

Local environmental effects of aquaculture farming sea bream/sea bass in the Mediterranean Sea; A MOM (Modelling- Ongrowing fish farm-Monitoring system) model study

1 Objective

The objective of this study was to investigate the local effect of fish farming at six ECASA sites in the Mediterranean Sea. The farmed species at these sites are sea bream or sea bass, or both species.

A secondary objective was to apply and test the model for new species. The model was originally developed for salmon but other species have been introduced in the model during the ECASA project.

2 Introduction

The model estimates the environmental effects of fish farming on local scale (zone A). It calculates the holding capacity under existing conditions, but the model results do also indicate how to increase the holding capacity at a site. The two basic criteria in the MOM model are:

1) The accumulation of organic matter under and in the vicinity of the fish farm must not result in extinction of the benthic macro fauna ($O_2 > 2$ ml/l). This condition is met if the flux of organic matter from the farm is adjusted to local dispersion conditions so that the assimilation capacity of the benthic system is not exceeded.

2) The water quality in the net pens must meet the needs of the fish. This means that the concentration of oxygen is kept above the threshold level and that the concentration of ammonium and other potentially harmful substances are kept below the threshold values. These conditions can be met if the respiration of, and emissions from the fish are adjusted to the rate of water renewal in the net pens.

3 Short model description

The MOM model can be used to calculate the holding capacity (TPF-Total Fish Production) of an area for fish farming. The model calculations are based on requirements on the water quality for fin fish in the cages, and for the benthos beneath the cages. The model contains four sub-models: a fish model, a cage water quality model, a dispersion model, and a benthic model. The environmental effects of fish farming on the surrounding water and on the water quality in the farm are calculated as oxygen and ammonium concentrations in the farm and oxygen concentrations at the bottom below the farm. The model also calculates the nutrient release from the farm to the surface water. The holding capacity is expressed as the minimum of the TPF based on oxygen and ammonium concentrations in the cages and oxygen concentration of the bottom water (i.e. of TPF_{O_2} , TPF_{NH_4} , and TPF_{bent}).

The MOM model has been applied to numerous fish farm locations all over Norway during more than a decade as a part of the MOM-system (Ervik et al., 1997., Hansen et al., 2001, Stigebrandt et al., 2004). The MOM-system (Monitoring-Ongrowing fish farms-Modelling) which is the Norwegian environmental regulations for fish farming is designed for observation, prediction, and regulation of the local environment impact of intensive marine fish farming. The MOM model was originally developed for Salmon. During the ECASA-

project and another EU project (SPEAR) a number of new species of fish was included in the fish model.

3.1 Current characteristics

The current characteristics at the site are important factors influencing the model result. Three different characteristics of the current speed are needed to calculate the environmental effects in and below the farm:

- 1) U_{\min} - the dimensioning current speed in the surface water which is calculated based on the longest time it takes for the water to pass through the group of cages. It is estimated from current measurements at the level of the farm. This dimensioning current speed is used to calculate the lowest/highest concentration of oxygen/ammonium expected in the net pens.

If the current measurements are performed before the establishment of the farm or away from the farm, a reduction factor should be applied simulating the effect of current resistance caused by the cages and algae growing on the net pens.

- 2) U_{std} - the fluctuation component of the current which is calculated as the standard deviation of the current component perpendicular to the farm below the cages. The fluctuation component determines the spreading of organic matter from the farm. The fluctuating component is also used to estimate whether resuspension of sediment will occur in the farm area, which is the case for $U_{\text{std}} > 3.5$ cm/s. A value of $U_{\text{std}} > 3.5$ cm/s suggests that current speeds of more than 10 cm/s occur in the area (Stigebrandt and Aure 1995), which have been found to be the threshold current speed value for resuspension of organic matter from fish farms (e.g. Cromey et al. 2002).
- 3) U_{bent} – the dimensioning current in the bottom layer which is calculated as the minimum mean speed determined from the bottom current record. This characteristic is used to estimate the minimum oxygen transport from the water to the sediment below the cages.

4 Results

4.1. Dalmar - Croatia

4.1.1 Background

Three groups of cages are located between three islands in the archipelago of Croatia (Dalmar). The dominating current direction is NW to W with a mean speed of 8.6 cm/s in the surface layer and 2.5 in the bottom layer. The value of U_{std} at this site is rather high but below 3.5 cm/s, indicating sedimentation of organic matter below the farm. The MOM model is run on one cage group with sea bass (group 1) and one cage group with sea bream (group 2), where the cage group with sea bream is somewhat larger. The water depth in the area is between 20-35 m. The cage groups are run separately. The number of cages in each group is 14 divided in two rows with the diameter of the net pens of 19 m (group 1) and 22 m (group 2) and with a separation between the net pens of 16 m and 21 m, respectively. The number of cages in each group and the farm layouts are presented in Table 4.1.2.

The total production of the farm is 400 tonnes/year, with a production cycle of 15-24 months (see SDR-Dalmar). The fish in group 1 and 2 with older fish are given feed with protein content of 40-52%, and the factual food conversion ratio, FCR_{real} , is 2.5.

Model input:

Table 4.1.1. Farm layout

Site	No. cages	No. rows	diameter/ side length (m)	Spacing (m)	Water depth (m)	Reduction of flow factor (0-1)	Farm direction (deg)
Dalmar 1	14	2	19 (d)	21	25	0.8	22 deg.
Dalmar 2	14	2	22 (d)	16	20	0.8	40 deg.

