3. Accumulation rate of measured organic material flux (g m^{-2} yr^{-1}) in 2008. Data are ash free dry weight (AFDW). Negative or zero values are due to subtraction from the control stations. NA: Not available due to loss of trap.

Station	March 2008	April 2008	May 2008	June 2008	August 2008	Station Mean
Center	1004	866	2912	572	2961	1662.9 ± 1173
North 1	688	11	18	4133	142	998.5 ± 1774
North 2	455	245	397	286	NA	345.6 ± 97
East 1	170	0	22	566	60	163.4 ± 234
East 2	277	162	824	3032	NA	1073.8 ± 1337
South 1	399	317	1607	1000	NA	830.7 ± 600
South 2	353	249	1371	NA	1081	763.6 ± 549
West 1	493	842	0	NA	1034	592.3 ± 454
West 2	551	339	518	NA	424	458.1 ± 96
Monthly Mean	487.8 ± 246	336.7 ± 317	852.1 ± 969	1598.1 ± 1593	950.4 ± 1076	

Table 4. Mean accumulation rate of measured and predicted organic material (g m^{-2} yr^{-1}) in sediment traps underneath the commercial farm in 2008 and 2009. Data are ash free dry weight (AFDW). Negative values are due to subtraction from control station. NA: Not available due to loss of trap.

Stations	2008 Measured (g m^{-2} yr^{-1})	2008 Predicted (g m^{-2} yr^{-1})	2009 Measured (g m^{-2} yr^{-1})	2009 Predicted (g m^{-2} yr^{-1})
Center	1663	3179	1825.7	4894
North 1	998	2425	483.5	4870
North 2	346	185	NA	4591
North 3	-	-	1148.9	2473
North 4	-	-	1256.8	682
North 5	-	-	NA	0
East 1	163	1729	807.7	3986
East 2	1074	35	1922.9	1862
East 3	-	-	1512.6	52
East 4	-	-	NA	2
East 5	-	-	1096.2	0
South 1	831	2112	467.3	4118
South 2	764	69	723.5	2130
South 3	-	-	1006.7	173
South 4	-	-	722.0	6
South 5	-	-	1475.4	0
West 1	592	1505	4754.6	4644
West 2	458	25	1278.2	3151
West 3	-	-	1516.2	393
West 4	-	-	1044.9	24
West 5	-	-	NA	0
Mean	765	1251.6	1355.5	1811.9

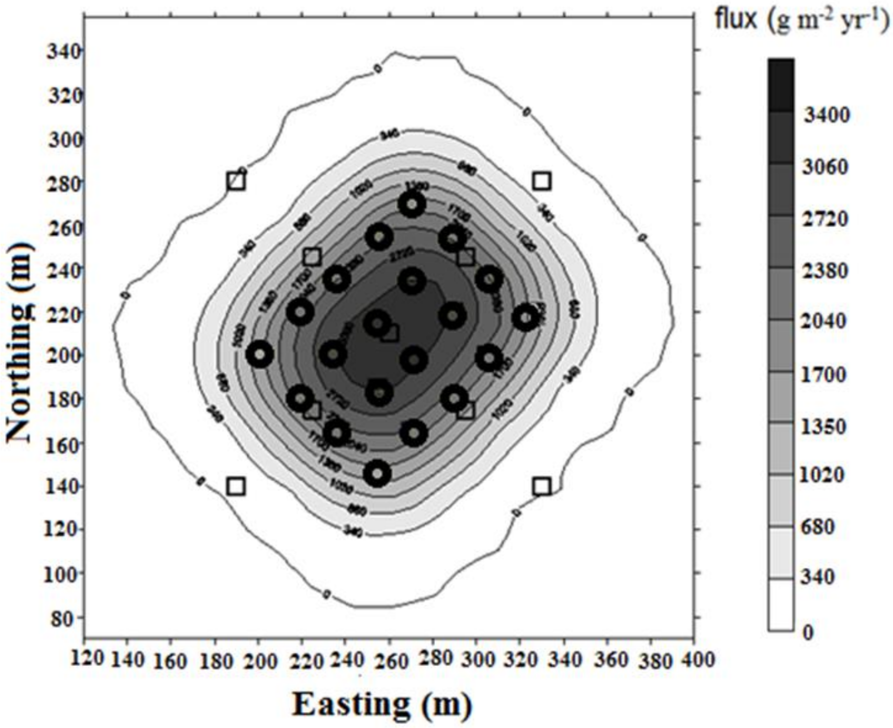

Figure 4. Predicted deposition rate (flux) of particulate organic materials derived from fecal waste and uneaten feed (g m^{-2} yr^{-1}) based on data collected in May 2008.

