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Note

Predicting aquaculture waste from gilthead seabream (*Sparus aurata*) culture using a nutritional approach

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Abstract – A model to estimate the waste production from sea cage culture was established. Using known feed inputs of nitrogen, phosphorus and organic matter, the model quantifies waste discharge from seabream culture. Daily feed intake and growth in *Sparus aurata* fed a commercial diet with known composition were measured and found to be dependent on fish weight and water temperature. Digestibility of the commercial feed was measured using chromic oxide as a marker and collection of feces by stripping. The proximate composition of *Sparus aurata* at different sizes was determined and nitrogen and phosphorus content were on average 28.5 and 7.2 $g \cdot kg^{-1}$ body mass, respectively. Excretion of ammonia-nitrogen and inorganic phosphorus after metabolic processes was calculated as the difference. © Ifremer/Elsevier, Paris

Mass-balance model / growth model / digestibility / body composition / nitrogen / phosphorus / *Sparus aurata*

1. INTRODUCTION

The recent and continuing expansion of seabream and seabass cage farming in the Red and Mediterranean seas has led to questions on the degree of the ecological impact that can be anticipated in the future. The Red Sea farms in question are situated in southern Israel, in the Gulf of Aqaba, in close proximity to the borders of Egypt, Jordan and Saudi Arabia. The water in this region is highly oligotrophic [7] due to minimal runoff from the surrounding deserts and a low population density. The high nitrogen and phosphorus concentrations of aquaculture discharges are a potential threat to the oligotrophic water of the Gulf. Nutrient enrichment can alter the community of plants and organisms [6] and might endanger fragile ecosystems such as the coral reefs [2], which are abundant in the Gulf. There is growing pressure to develop methods for predicting the effects of fish farms on their surroundings and to develop an environmentally friendly mariculture.

In mariculture, the majority of the feed waste dissolves directly into the water, dispersing quickly and making monitoring and quantification difficult. Therefore, a mass-balance model [3, 4] is proposed here instead of the conventional chemical approach. This paper deals with the methods used to derive the parameters for the following model: feed intake = retention + feces + excretion

2. MATERIALS AND METHODS

2.1. Growth and feed intake

Various small scale growth experiments were performed in triplicate tanks with gilthead seabream ranging from 1 to 400 g. The fish were fed twice daily to satiation, taking care that no food was left uneaten. Food used in these trials was a local commercial seabream diet (Matmor Inc., M.P. Evtach, Israel) with composition as shown in *table I*. According to the increasing fish sizes, 0.2 or 3 m^3 tanks were stocked at densities ranging from 0.25 to about 10 $kg \cdot m^{-3}$ at the end of a growing trial. The outdoors tanks were supplied with flow-through sea water (41 ppt, flow rate

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Table I. Proximate composition of the commercial diet fed to gilthead seabream (in $g \cdot kg^{-1}$ and $MJ \cdot kg^{-1}$) on an as fed basis.

Dry matter	929
Gross energy	19.3
Protein	460
Lipid	115
Ash	110
Phosphorus	14.1
Nitrogen	73.6
Digestible protein[1]	380
Digestible energy[1]	15.0

[1] Obtained through digestibility tests.

8 $L \cdot min^{-1}$) at ambient temperatures ranging from 19–26 °C during the course of the year.

Fish were weighed every 14 days, and the average daily weight gain and daily feed intake during two successive weighings was calculated. The corresponding body weight used in these calculations was the average weight of the fish during that period. Thus two sets of each 100 raw data relating weight gain to fish weight and temperature and also feed intake to fish weight and temperature were obtained.

2.2. Digestibility

Apparent digestibility coefficients (ADC) of the commercial diet were determined in triplicate using fish weighing from 300 to 400 g [5]. Chromic oxide (Cr_2O_3) was added as 0.8 % to the food as a marker and feces were collected by stripping. Equation (1) was used to calculate the apparent digestibility coefficients for nitrogen (N) and phosphorus (P):

$$ADC = 100 - [100 \times (Cr_{diet}/Cr_{feces}) \times (x_{feces}/x_{diet})] \quad (1)$$

where *Cr*: chromic oxide, and *x*: nutrients N or P.

The separation of feces into soluble and particulate matter was measured after submersing three groups of duplicate samples of dried feces into beakers filled with distilled water at a temperature of 23 °C. The samples were stirred from time to time to simulate movement of feces in the water column under the sea cages. The samples were filtered after 6, 24 and 48 h using pre-weighed and pre-dried filter paper (Whatman 1, qualitative) and the remaining matter was dried and analyzed for nitrogen and phosphorus. Soluble matter was then calculated as the difference.

