Vol. 3: 187–195, 2013
doi: 10.3354/aei00059

AQUACULTURE ENVIRONMENT INTERACTIONS
Aquacult Environ Interact

Published online April 10

Waste loading into a regulated stream from land-based trout farms

Mehmet Ali Turan Koçer*, Mahir Kanyılmaz, Adil Yılayaz, Hüseyin Sevgili

Mediterranean Fisheries Research, Production and Training Institute, Hurriyet Mah Akdeniz Bul No:2, 07192, Döşemealtı, Antalya, Turkey

ABSTRACT: This study aimed to characterize the effluents of 3 flow-through farms with annual production rates of 250, 750 and 2500 t yr^{-1} at a site with a total annual production of 4400 t yr^{-1}. We determined the nutrient loads from rainbow trout *Oncorhynchus mykiss* farms using nutritional and hydrological mass-balance models and estimated the fluxes into a regulated stream and into the Mediterranean Sea between March 2008 and February 2009. When compared with the influent, farming activity significantly decreased dissolved oxygen ($p < 0.001$) and increased biochemical oxygen demand, suspended solids, and nitrogen and phosphorus fractions ($p < 0.05$) in the effluents. The load predictions of 44.3 kg N and 8.4 kg P t^{-1} of fish produced by the nutritional method were close to the measured values of 43.9 kg N and 8.8 kg P t^{-1} of fish produced. The load prediction for suspended solids was the same as the measured value of 278 kg t^{-1} of fish produced. The predictions were well correlated with measurements for suspended solids and for total nitrogen and phosphorus. The estimated annual mass fluxes of nitrogen and phosphorus from trout farms at the site into the eastern Mediterranean Sea were 125 to 127 and 24 to 25 t yr^{-1}, respectively. The nutritional mass-balance model may be the method of choice as a decision tool for the environmental impact assessment of land-based aquaculture because of its simplicity and easy application.

KEY WORDS: Rainbow trout · *Oncorhynchus mykiss* · Farm effluents · Waste loads · Mass-balance models · Mediterranean Sea

INTRODUCTION

The environmental impacts of aquaculture activities have drawn considerable attention over recent years (Subasinghe et al. 2009). To control the environmental impacts of aquaculture, some countries have instituted various limitations to either stocking density and feed use or concentrations of suspended solids, organic matter, and nutrients in effluents (Tacon & Forster 2003). Although environmental impact assessments are mostly based on the concentrations of particular compounds in the effluents of land-based farms, the pollution of receiving water bodies is mainly related to total waste loads per unit time (Rodrigues 1995). To estimate total waste loads many efforts have been made to date (e.g. Cho et al. 1991, Kelly et al. 1996, Aubin et al. 2011). The main purpose of load estimations is to predict the existing and future discharge of suspended solids, organic compounds, and nutrients, thereby allowing authorities to quantify the environmental impacts of activities with the greatest accuracy (Frier et al. 1995).

Waste loads from land-based aquaculture have commonly been estimated using mass-balance models containing 2 main approaches: hydrological and nutritional methods, which are also called chemical/limnological and biological/bioenergy methods, respectively. The hydrological method is based on the measurement of selected indicators between the inlet and the outlet of fish farms by taking the flow

*Email: matkocer@akdenizsuurunleri.gov.tr

Publisher: Inter-Research· www.int-res.com

rate into consideration (Roque d'Orbcastel et al. 2008, Aubin et al. 2011). However, there may be uncertainties arising from changing farm practices and sampling methodologies, which can result in temporal variations in the suspended solids and nutrient concentrations in the effluent (Cho et al. 1991, Papatryphon et al. 2005). This method may be required for frequent or continuous monitoring of inflow and outflow water quality to assure data precision and accuracy (Kelly et al. 1996).

The nutritional method has been developed as a simple and economical alternative to the hydrological method, and uses a simple nutrient balance and bioenergetics approach (Cho & Bureau 2001). The principle is based on the assessment of the difference between the nutrients and digestible energy supplied to fish and their body nutrient and energy gains. The proportion not retained by the fish for growth is released into the water and constitutes the waste emissions of the fish farm (Cho & Bureau 2001, Aubin et al. 2011).

Aquaculture is one of the fastest-growing industries in Turkey, having enlarged in volume by >20% between 2000 and 2010. Rainbow trout *Oncorhynchus mykiss*, with a 78 000 t yr^{-1} production rate in 2010, was the dominant species, representing 99% of the production in Turkish inland waters (TURKSTAT 2012). Turkey is currently the third-largest farmed-finfish producer in Europe and the top producer of rainbow trout (Deniz 2010). However, there are not only limited data on the estimation of the carrying capacity of Turkish river basins for land-based aquaculture, but also on the waste load estimation from trout farms (but see Pulatsü et al. 2004, Kırkagaç et al. 2009, Taşeli 2009, Tekinay et al. 2009, Bilgrin Yıldırım & Pulatsü 2011).