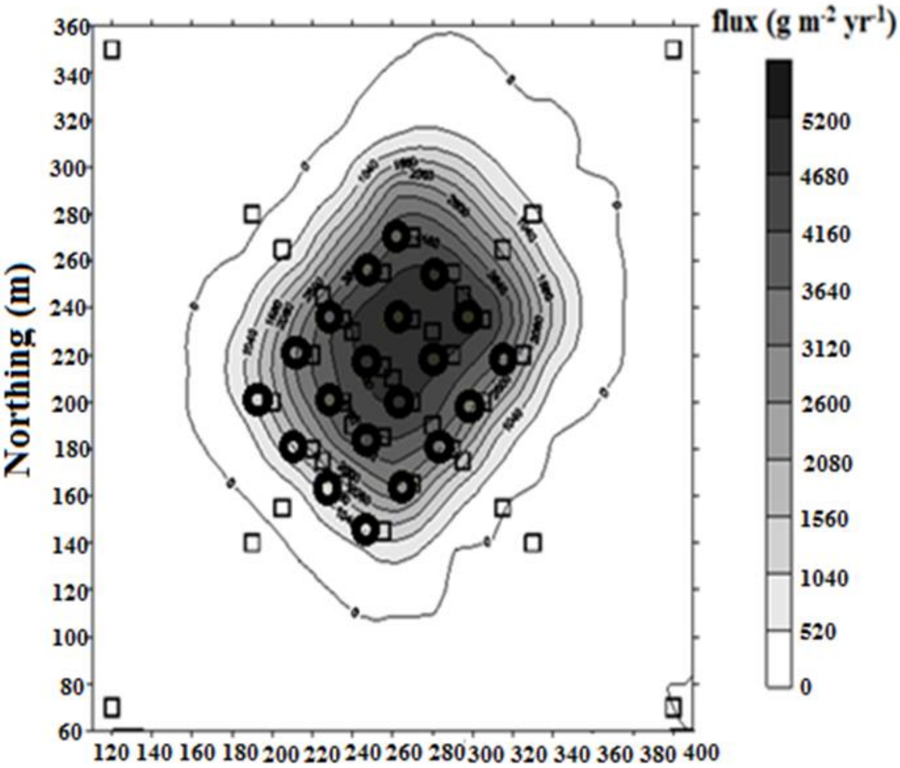

Figure 5. Predicted deposition rate (flux) of particulate organic materials derived from fecal waste and uneaten feed (g m^{-2} yr^{-1}) based on data collected in September 2009.

DISCUSSION

Current Speed and Direction

Current speeds are critical on the extent of environmental impact of cage farms as a mechanism by which organic material accumulation over the seabed is reduced and oxygen delivery to the sediment is increased (Findlay and Watling 1997). A minimum mean current speed of 10 cm s^{-1} has been reported for sustainable aquaculture and no excessive accumulation of organic material has been reported at current speeds > 8 cm s^{-1} (Yokoyama et al. 2006). Based on recording durations of min 2h and max 33 days, our results showed that over the three-year period, the mean current speed was 2.6 cm s^{-1} with min 0.5 and max 10.5 cm s^{-1} near the farm site. Short-term (for periods ranging from 2 hours to 3 days) data on current speed and direction collected every month was in good agreement with those of long-term measurements obtained during the sediment trap trials except in November 2007. Such differences in current direction are expected especially during fall and spring which are typical wet seasons in the Mediterranean when weather conditions change frequently before episodic rain events. Overall, measured current speeds do not indicate the presence of no-flow conditions and dead zones underneath the cages. However, for practical considerations, field work in the present study was performed under no wind or low wind conditions. Therefore, the influence of extreme weather conditions on current speed throughout the water column may have been underestimated. In addition, current measurements from ship board indicated bottom currents > 60 cm s^{-1} in the vicinity of the fish farm and in different parts of Gerence Bay and suggest sporadic if not regular occurrences of strong bottom currents in Gerence Bay. Such trends have limited effects on organic enrichment of the sediment (Findlay and Watling 1997) and indicate the importance of accurate and representative current measurements in farm sites with particular emphasis on near-bottom currents.