2.3. Fish and food

During the course of the growing period 23 groups of 10–20 equal sized fish each were selected for determination of body composition with average weights ranging from 1 to 250 g (fish differing by more than 10 % from the mean were excluded). Before being used for analysis, the frozen fish were cut into small pieces and ground twice through a meat grinder using a 3 mm die. A sample for estimation of dry matter was taken from the ground fish before the remaining homogenate was freeze-dried. The freeze-dried samples were later mixed again using a blender before all remaining analyses were carried out. The feed samples were finely ground in a hammer mill using a 1 mm screen.

2.4. Analytical procedures

Identical analyses were applied for diets, feces and fish body homogenates and performed in duplicates. Dry matter of fresh samples was calculated by weight loss after 24 h drying at 105 °C. Ash was calculated from the weight loss after incineration of the samples for 24 h at 550 °C in a muffle furnace. Nitrogen was measured using the Kjeldahl technique. Total phosphorus was determined after ashing the samples and using the vanado-molybdate method [1]. The resulting color was measured by spectrophotometer against a phosphorus standard at 435 nm. Energy content was measured by combustion in a Parr bomb calorimeter using benzoic acid as standard.

2.5. Statistical procedures

All the equations were obtained by applying linear regression analysis using the software SPSS 6.1 for Windows (SPSS Inc. 1989–1992). Descriptive statistics are mean ± SE if not otherwise noted.

3. RESULTS AND DISCUSSION

3.1. Growth and feed intake

The relationship between weight gain (Y_1), body weight (X) and temperature (T) was not linear and the raw data fitted best to the logarithmic transformation of the data in the manner of

$$\log Y_1 = \log a_1 + b_1 \log X + c_1 T \quad (2)$$

The antilog of this expression produces the final equation:

$$Y_1 = a_1 X^{b1} e^{c1T} \quad (3)$$

The parameters (± SE) describing the relationship are as follows: Y_1 = weight gain ($g.fish^{-1} \cdot day^{-1}$); a_1 = 0.0167 ± 0.0062; b_1 = 0.621 ± 0.033; c_1 = 0.055 ± 0.014 (for temperatures between 20 and 26 °C); and r^2 = 0.85.

The daily feed intake (Y_2) dependent on weight (X) of fish and temperature (T) could be described by the same equation using the following parameters (± SE): Y_2 = feed intake ($g.fish^{-1} \cdot day^{-1}$); a_2 = 0.017 ± 0.0049; b_2 = 0.710 ± 0.028; c_2 = 0.060 ± 0.011 (for temperatures between 20 and 26 °C); and r^2 = 0.89.

By applying the two equations which describe daily feed intake and growth, specific feeding tables can be established using a simple spreadsheet computer program (*table II*). Growth predictions for a range of fish sizes as well as different temperatures can be made; in this example, data were calculated at a water temperature of 23 ± 1.8 °C which is the average yearly surface temperature of the Gulf of Aqaba. As can be seen, absolute weight gain as well as the amount of food eaten increases with increasing weight while the efficiency of retention as added body mass decreases with increasing fish size, which is reflected in the rising FCR values.

3.2. Composition of the retained body mass

Average nitrogen and phosphorus content were found to be on average 28.5 ± 1.8 $g \cdot kg^{-1}$ (mean ± SD) and 7.2 ± 1.0 $g \cdot kg^{-1}$ live weight, respectively.

By combining the information on nutrient composition of the feed (*table I*) with intake (*table II*) and the composition of the weight gain a more detailed description for nitrogen and phosphorus intake and their retention at various fish sizes can be given (*table III*). The same pattern as described before, specifically a decreasing efficiency of nutrient utilization for retention with increasing fish size, can be detected.

3.3. Quantification and fractionation of feces

Using equation (1) for evaluating the digestibility of the commercial feed the following apparent digestibility coefficients were determined (*table IV*).

After fractionation of the feces using the procedure as described above, the portions of solid and dissolved fecal matter could be quantified as shown in *table V*. The fractionation reached a plateau already after 6 h, no significant changes were observed for the next 42 h and the average value was used for further calculations.

3.4. Nitrogen and phosphorus budget in seabream culture

Using the various sections of the mass-balance equation derived for gilthead seabream, the nutrient budget of a commercial farm can be provided, assuming the same feed is used and mortality is already accounted for (*figure I*). To produce 1 ton of 400 g fish, 1 790 kg of food is needed, which corresponds to a FCR of 1.79. This is equivalent to an input of 132 kg nitrogen and 25 kg phosphorus. About 22 % of the nitrogen and 29 % of the phosphorus is taken up by the fish as growth over the whole period. From the feed, nitrogen and phosphorus, 17 and 52 % respectively, are excreted as feces. A portion of this fecal matter then dissolves in the water leaving about 10 % of the feed nitrogen and 44 % of the feed phosphorus to accumulate in the sediment. The remainder of the budget

Table II. Prediction of weight gain, feed intake and feed conversion efficiency for *Sparus aurata* fed on a commercial diet (at a water temperature of 23 °C).