Table 4.1.2. Surrounding water characteristics

Site	Sal. (psu)	Temp. (C)	Ox. (%)	Amm. (mg/l)	Currents (cm/s)	U_{min}	U_{std}	U_{bent}
Dalmar 1	38	12-20	97%	0.001		1.2	3.0	1.1
Dalmar 2	38	12-20	97%	0.001		1.2	3.0	1.1

Table 4.1.3. Fish data (from Cephalonia, Greece, Magill et al. 2006)

site	Fish	Start weight (g)	End weight (g)	Protein cont. (0-1)	Fat cont. (0-1)	Sinking speed of faeces (cm/s)
Dalmar 1	sea bass	10	330	0.2	0.04	0.7
Dalmar 2	sea bream	10	330	0.2	0.04	0.5

Table 4.1.4. Food data

	Protein cont. (0-1)	Fat cont. (0-1)	Carbohydrate cont. (0-1)	Ash cont. (0-1)	Sinking speed of faeces cm/s	$FCR_{teo}/$ FCR_{real}
Dalmar 1	0.43	0.22	0.02	0.07	8	1.19/2.5
Dalmar 2	0.43	0.22	0.02	0.07	8	1.25/2.5

4.1.2 Results

The water quality in the net pens is not a problem at this site, with an U_{min} of 1.2 cm/s the longest estimated flushing time is approximately 1.0 and 1.5 hour, respectively for the two cage groups 1 (Dalmar 1) and 2 (Dalmar 2). The longer flushing time for cage group two is due to larger net pens but it is also due to a less optimal orientation of this cage group. Current data suggest that the most optimal farm direction at this site is 20-25 degrees, as in the case with Dalmar 1. According to the model output, the water quality in the cages will be sufficient for a production of up to 2400 tons/year. The limitation of this site is the benthic conditions.

The outlet of dissolved nutrients from the farms per 1 tonne of fish production are 7 kg and 8 kg of phosphorus (P), and 43 kg and 46 kg of nitrogen (N) for Dalmar 1 and 2, respectively, and are calculated based on the requirement of the fish and the amount of protein in the food, where most of the nutrients are tied up. The excessive nutrients can be reduced by reducing the protein content of the feed. The real outlet of dissolved nutrients is hard to validate, but at this site bioassay studies showed a local increase in the *chl a* concentration due to excessive nutrients from the farm, but no effects on B or C scale was shown (SDR-Dalmar).

The outlet of particulate matter from the cage groups with the estimated holding capacity per 1 tonne of fish production are; 17/16 kg (P), 101/97 kg (N), 123/129 kg of faeces, and 1307/1252 kg of wasted food at Dalmar 1/Dalmar 2. The wasted food was calculated based on the theoretical food conversion ration FCR_{teo} and the food conversion ratio given by the farmer FCR_{real} (see Table 4). FCR_{teo} is based on the requirement of the fish and type of feed given. The figures show a slightly larger sedimentation rate beneath the cage group with sea bass than with sea bream.

If the particulate matter end up below or in the vicinity of the farm depends on U_{std} (see description above). The standard deviation of the current at Dalmar 1 and 2, perpendicular to the farm are shown in Table 4.1.2 and even though rather high, they are under the threshold value of 3.5 cm/s for resuspension. Most of the outlet of organic matter will therefore settle below or in the vicinity of the farm according to the model. The maximum carbon flux to the sediment without causing total oxygen deficiency (<0.1 mg/l) is $720 \text{ gC/m}^2/\text{year}$ and is calculated from the value of U_{bent} transporting new oxygen to the sediment. This can be compared with values of sedimentation of $40 \text{ gC/m}^2/\text{day}$ below Dalmar 1 measured during the ECASA project (SDR-Dalmar.) In an earlier study (Anonymous, 2001) of the site with a production of 50 tonnes/year, it is shown that up to 10% of the area below cages was covered by bacteria indicating anoxic conditions.

The production cycle from 10 to 330 g fish is 22 months according to the model, which is confirmed by the time given by the farmer of 15-24 months. The median weight of the fish during the production cycle is 93 g.

4.1.3 Conclusion

The holding capacity of the site area is not sufficient for the present production of 400 tonnes/year, or for the earlier production of 50 tonnes/year according to the first criterion of the MOM model. This was shown by both the MOM model results and by observations. The maximal production at this site based the two criteria given in the MOM model, i.e. 1) oxygen concentration above 0.1 mg/l at the bottom below and in the vicinity of the farm, and 2) sufficient water quality in the net pens, is about 15 tonnes/ year with a biomass of 4-5 tonnes. The first criterion limits the production. The maximum total farm production according to criteria two is 2400 tonnes/year.

The holding capacity of the site can be increased by using smaller cages and placing the cages in single rows with large separation, resulting in better spreading of the organic matter settling from the farm. It can also be decreased by decreasing FCR_{real} . The protein retention of the fish is only 18 %, why the protein content in the fish food can be reduced considerably.

4.2. Sounio-Greece

4.2.1 Background

Three groups of cages are located along the coast of Sounio on the southern side of the Sound between Sounio and the main land. The dominating current is in the direction of the sound which is ESE (100 degrees) with a mean speed of 6.5 cm/s at 10 m depth. The value of U_{std} at this site is high and above 3.5 cm/s, indicating only temporary sedimentation of organic matter below the farm. 80 % of the production at this site is sea bream, but we have no information about in which of the cage groups the two species are farmed. The MOM model is run on three cage groups with sea bream in group 1 and 2, and sea bass in group 3. The water depth is 17 m. The cage groups are run separately. The number of cages in each group and the farm layout is presented in Table 4.2.1.

The total production of the farm is 290-340 ton/year, with a production cycle of 14-15 months for an end weight of 350 g (see SDR-Sounio). The fish (80% sea bream) are given feed with protein content of 43-56%, and the real food conversion, FCR_{real} , ratio is 2.0.