In the present study, we aimed to characterize the effluents of flow-through farms with different production capacities in a major rainbow trout site and estimate emissions of suspended solids, nitrogen, and phosphorus by the hydrological and the nutritional methods based on monthly data of water quality monitoring and annual average farm records. We also aimed to predict total nutrient flux from the farms into the Mediterranean Sea through the receiving stream using a simplified mass-loading model.

MATERIALS AND METHODS

Study site and trout farms

Eşen Stream, arising 2000 m above sea level and discharging into the Mediterranean Sea is the most significant rainbow trout *Oncorhynchus mykiss* production site of the flow-through raceways in Turkey. Its catchment comprises 50 farms, with a licensed capacity of about 7500 t yr^{-1} and 176 million fry yr^{-1}. Most of the production takes place at the Çaygözü site, midstream in the basin. At this site, the 9 single-pass flow-through farms, with a total capacity of 4400 t yr^{-1}, are located along a stream reach of 2 km (Fig. 1).

The stream flow is diverted to a hydroelectric power generation in the upper stream region. A hydroelectric power plant (HEPP 1) is operated using the tail water of an upstream dam, and its outlet is discharged to the Çaygözü site. Then the flow is dammed up with a control gate (Regulator 1) below HEPP 1 and diverted into a conveyance canal. The conveyance canal water is used for irrigation (Regulator 2), and then, through a second hydroelectric power plant (HEPP 2), is finally discharged into Fethiye Bay part of the Mediterranean Sea (Fig. 1).

The total annual flow of the stream reach taking the discharges of all the trout farms was 373 × 10^6 m^3 yr^{-1} over the study period, between March 2008 and February 2009. A significant portion of the total flow (312 × 10^6 m^3 yr^{-1}) was diverted into the conveyance canal by Regulator 1. About a third of this portion

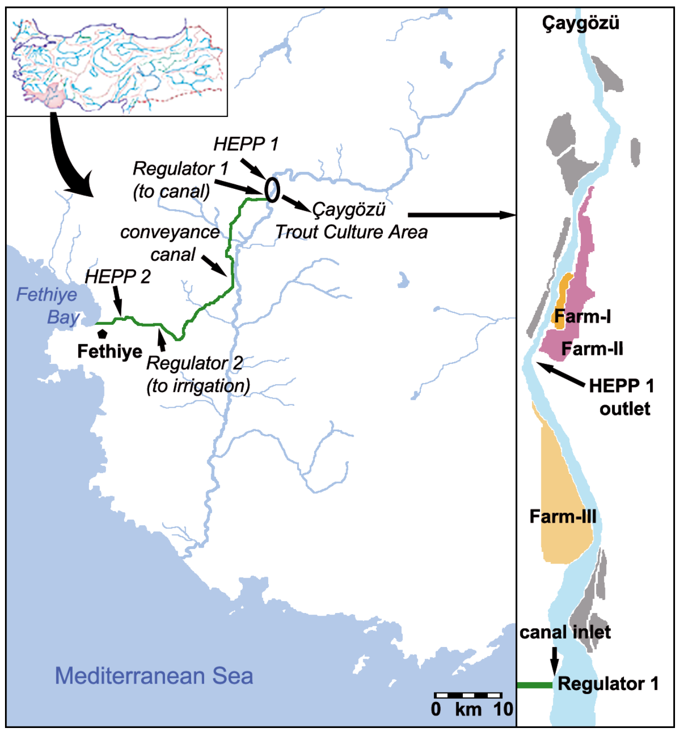

Fig. 1. Location of Eşen Stream (left panel and inset) and the monitored farms at the Çaygözü site (right panel) in Turkey. HEPP: hydroelectric power plant

(109×10^6 m^3 yr^{-1}) was used for irrigation diverted by Regulator 2, whereas the rest was discharged into Fethiye Bay (Fig. 1).

We monitored effluents of 3 farms with different production rates at the Çaygözü site. Farms I and II took their inflows from the stream receiving effluents from 4 other farms further upstream, with a total annual capacity of about 350 t yr^{-1}. Together with another one, these farms had a total annual capacity of 1200 t yr^{-1}, and their effluents discharged to the stream above the inflow of Farm III, in addition to the outflow from HEPP 1 (Fig. 1).