Weight (g/fish)	Weight gain (g/fish/day)[1]	Feed intake (g/fish/day)[2]	Total amount of feed consumed (g/fish)[3]	Time of growth (days)[4]	FCR[5]
1	0.06	0.07		0	1.14
10	0.25	0.35	11.8	62	1.31
50	0.67	1.09	73.1	152	1.49
100	1.03	1.78	156.8	211	1.58
200	1.59	2.91	334.7	287	1.68
300	2.04	3.88	521.2	343	1.74
400	2.44	4.76	713.5	387	1.79

[1,2] Calculated using the respective equations at an average temperature of 23 °C.
[3] Predicted total feed consumption per fish.
[4] Predicted time of growth.
[5] Predicted feed conversion ratio – feed consumed (g)/weight gained (g).

Table III. Efficiency of utilization of nitrogen and phosphorus in gilthead seabream dependent on body weight (at 23 °C).

Weight (g/fish)	Weight gain (g/fish/day)	N intake (mg/day/fish)	P intake (mg/day/fish)	N efficiency (%)	P efficiency (%)
1	0.06	5	0.9	34	45
10	0.25	25	4.8	27	37
50	0.67	80	15.2	24	32
100	1.03	131	24.9	23	30
200	1.59	214	40.7	21	28
300	2.04	285	54.3	20	27
400	2.44	350	66.6	20	26

Table IV. Apparent digestibility coefficients (ADC) of the commercial diet fed to gilthead seabream (mean ± SD).

	ADC (%)
Energy	77.8 ± 0.2
Nitrogen	82.8 ± 0.6
Phosphorus	47.8 ± 2.8
Organic matter	68.9 ± 0.5
Dry matter	60.7 ± 1.1

(excretion) is calculated as the difference and consists mainly of ammonia-bound nitrogen released through the gills and of phosphorus excreted as ortho-phosphate via the urine.

Using the ADC values and the information about the fractionation of the feces (*tables IV* and *V*) the production of 1 ton of fish up to a marketable size of 400 g would produce 447.5 kg total solids, from which 322.2 kg will be organic matter, 13.2 kg nitrogen and 11 kg phosphorus, which will settle down on the sediment, and a total of 89.7 kg soluble nitrogen and 6.8 kg soluble phosphorus.

In seabream culture in Israel, there are no regulations yet concerning the feed. But governmental regulatory authorities are limiting total production in the Gulf of Aqaba until sufficient data on the environmental impact of the sea cages is available to allow responsible decisions on future expansion. Being able to predict aquaculture waste from a fish farm provides a helpful tool for both the farmer and the government regulator. Using this model, the farmer can predict the feed used to grow his fish. At the same time, government regulators can use this model to predict 'environmental enrichment' resulting from the operation of farms in their jurisdiction.

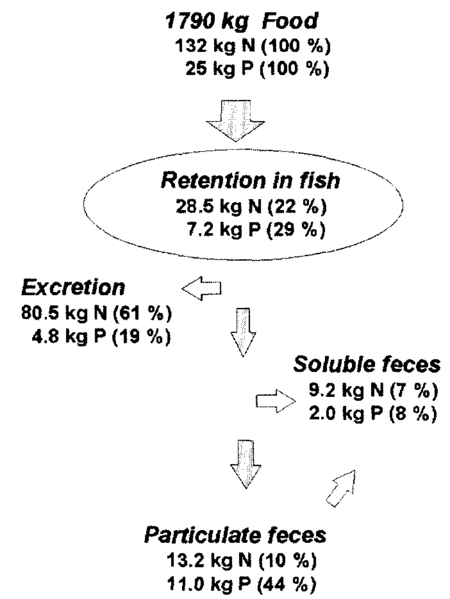

Figure 1. Nutrient budget for gilthead seabream culture in kg·ton^{-1} fish produced up to 400 g size (all percentages expressed relative to feed input).

Table V. Remaining particulate matter and nutrients after submersion of feces in water for 6, 24 and 48 h (expressed as percentages relative to initial fecal DM, mean ± SD).

	6 h	24 h	48 h	average value after 48 h
Nitrogen	57.4 ± 0.11	54.9 ± 2.13	56.8 ± 0.59	56.4 ± 1.07
Phosphorus	88.3 ± 0.67	81.5 ± 0.76	84.0 ± 1.57	84.6 ± 2.81
Organic matter	59.0 ± 0.36	57.8 ± 0.65	57.8 ± 0.11	58.2 ± 0.57
Dry matter	65.0 ± 0.64	63.7 ± 0.31	64.6 ± 0.44	64.4 ± 0.54

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