Model input:

Table 4.2.1. Farm layout

Site	No. cages	No. rows	diameter/ side length (m)	Spacing (m)	Water depth (m)	Reduction of flow factor (0-1)	Farm direction (deg)
Sounio 1	9	3	19 (d) & 13	20	17	0.8	90
Sounio 2	12	2	12	2	17	0.8	90
Sounio 3	6	2	15	2	17	0.8	90

Table 4.2.2. Surrounding water characteristics

Site	Sal. (psu)	Temp. (C)	Ox. (mg/l)	Amm. (mg/l)	Currents (cm/s)	U_{min}	U_{std}	U_{bent}
Sounio 1	38	14-25	5	0.003		0.7	5.8	1.1
Sounio 2	38	14-25	5	0.003		0.45	5.8	1.1
Sounio 3	38	14-25	5	0.003		0.55	5.8	1.1

Table 4.2.3. Fish data (from Cephalonia, Greece, Magill et al. 2006)

site	Fish	Start weight (g)	End weight (g)	Protein cont. (0-1)	Fat cont. (0-1)	Sinking speed of faeces (cm/s)
Sounio 1	sea bream	10	380	0.2	0.04	0.5
Sounio 2	sea bream	10	380	0.2	0.04	0.5
Sounio 3	sea bass	10	380	0.2	0.04	0.7

Table 4.2.4. Food data

	Protein cont. (0-1)	Fat cont. (0-1)	Carbohydrate cont. (0-1)	Ash cont. (0-1)	Sinking speed of faeces cm/s	FCR_{teo}/FCR_{real}
Sounio 1	0.43	0.22	0.02	0.07	8	1.29/2.0
Sounio 2	0.43	0.22	0.02	0.07	8	1.21/2.0
Sounio 3	0.43	0.22	0.02	0.07	8	1.25/2.0

4.2.2 Results

The water quality at this site is good but since the main axes of the smaller cage groups are parallel to the direction of the main current the through flow is not optimised and according to the model the limiting criteria is the water quality in the cages at this site. The larger cage group has 3 rows which also limits the through flow. With the values of the dimensioning current (U_{min}) shown in Table 2, the longest flushing times are 2 h 20 min for Sounio 1, and 1h 40 min for Sounio 2 and 3. The oxygen concentration of the surrounding water is 5 mg/l due to the high temperature and salinity, and with the configuration of Sounio 1 the calculated holding capacity at the site is about 720 tonne/year, and only about 300 tonnes/year with the configuration of Sounio 2 and 3. The reason for the larger holding capacity shown for Sounio 1 is the longer distance between net pens and it can be increased further with even more separated net pens and/or smaller pens, which will increase the through flow and thereby the holding capacity of the site.

The outlet of dissolved nutrients from the cage groups per 1 tonne of fish production are 8 kg of phosphorus (P), and 45 kg of nitrogen (N) for Sounio 1-3, and are calculated based on the requirement of the fish and the amount of protein in the food, where most of the nutrients are tied up. The excessive nutrients can be reduced by reducing the content of protein in the feed. The outlet of dissolved nutrients is hard to validate, but at this site bioassay studies showed a locally increased chl *a* concentrations at and in the vicinity of the farm (0-50 m)

compared to the reference station further out in the Sound, but no effects on B or C scale were shown (see SDR-Sounio).

The outlet of particulate matter from the farm per 1 tonne of fish production are with the estimated holding capacity; 10/11/8 kg (P), 58/64/47 kg (N), 137/125/130 kg of faeces, and 706/794/738 kg of wasted food at Sounio 1/2/3. The wasted food was calculated based on the theoretical food conversion ration FCR_{teo} and the food conversion ratio given by the farmer FCR_{real} (see Table 4). FCR_{teo} is based on the requirement of the fish and type of feed given. The figures show a slightly smaller sedimentation rate from Sounio 1 than below the other cage groups as a result of the cage group configuration with rather large distances between the net pens. The model results show that most of the outlet of particulate matter from the cages does not settle at the bottom in the farm area due to the large current speed and the oxygen concentration at the bottom is above the critical level of 3 mg/l. ECASA observations at the site show that the density of the benthic fauna (No. of individuals) increases below the cages, while the diversity decreases. This indicates an enrichment of organic matter below the cages compared to the surrounding bottom, but a well oxygenated bottom, which agree with the model result.

The production cycle of this site is 14-15 and the model predicts 16.5 month for the fish to reach the weight of 380 g with an initial weight of 10 g, and with a median weight of 110-116 g during the production cycle. The larger median weight at this site compared to the Croatian site indicate a faster growth, which is also seen in the shorter production cycle of the Sounio site. The faster growth is probably due to higher water temperatures in the waters of Sounio than in Croatia.

4.2.3 Conclusion

This site is well suited for fish farming due to the high current speed in the sound between Sounio and the main land of Greece. The holding capacity of the farm with the configuration of Sounio 1 and with both MOM criteria fulfilled (see above) is 720 tonnes/year which is above the present production of 290-340 tonnes/year. The configuration of the farm is not optimal and the holding capacity of the site may be increased by separating the net pens even further, using smaller pens and place them in single rows perpendicular to the main current direction. One may also decrease FCR_{real} at this site. The protein retention of the fish with $FCR_{real}=2.0$ is only 23 %, why the protein content in the fish food can be reduced considerably.

4.3. Cephalonia-Greece

4.3.1 Background

At the time of the study, five groups of cages were located at Kokkinos Vrakhos in the Gulf of Cephalonia. The dominating current is in the NW to SE direction with a mean speed of 2.4 cm/s. Maximum speed was recorded at 17 cm/s. The value of U_{std} at this site is just above above 3.5 cm/s at 10 m depth, indicating periods of resuspension of the sediment below the farm. We have no information if sea bream or sea bass dominate in the farm, why we test both species. The MOM model is run on three of the cage groups at the farm and each of them is run with sea bream or sea bass in the net pens, i.e. two runs per cage group. The water depth is 19.5 m. The cage groups are run separately. The number of cages in each group and the farm layout are presented in Table 4.3.1.

The production is 1000 tonnes per year with a highest biomass of 2000 tonnes (see SDR-Cephalonia). The production cycle is 3 years with an end weight of the fish of 1500 g. The fish are given feed with protein content of 43-56%, and the real food conversion ratio, FCR_{real} , is 1.7-2.4.