The existence of sporadic high bottom currents is also a possible explanation for differences in measured and predicted levels of flux. With such increases in current velocity, resuspension, dispersion and reduction of particulate materials on the seabed will occur (Findlay and Watling 1997; Cromey et al. 2002a). On the other hand, reported values of current speeds at which resuspension occurs are contradictory. For example, Cromey et al. (2002a) reported the critical limit for resuspension as 9.5 cm s^{-1}. In marine sediments, resuspension occurs at bottom speeds of 20-40 cm s^{-1} (Tengberg et al. 2003) whereas Dudley et al. (2000) reported a higher threshold of 33-66 cm s^{-1} for resuspension. In contrast, Doglioli et al. (2004) reported no resuspension at current speeds < 4 cm s^{-1} at depths > 30 m. Factors such as bottom topography, substrate composition and consolidation may affect the current speed at which resuspension occurs at a given site.

Comparison of Measurement and Prediction

There were discrepancies between mean measured and predicted levels of organic material flux in both experiments. In 2008, the mean predicted level of flux (1251.6 g m^{-2} yr^{-1}) was higher than the mean measured level (765.0 g m^{-2} yr^{-1}). Similarly, in 2009, the mean measured level of flux (1355.5 g m^{-2} yr^{-1}) was lesser than the predicted value (1811.9 g m^{-2} yr^{-1}). In addition, there were considerable discrepancies between measured and predicted levels of flux at each station. In this study, the measured levels of particulate waste flux in 2008 and 2009 were within reported values (133.6 - 46355 g m^{-2} yr^{-1}) (Gowen and Bradbury 1987; Kalantzi and Karakassis 2006; Kutti et al. 2007). The simulations on the dispersion of organic load was considerably lesser and indicated that a substantial proportion of the material was deposited within 50-75 m of the farm compared to observed impact area. The poor prediction by some traps especially those located on stations at 200 m from the center may be due to absence of a process in the model. Similar discrepancies have been reported (Chamberlain and Stucchi 2007; Weise et al. 2009; Cromey et al. 2012) and various factors may play a major role in discrepancies between measured and predicted levels of organic material accumulation. Among these factors, the bottom topography can be excluded as the depth underneath the cages was uniform with a flat bathymetry. It has been reported that the presence of steep underwater gradients may cause periodic slumping of material down the slope (Klaucke et al. 2000; Cromey et al. 2002a). Also, shallower sites with a depth of < 15 m may be subjected to resuspension by wind-wave activity caused by orbital fluid velocities (Cromey et al. 2002a) which was out of the scope of simulations due to the fixed depth of 50 m.

Overtime, substrate composition underneath newly established farms changes and once the farm is established, texture of the sediment underneath the cages become loose. The loose surface layer contains unconsumed feed and feces (Pawar et al. 2001) and has higher water content (88.8-95%) compared to the control station (20%) (Karakassis et al. 1998; Yokoyama et al. 2006) which is more likely to resuspended. Farm sediment thickness also changes seasonally as a factor of feeding with differences up to 50% between January and June (Karakassis et al. 1998) that indicates higher potential for resuspension when feed input is higher in warmer temperatures. These factors have varying effects on the resuspension of accumulated material and therefore, may affect the rate of solid accumulation. Location of traps from the surface of the seabed is, therefore, critical in sediment trap studies. In this study, the observed differences in the accumulated material recovered from traps in 2008 and 2009 may be due to the distance of traps from the surface of the seabed. In 2008, the mouths of traps were 300 cm off the bottom whereas in 2009, trap mouths were 110 cm off the seabed. Therefore, the higher accumulation rates in 2009 may have been due to resuspended material reaching to the mouth of the traps in comparison to lower accumulation rates observed in 2008. Therefore, for the most accurate, site specific data, visual observations by divers or Remotely Operated Vehicles are required to determine at which current speeds resuspension occur.