Model input:

Table 4.3.1. Farm layout

Site	No. cages	No. rows	Diameter / side length (m)	Spacing (m)	Water depth (m)	Reduction of flow factor (0-1)	Farm direction (deg)
Cephal 1	18	2	15 (d)	4	19.5	0.8	5
Cephal 2	16	2	15 (d)	4	19.5	0.8	5
Cephal 3	18	2	15	2	19.5	0.8	5

Table 4.3.2. Surrounding water characteristics

Site	Sal. (psu)	Temp. (C)	Ox. (mg/l)	Amm. (mg/l)	Currents (cm/s)	U_{min}	U_{std}	U_{bent}
Cephal 1	38	14-25	5.7	0.0054		0.27	3.9	1.1
Cephal 2	38	14-25	5.7	0.0054		0.30	3.9	1.1
Cephal 3	38	14-25	5.7	0.0054		0.27	3.9	1.1

Table 4.3.3. Fish data (from Cephalonia, Greece, Magill et al. 2006)

site	Fish	Start weight (g)	End weight (g)	Protein cont. (0-1)	Fat cont. (0-1)	Sinking speed of faeces (cm/s)
Cephal 1	sea bream	10	1500	0.2	0.04	0.5
Cephal 2	sea bream	10	1500	0.2	0.04	0.5
Cephal 3	sea bass	10	1500	0.2	0.04	0.7

Table 4.3.4. Food data

	Protein cont. (0-1)	Fat cont. (0-1)	Carbohydrate cont. (0-1)	Ash cont. (0-1)	Sinking speed of faeces cm/s	FCR_{teo}/FCR_{real}
Cephal 1	0.43	0.22	0.02	0.07	8	1.29/2.0
Cephal 2	0.43	0.22	0.02	0.07	8	1.21/2.0
Cephal 3	0.43	0.22	0.02	0.07	8	1.25/2.0

4.3.2 Results

The water quality at this site is good but since the main axes of the cage groups are along the direction of the main current the through flow is not optimised and the limiting criterion is in fact the water quality in the cages at this site. With the values of the dimensioning current (U_{min}) shown in Table 2, the longest flushing times are above 3 hours for all groups, and the longest flushing time occurs rather frequently. The oxygen concentration of the surrounding water is 5.7 mg/l, and with the configuration of Cephalonia 1-3, the maximum holding capacity is about 300 tonnes per year for each cage group, with a biomass of about 300 tonnes. The conditions in the groups with circular net pens is somewhat better due to longer distance between the net pens, and the holding capacity can be increased further with even more separated net pens, which will increase the trough flow and thereby the holding capacity of the site. There are only minor differences in the holding capacity keeping sea bream or sea bass in the cage groups.

The outlet of dissolved nutrients from the cage groups per 1 tonne of fish production are 10 kg of phosphorus (P), and 58 kg of nitrogen (N) for Cephalonia 1-3, and are calculated based on the requirement of the fish and the amount of protein in the food, where most of the nutrients are tied up. About the same but less outlet of dissolved nutrients were found for sea bass than sea bream, with the same food. The excessive nutrients can be reduced by reducing

the fraction of protein in the feed. The outlet of dissolved nutrients is hard to validate, but at this site bioassay studies showed a local increase in the chl *a* concentrations at and in the vicinity of the farm (0-50 m) compared to the reference station, but no effects on B or C scale were shown (Pitta et al. 1999, SDR-Cephalonia).

The outlet of particulate matter from the farm per 1 tonne of fish production is 13 kg (P), 78 kg (N), 147 kg of faeces, and 977 kg of wasted food at Cephalonia 1-3. The wasted food was calculated based on the theoretical food conversion ration FCR_{teo} and the food conversion ratio given by the farmer FCR_{real} (see Table 4). FCR_{teo} is based on the requirement of the fish and type of feed given. The figures show a slightly smaller sedimentation rate with sea bream than with sea bass in the cages. The model results show that most of the outlet of particulate matter from the cages does not settle at the bottom below or near the farm due to the large current speed and the oxygen concentration at the bottom is above the critical level of 3 mg/l. ECASA observations at the site show that both the density (no. of individuals) and the diversity decreases below the cages. This indicates an enrichment of organic matter below the cages compared to the surrounding bottoms, but a well oxygenated bottom, which agree with the model result. ECASA observations thus show that the enrichment of organic matter seems larger at this site than at Sounio. This is in agreement with the variability of the current estimated as the standard deviation U_{std} at the two sites. The value of U_{std} at Cephalonia is above but rather close to the threshold value of resuspension, while U_{std} at Sounio is well above the threshold value indicating more frequent occasions of resuspension.

The production cycle for the fish to reach the weight of 1500 g with an initial weight of 10 g at this site is about 3 years and the model predicts 2.7 years for sea bream and 2.4 years for sea bass, with a median weight of 300 and 370 g during the production cycle. We do not know which specie that dominates at the site, but the model results point to sea bream, or that the condition for the fish are not optimal.

4.3.3 Conclusion

This site is suited for fish farming due to the rather high current speed. The holding capacity of the farm with the configurations of Cephalonia 1-3 and with both MOM criteria fulfilled (see above) is 300 tonnes per year for each of the groups tested by the model. Two cages groups that were not tested are somewhat smaller. Together the tree cage groups tested have a holding capacity of about 900 tonnes per year. The estimated total holding capacity of the farm is thus above the present production of the site of 1000 tonnes per year. The limiting criteria at this site is the water quality in the cages where the oxygen levels might too low during occasions due to the rather long maximum flushing time of about 3 hours occurring in periods of weak current speed. The configuration of the farm is not optimal and the holding capacity of the site may be increased by separating the net pens further and/or using smaller pens and place them in single rows perpendicular to the main current direction. One may also decrease FCR_{real} at this site. The protein retention of the fish with $FCR_{real}=2.0$ is only 23 %, why the protein content in the fish food can be reduced considerably.

Depending on whether sea bass or sea bream is the dominating specie in the farm, the production cycle seems to be too long due to sub optimal conditions, and might therefore be shortened by improving the conditions at the site.

4.4. Piran – Slovenia

4.4.1 Background

Two groups of cages are located in the inner part of the Piran Bay in the southern part of Gulf of Trieste. Freshwater discharge to the bay occurs during a short period in spring. The

dominating current directions vary during the year with north easterly and easterly currents dominate during spring, while they are more evenly distributed during summer. The mean speed is 2.5 cm/s in the surface and the bottom layer. The value of U_{std} based on hourly data at this site is 3.9 cm/s, which is above the threshold value of resuspension (3.5 cm/s). This indicates that the particulate organic matter settling from the farm is spread over a larger area than the farm, and that occasions of resuspension of the sediment below the farm occur. The MOM model is run for both cage groups with sea bass. The water depth in the area is about 14 m. The cages groups are run separately. The number of cages in the first cage group (Piran 1) is 8 divided in two rows with the diameter of the net pens of 8 m and with a separation between the net pens of 4 m. The number of cages in the second cage group (Piran 2) is 20 divided in three rows with the diameter of the net pens of 12 m and with a separation between the net pens of 8 m and 50 m between rows (Table 4.4.1).

The total production of the farm is 71 tonnes/year with a production cycle of 4 years (see SDR-Piran). The fish are given feed with protein content of 40-47%, and the real food conversion ratio is 2-2.4.

Model input:

Table 4.4.1. Farm layout

Site	No. cages	No. rows	diameter/ side length (m)	Spacing (m)	Water depth (m)	Reduction of flow factor (0-1)	Farm direction (deg)
Piran 1	8	2	8 (d)	4	14	0.8	330
Piran 2	20	3	12 (d)	8 (50)	14	0.8	330

Table 4.4.2. Surrounding water characteristics

Site	Sal. (psu)	Temp. (C)	Ox. (mg/l)	Amm. (mg/l)	Currents (cm/s)	U_{min}	U_{std}	U_{bent}
Piran 1	38.5	7-24	7-10	0.003		0.6	3.8	0.55
Piran 2	38.5	7-24	7-10	0.003		1.5	3.8	0.55

Table 4.4.3. Fish data (from Sounio, Greece, Magill et al. 2006)

site	Fish	Start weight (g)	End weight (g)	Protein cont. (0-1)	Fat cont. (0-1)	Sinking speed of faeces (cm/s)
Piran 1	sea bream	10	1000	0.2	0.04	0.5
Piran 2	sea bream	10	1000	0.2	0.04	0.5

Table 4.4.4. Food data

	Protein cont. (0-1)	Fat cont. (0-1)	Carbohydrate cont. (0-1)	Ash cont. (0-1)	Sinking speed of faeces cm/s	FCR_{teo}/FCR_{real}
Piran 1	0.40	0.23	0.02	0.07	8	1.34/2.0
Piran 2	0.40	0.23	0.02	0.07	8	1.34/2.0

4.4.3 Results

The water quality in the cages at this site is good but since the main axes of the cages groups are along the direction of the main current the through flow is not optimised. The limiting criterion at this site is the oxygen condition in the cage. The larger cages group have 3 rows which also obstruct the through flow. With the values of the dimensioning current (U_{min}) shown in Table 4.4.2, the longest flushing times are 1 hour at Piran 1, and about 2 hours at Piran 2. The oxygen concentration of the surrounding water varies between 5-7 mg/l due to the variation in temperature. With the configuration of Piran 1 the holding capacity

according to criteria one (3 mg/l) for the site is about 145 tonnes per year, and about 1100 tonnes per year with the configuration of Piran 2, which together is well above the present production of 170 tonnes/year. The reason for the much larger holding capacity shown for Piran 2 is the longer distance between net pens and the holding capacity can be increased further by separating the cages at Piran 1, which will increase the trough flow and the spreading of particulate organic matter, and thereby the holding capacity of the site.

The outlet of dissolved nutrients with the feed composition in Table 4.4.4 from both cage groups per 1 tonne of fish production are 7 kg of phosphorus (P), and 43 kg of nitrogen (N) and are calculated based on the requirement of the fish and the amount of protein in the food, where most of the nutrients are tied up. The excessive nutrients can be reduced by reducing the part of protein in the feed. The outlet of dissolved nutrients is hard to validate, and at this site we had no information of the bioassay study result. According to observations of nutrient concentrations in the water column there are no increased concentrations at and in the vicinity of the farm, but without bioassay studies it is hard to tell.

The outlet of particulate matter from the farm per 1 tonne of fish production at both cage groups are; 9 kg (P), 51 kg (N), 137 kg of faeces, and 662 kg of wasted food. The wasted food was calculated based on the theoretical food conversion ration FCR_{teo} and the food conversion ratio given by the farmer FCR_{real} (see Table 4.4.4). FCR_{teo} is based on the requirement of the fish and type of feed given. The model results show that most of the outlets of particulate matter from the cages are spread over a large area since the standard deviation of the current speed is above the critical value for resuspension. But the farm depth is half the total depth at the site and the distance between the cages and the bottom is only about 5 m. Current speeds measured at mid depth away from the farm were used to estimate the spreading of organic waste from the farm. If the current conditions below the farm do not correspond to the observation due to the shallowness of the area between the cages and the bottom the spreading may be overestimated.

With the right configuration of the farm such as at Piran 2 the large variability of the currents at this site seem to result in a higher holding capacity than the present production according to the model indicating a low to medium exploitation of the site due to fish farm activity. Observations of meiofauna beneath and in the vicinity of the farm show plenty of worms, such as polychaetes, nematodes, and turbellaries, but also copepods and a few bivalves. The composition of meiofauna and the low diversity seem similar below the fish farm and at the reference station and indicate an enrichment of organic matter in the bay. This might partly be due to the large spreading of the particulate organic matter from the farm or due to other local sources. The minimum oxygen saturation in the bottom water is about 60 % according to historical data from 1980 to 2005. This agrees with oxygen concentrations being well above 3 mg/l, which was the threshold value used to estimate the holding capacity due to accumulation of organic matter.

The production cycle of this site is about 4 years and the model predicts 3 years for the fish to reach the weight of 1000 g with an initial weight of 10 g, and with a median weight of 278 g during the production cycle. The production cycle calculated by the model is calculated from maximal growth of the fish specie at the local water temperature. The difference of 1 year between the actual production cycle and the time estimated by the model may indicate that conditions are not optimal for the fish produced at this site. The actual production cycle and the production cycle calculated by the model agreed well for all the sites also growing sea bass, indicating that the model is capable of estimating the maximal growth of this specie. Personal communication with the farmer confirms an increasing length of the production cycle during the some years. The reason for this is not fully understood but the quality of fingerlings and also unusually high temperatures during summer were discussed. Higher temperatures decrease the oxygen concentrations in the water column.