Another reason for differences between measured and predicted levels of organic load is the duration of sediment trap trials. Deployment of sediment traps for shorter periods (2-5 days) is preferred to prevent or minimize potential errors due to daily cage management routines such as harvesting and net changing that potentially cause erroneous measurements. Excess biofouling and debris fallout from nets have been reported as important sources of deposit (McKindsey et al. 2009; Weise et al. 2009; Cromey et al. 2012). However, short-term trap deployments less than 2-3 days may not be practical due to the amount of material collected at stations located in low flux zones and particularly in farms with lower production capacity. For most accurate results, only feeding activity should be allowed and all other maintenance routines should be postponed including harvesting and cage maintenance during sediment trap studies. In this study, such daily routines may also explain outlier values observed in all trials and high variations in repeated monthly measures of solid accumulation in traps deployed at the same stations over March-August 2008. Although long-term experiments may provide more reliable data, strict control of experimental conditions over a period of 30 days may not be possible under commercial operations. Timing of trap studies with periods when feeding rates are highest, i.e. during summer. This may help minimize potential errors and duration of trap studies.

Another important factor that may have an effect on discrepancies between measured and predicted levels of flux is the presence of wild fish assemblages around the cage farms. Studies carried out before and after establishment of cage farms indicated a considerable increase in wild fish populations following establishment (Pearson and Black 2000; Machias et al. 2004; Vita et al. 2004; Felsing et al. 2005; Tuya et al. 2006). Daily feeding routine of stocked biomass within the cages is considered as the major factor for increased densities of wild fish assemblages (Tuya et al. 2006). The aggregative effect of fish farms on the densities of wild fish assemblages during operation are considerable and may account to 50 times higher compared to those of controls after cessation of operation (Tuya et al. 2006). The wild fish assemblages attracted to cage farms consume uneaten particles and reduce the organic load derived from feeding activity and defecation and thus may have a considerable effect on the amount of accumulated matter. For example, Vita et al. (2004) reported that up to 80% of organic particulate material may be consumed by wild fishes around cage farms and no accumulation of fish feed or feces over the sediment under cages. However, despite improved performance of their model when the effect of wild fish assemblages on feeding was accounted for in their simulations (Cromey et al. 2012) in modeling studies, due to seasonal differences in the number and species of wild fish assemblages, it may be difficult to incorporate the effects of reduction in organic material derived from cage farms. Therefore, although no such effect is expected in newly established farms, the effects of wild fish assemblages on accumulation and distribution of particulate organic materials remain to be the most important latent variable in established cage farms.

In conclusion, sediment trap studies offer a practical and inexpensive approach to characterize organic load derived from cage farms. However, validation efforts by modeling prove problematic. In this study, near-bottom currents in the farm site, resuspension of accumulated material and the presence of wild-fish assemblages are identified as three major factors that have effects on organic material accumulation and validation of model outputs. Repeated measurements of flux over a period of one month have resulted in considerable variations in consecutive trials and indicated uncontrollable temporal physical changes in sea conditions and the need for strict control of the maintenance routines in the farm site. Short-term sediment trap trials, give high capacity farms with deposition rates i.e. > 1.000 g m^{-2} yr^{-1}, may eliminate any input of particulate material due to routine farm operations and minimize variations due to seasonal differences in physical conditions of the sea. However, long-term sediment trap trials are also required for low-capacity farms and low-flux zones to determine dispersal boundaries. While only 9 traps may be adequate to measure deposition in high flux zones (i.e. 50 m from the center), > 20 traps with two replicates per station are recommended to determine the dispersal boundaries of POM. In addition to long-term, site-specific data on current speeds throughout the water column, data on near-bottom current speeds are essential and visual observations are required for verification of resuspension events underneath the cages. The effect of wild fish assemblages on the accumulation of organic material remains to be a latent variable and is unlikely to be a feasible approach in modeling studies in established farms.

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