4.4.3 Conclusion

This site does meet the first criteria of the MOM model with the critical oxygen concentrations at the bottom given the value 3 mg/l. Observations of meiofauna show that it is not extinct, and agree with model results. At shallow sites such as this one the spreading of organic waste may be less than calculated by the model based on observations away from the farm, since the current conditions below the farm may be affected by the cage construction, reducing the current speed.

The longer production cycle given by the farmer than calculated by the model indicates that the conditions or configuration of the farm are not optimal at this site and this was confirmed by the farmer who had experienced an increasing production cycle during the last years. One may decrease FCR_{real} at this site. The protein retention of the fish with $FCR_{real}=2.0$ is only 25 %, why the protein content in the fish food can be reduced considerably.

4.5. Porto Ecole-Italy

4.5.1 Background

Two cages are located at Porto Ecole on the west coast of Italy. The current is the ENE or WSW and has a mean speed of 6.0 cm/s at 10 m depth. The value of U_{std} at this site is high and above 3.5 cm/s, indicating minor sedimentation of organic matter below the farm. The MOM model is run on both cages with sea bream in cage 1, and sea bass in cage 2, both cages are the same size (Table 4.5.1). The water depth is 30 m and the cages are submerged below the surface. The cages are run separately.

The potential total production of the farm is 360 tonnes/year with an end weight of 350-400 g. The fish are give feed with protein content of 46-52%, and the real food conversion ratio, FCR_{real} , is 1.5-2.0.

Model input:

Table 4.5.1. Farm layout

Site	No. cages	No. rows	diameter/ side length (m)	Spacing (m)	Water depth (m)	Reduction of flow factor (0-1)	Farm direction (deg)
PortoE 1	1	1	19	0	30	0.8	0
PortoE 2	1	1	19	0	30	0.8	0

Table 4.5.2. Surrounding water characteristics

Site	Sal. (psu)	Temp. (C)	Ox. (mg/l)	Amm. (mg/l)	Currents (cm/s)	U_{min}	U_{std}	U_{bent}
PortoE 1	38	12-26	6	0.002		0.77	9	0.85
PortoE 2	38	12-26	6	0.002		0.77	9	0.85

Table 4.5.3. Fish data (from Cephalonia, Greece, Magill et al. 2006)

site	Fish	Start weight (g)	End weight (g)	Protein cont. (0-1)	Fat cont. (0-1)	Sinking speed of faeces (cm/s)
PortoE 1	sea bream	10	380	0.2	0.04	0.5
PortoE 2	sea bass	10	380	0.2	0.04	0.7

Table 4.5.4. Food data

	Protein cont. (0-1)	Fat cont. (0-1)	Carbohydrate cont. (0-1)	Ash cont. (0-1)	Sinking speed of faeces cm/s	FCR _{teo} /FCR _{real}
PortoE 1	0.46	0.22	0.02	0.09	8	1.29/1.7
PortoE 2	0.46	0.22	0.02	0.09	8	1.29/1.7

4.5.2 Results

The water quality at this site is good and it is optimised as the two cages are well separated, but the limiting criterion according to the model is in fact the water quality in the cages at this site. The longest flushing times are 40 min at occasions with weak current speed with the values of the dimensioning current (U_{\min}) shown in Table 4.5.2. This figure may be underestimated since the recording frequency is low (1hour). The oxygen concentration of the surrounding water is 6 mg/l and the holding capacity based on both criteria of the MOM model is about 460 tonnes/year and 490 tonnes/year for sea bream and sea bass, respectively, which is well above the present production of 180 tonnes/year and cage group.

The outlet of dissolved nutrients from the cage groups per 1 tonne of fish production are 8 kg of phosphorus (P), and 47 to 50 kg of nitrogen (N), where the higher figure for nitrogen is calculated for sea bass. The outlet of dissolved nutrients is calculated based on the requirement of the fish and the amount of protein in the food, where most of the nutrients are tied up. The excessive nutrients can be reduced by reducing the amount of protein in the feed. The outlet of dissolved nutrients is hard to validate, and at this site there are no bioassay studies and no other studies of possible eutrophication effects of the farm. Based on knowledge on other ECASA sites with similar current characteristics one may suggest that there are no effects on B or C scale. (Pitta et al.1999, SDR-Sounio, SDR-Dalmar).

The outlet of particulate matter from the farm per 1 tonne of fish production are; 7/8 kg (P), 44/48 kg (N), 127/122 kg of faeces, and 471/526 kg of wasted food, where the last figures is for sea bass, suggesting a larger loss of excessive feed for this fish specie using the same feeding rate. The wasted food was calculated based on the theoretical food conversion ration FCR_{teo} and the food conversion ratio given by the farmer FCR_{real} (see Table 4). FCR_{teo} is based on the requirement of the fish and type of feed given. The model results show that most of the outlet of particulate matter from the cages does not settle at the bottom due to the large fluctuation of the current speed ($U_{\text{std}}=9$ cm/s) and the oxygen concentration at the bottom is above the critical level of 3 mg/l. Observations at the site (Porrello et al. 2005) show high levels of organic enrichment, indicating that much of the organic matter settling from the farm are in fact not transported away by the occasionally high current speeds as predicted by the model.

The production cycle of this site according to the model is 16.5-18 months for the fish to reach the weight of 380 g with an initial weight of 10 g, and with a median weight of 103-108 g during the production cycle. The higher figures are for sea bass. This is similar to the production cycle at the Sounio site in Greece. The faster growth than at the Croatian site is probably due to higher temperatures in the waters of the sites in Greece and Italy.

4.5.3 Conclusion

This site is well suited for fish farming due to the high current speed. The holding capacity of the farm with the present configuration, where the cages are well separated is about twice the present production of the area indication a low exploitation of the site. But, this conclusion is based on the model results that only a minor part of the organic matter settling from the cages will settle at the seafloor, but according to observations this does not seem to be correct. The results from the model and observation do not match. One may speculate that the current measurements made are not representative to the area below the cage. The cages are

submerged below the surface and may affect the current velocity below the cages, reducing the current speed. The spreading of particulate matter is than less than calculated by the model, which is what is seen at the site. The difference between FCR_{real} and FCR_{theory} is the smallest in this study, but one may decrease FCR_{real} also at this site. The protein retention of the fish is only 26 %, why also the protein content in the fish food can be reduced considerably.

4.6. Bisceglie-Italy

4.6.1 Background

Four groups of cages are located on open sea NE of Bisceglie harbour, 3.2 km away from the coast. The dominating current is in the ESE and WNW direction, with a mean speed of 13.8 cm/s and 9.7 cm/s at 2 m and 18 m depths, respectively. The value of U_{std} at this site is high and above 3.5 cm/s, indicating minor sedimentation of organic matter below the farm. The fish farm produce sea bream and sea bass. The MOM model is run on three cage groups with sea bream in group 1 and 2, and sea bass in group 3. The cage groups are of the same size but group 1 is oriented perpendicular to the main current, while the other two are place in the direction of the main current. The water depth is 21.5 m. The cage groups are run separately. The number of cages in each group and the layouts are presented in Table 4.6.1.

The total production of the farm is 700-900 tonnes/year, with a production cycle of 12-14 months and an end weight of 350-400 (see SDR-Bisceglie). The fish are given feed with protein content of 46-52%, and the real food conversion ratio, FCR_{real} , is 1.5-2.0.

Model input:

Table 4.6.1. Farm layout

Site	No. cages	No. rows	diameter/ side length (m)	Spacing (m)	Water depth (m)	Reduction of flow factor (0-1)	Farm direction (deg)
Bisceglie 1	9	3	19 (d) & 13	20	22	0.8	90
Bisceglie 2	12	2	12	2	22	0.8	90
Bisceglie 3	15	2	15	2	22	0.8	90

Table 4.6.2. Surrounding water characteristics

Site	Sal. (psu)	Temp. (C)	Ox. (mg/l)	Amm. (mg/l)	Currents (cm/s)	U_{min}	U_{std}	U_{bent}
Bisceglie1	38	14-25	5	0.003		0.85	12	0.68
Bisceglie2	38	14-25	5	0.003		0.93	12	0.68
Bisceglie3	38	14-25	5	0.003		0.93	12	0.68

Table 4.6.3. Fish data (from Cephalonia, Greece, Magill et al. 2006)

site	Fish	Start weight (g)	End weight (g)	Protein cont. (0-1)	Fat cont. (0-1)	Sinking speed of faeces (cm/s)
Bisceglie 1	sea bream	10	380	0.2	0.04	0.5
Bisceglie 2	sea bream	10	380	0.2	0.04	0.5
Bisceglie 3	sea bass	10	380	0.2	0.04	0.7

Table 4.6.4. Food data

	Protein cont. (0-1)	Fat cont. (0-1)	Carbohydrate cont. (0-1)	Ash cont. (0-1)	Sinking speed of faeces cm/s	FCR _{teo} /FCR _{real}
Bisceglie 1	0.46	0.22	0.02	0.09	8	1.14/1.7
Bisceglie 2	0.46	0.22	0.02	0.09	8	1.14/1.7
Bisceglie 3	0.46	0.22	0.02	0.09	8	1.09/1.7

4.6.3 Results

The water quality at this site is good, but since two of the cage groups are placed along the direction of the main current the through flow is not optimised and the limiting criteria is in fact the water quality in the cages at this site. With the values of the dimensioning current (U_{min}) shown in Table 4.6.2, the longest flushing times are about one hour for Bisceglie 1, and 1.5 hours for Bisceglie 2 and 3. The oxygen concentration of the surrounding water is 6.3 mg/l, and with the configuration of Bisceglie 1 the holding capacity is about 410 tonnes/year, and about 370 tonnes/year with the configuration of Bisceglie 2 and 3. The reason for the larger holding capacity shown for Bisceglie 1 is the shorter farm length in the main current direction. The holding capacity can be increased further with even more separated net pens, which will increase the trough flow and thereby the holding capacity of the site.

The outlet of dissolved nutrients from the cage groups per 1 tonne of fish production are 7 kg of phosphorus (P), and 44 kg of nitrogen (N) for Bisceglie 1-3, and are calculated based on the requirement of the fish and the amount of protein in the food, where most of the nutrients are tied up (REF). The release of dissolved nutrients is a few kg less with sea bass in the pens. The excessive nutrients can be reduced by reducing the amount of protein in the feed. The outlet of dissolved nutrients is hard to validate. Local peaks of chlorophyll were observed at the stations near the farm but it is hard to tell from measurements how large the eutrophication effect due to the farm release of nutrients is. A Bioassay study at the site confirmed a fast dilution of released nutrients (SDR-Bisceglie).

The outlet of particulate matter from the farm per 1 tonne of fish production are with the estimated holding capacity; 8/9 kg (P), 50/54 kg (N), 163/156 kg of faeces, and 563/614 kg of wasted food at Bisceglie 1-2 with sea bream and Bisceglie 3 with sea bass. The wasted food was calculated based on the theoretical food conversion ration FCR_{teo} and the food conversion ratio given by the farmer FCR_{real} (see Table 4). FCR_{teo} is based on the requirement of the fish and type of feed given. The results show a slightly higher release of faeces and food from the cage with sea bass. The model results show that most of the outlet of particulate matter from the cages does not settle at the bottom due to the occasional high current speed and the oxygen concentration at the bottom is above the critical level of macro fauna of 3 mg/l. ECASA observations at the site show that the density of the biomass and the diversity increases towards the cage group, except at station S1 close to the cage where the biomass increase rapidly with a small decrease in the diversity. This indicates a minor enrichment of organic matter below the cages compared to the surrounding bottom attracting more species, and a well oxygenated bottom, which agree with the model result.

The production cycle of this site is 12-14 and the model predicts 16.5 month for the fish to reach the weight of 380 g with an initial weight of 10 g, and with a median weight of 109-118 g during the production cycle. The starting weight given by the farmer is between 10 and 100 g and the by the model calculated production cycle with a starting weight of 50 g is 12.7 months for sea bream and 12.3 months for sea bass. The results indicate a slightly faster growth of sea bass than of sea bream during the same conditions.

4.6.3 Conclusion

This site is well suited for fish farming due to the high variability of the current speed. The holding capacity of the farm with the configuration of Bisceglie 1 and Bisceglie 2-3, and with both MOM criteria fulfilled (see above) is 410 tonnes/year and 2·370 tonnes/year which is above the present total production of 700-900 tonnes/year. The limiting criterion is the water quality in the cages. The configuration of the farm is not optimal and the holding capacity of the site may be increased by separating the net pens even further and place them in single rows perpendicular to the main current direction. One may also decrease FCR_{real} at this site. The protein retention of the fish is only 26 %, why also the protein content in the fish food can be reduced considerably.

5 Summary

The production cycle was given for most sites and can be compared with the production cycle estimated from maximum growth in the model. The production cycles given by the farmers are usually an interval, which may be due to different fish species or a varying starting weight. The only site for which the interval is explained is at Bisceglie in Italy giving the starting weight (10-100 g) as the cause for different length of the production cycle. The model calculates the production cycle from a starting weight of 10 g or 50 g, and the different end weight given for the sites (Table 5.1).

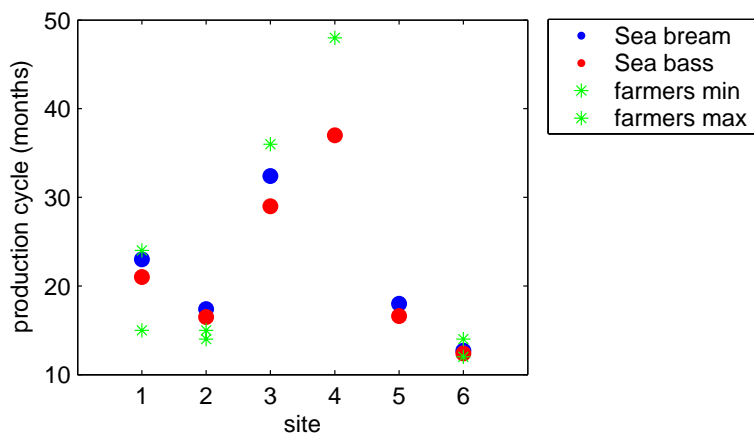


Figure 5.1. The production cycle of each site calculated with a starting weight of 10 g or 50 g, and a typical end weight of the fish given by the farmer (dots), see Table 7.1. And minimum and maximum production cycle given by the farmer (stars). The sites are: 1) Dalmar-Croatia, 2) Sounio-Greece, 3) Cephalonia-Greece 4) Piran-Slovenia, 5) Porto Ecole-Italy, and 6) Bisceglie-Italy.

With the starting weight used in the model it then calculates a maximum production cycle in the upper end of the interval given by the farmer.

Table 5.1. The start and end weight used in the model for calculation of the production cycle.

site	Start weight	End weight	End weight given by farmer
Dalmar-Croatia	10 g	330 g	330 g
Sounio-Greece	10 g	380 g	350-400 g
Cephalonia-Greece	10 g	1500 g	1500 g
Piran-Slovenia	10 g	1000 g	1000 g
Porto Ecole-Italy	10 g	380 g	350-400 g
Bisceglie-Italy	50 g	380 g	350-400 g

The model estimates the shortest production cycle possible based on good water quality and local temperature. Comparing the estimated length of the production cycle with the factual length will indicate if the growth is optimised or not, and the growth can thereby be used as an indicator of the water quality of the farm. The results in Figure 7.1 show that the model seems to be able to predict the production cycle of sea bream and sea bass. It may be noted that the production cycle of sea bass is shorter than of sea bream at all sites. At Sounio in Greece it seems that the growth is faster than predicted by the model, and this indicates that the model might underestimate the maximum growth, or that the information about this site is not correct. The difference between the production cycle predicted by the model and the one given by the farmer is about 25 % at Piran in Slovenia. The model result was confirmed by the farmer (see section 4.4). From the above results one realises that fish growth can be used as a water quality indicator, where the fish growth in the farm is compared to the maximum growth under good environmental conditions estimated by the model.

The flushing time of the cage groups at the different sites vary widely. The main axes of the cage groups at most sites (not the Italian) are in the direction of the main current. The reason for this is unknown to us but may be to reduce current drag. The effect is that the flushing of the net pens is not optimal at these sites. Since the limiting criterion at some of the sites according to the model was the water quality in the net pens this might be considered in future farming strategy.

The output of dissolved nutrients from the different farms was calculated by the model and was compared with the result from bioassay studies or observations of nutrient and chlorophyll concentrations at the sites. At those sites where bioassay experiments were performed a local effect of nutrient enrichment was shown, but the actual quantities were not given by the bioassay studies and can thereby not be confirmed. At sites with no bioassay studies it seemed hard to find any signs of eutrophication based on observations of nutrients and chlorophyll at the sites (see e.g. SDR-Dalmar).

The output of particulate phosphorus, nitrate, faeces, and feed is calculated for each tonne produced at the farm, but the only site where the flux or organic matter was measured was at Dalmar in Croatia. The highest sedimentation rate with local oxygen conditions that the site can cope with, still allowing macro benthos at the bottom below the farm, i.e. oxygen conditions above 2 ml/l is calculated by the model. The holding capacity of the farm is then estimated from the calculated dispersion of particulate matter produced by the farm. To judge the result of the model we used the information from ECASA observations and information in the site description reports, describing the effect of the fish farms at the bottom below and in the vicinity of the farms. The result of the model was found to be correct at most sites. At Porto Ecole in Italy the model result showed that the first MOM criterion was fulfilled ($O_2 > 2$ ml/l) based on the large variability of the current, while observations at the site indicate the opposite, i.e. a large enrichment of organic matter below the farm (Porrello et al. 2005).

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