Annual production capacities of the monitored farms were 250, 750, and 2500 t yr^{-1}, respectively. Feed was distributed by hand twice a day at predetermined levels, changing according to size and biomass. Inflow rates were 1.1, 2.4, and 5.0 m^3 s^{-1} in ascending order by farm size, while the measured temperatures were 13.8 ± 0.7°C, 14.1 ± 0.7°C, and 13.1 ± 1.5°C during the study period, respectively. Although Farms II and III had settling ponds for solids removal, their overflow rates were high (>400 m^3 m^{-2} d^{-1}) compared with the recommended values for optimal effluent settling (Stewart et al. 2006). Farm I had a microscreen drum filter unit for effluent treatment, which was not active during the study period. It can be seen from the data gathered that none of the farms in the studied area employed effective effluent treatment practices.

Water sampling and analyses

Monthly water samples were collected from the inlets and outlets of the farms. Flow rates in the farms, stream and conveyance canal reaches were measured monthly by a digital meter (Hydro-Bios, Model RHCM). Suspended solids, chemical/biochemical oxygen demand, ammonia, and nitrite were analyzed on the sampling day, while the other analyses were completed on the following day.

At the inlet and outlet of each farm, water was characterized *in situ* by means of a probe with polarographic and thermistor type sensors (Yellow Spring Instruments, Model 55) for temperature, dissolved oxygen (DO), and oxygen saturation (SAT). Suspended solids (TSS) were determined by filtration using a glass fiber filter. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were determined via the 5 d incubation and open reflux methods, respectively. Total ammonia nitrogen (TAN), nitrite nitrogen (NO_2-N), and nitrate nitrogen (NO_3-N) were determined by phenate, colorimetrical, and cadmium reduction methods, respectively. Soluble reactive phosphorus (SRP) and total inorganic phosphorus (TIP) were determined using the ascorbic acid method from filtered samples and hydrolyzed unfiltered samples, respectively. Total nitrogen (TN) was determined as nitrate following alkaline persulfate oxidation of unfiltered samples, while total phosphorus (TP) was determined as SRP following acidic persulfate oxidation. All laboratory analyses were performed according to standard methods (APHA 1998). Nutrient forms were determined using a spectrophotometer (Thermo, Model Helios-α).

Dissolved inorganic nitrogen (DIN = TAN + NO_2-N + NO_3-N), total organic nitrogen (TON = TN − DIN), and total organic phosphorus (TOP = TP − TIP) were calculated from total and inorganic fractions (APHA 1998).

Calculations and statistics

Differences ($\Delta C = C_{out} - C_{in}$) between outflow and inflow concentrations and relative concentration differences ($\%\Delta C = \Delta C/C_{in} \times 100$) in the monitored farms were calculated for each parameter (Sindilariu et al. 2009).

The nutritional method was based on data provided by feed manufacturers, farm records, and literature (Papatryphon et al. 2005, Roque d'Orbcastel et al. 2008) (Table 1). Although there could be seasonal variations in farm parameters such as fish stocks and feeding rates, we used the average annual feed conversion based on interviews with the farmers to estimate the average daily feeding rate. The hydrological method was based on concentration differences (ΔC) of parameters and flow rate measurements (Roque d'Orbcastel et al. 2008, Aubin et al. 2011).

Normality of data was tested for each parameter using the Shapiro-Wilk test. The differences of each parameter from zero with normal and non-normal distribution were tested using a *t*-test and Wilcoxon test, respectively. Comparisons of normally distributed ΔCs by production rate (l s^{-1} t^{-1} of fish produced) were made using analysis of variance (ANOVA), whereas the signed-rank test (Wilcoxon), followed by the Student's *t*-test, was used for non-normally distributed ΔCs. To understand the relations between farm production rates and the observed parameters, correlation coefficients were determined.

Nutrient flux (loading) into the Mediterranean Sea from the 9 land-based trout farms at the studied site was estimated by a simple mass-balance equation.

Table 1. Data used for nutritional mass-balance modelling in the present study

Feed management variables[a]	
Mean feeding rates (kg d^{-1})	
Farm I	750
Farm II	2260
Farm III	7530
Feed waste (%)	4
Feed conversion ratio	1.1
Mean feed composition (%)[b]	
Protein	44
Lipids	18
Carbohydrates	10
Ash	12
Fibre	3
Moisture	10
Phosphorus	1.2
Digestibility (%)[c]	
Protein	87
Lipids	95
Carbohydrates	60
Ash	50
Fibre	0
Phosphorus	45
Whole-body nutrient content[c]	
Nitrogen (kg kg^{-1})	0.0272
Phosphorus (kg kg^{-1})	0.004
Protein nitrogen content (%)	16

[a]From farm records; [b]from feed manufacturer; [c]from literature data (Papatryphon et al. 2005, Sindilariu 2007, Roque d'Orbcastel et al. 2008)

Mass flux in a given period can be calculated at a steady-state considering hydraulic balance (James 1993, Cox 2003). We estimated the mass-flux equation following the method of James (1993), with a slight modification. Because there is no inflow to the open channel system between the receiving stream reach and the sea (Fig. 1), we calculated the mass loading from the estimated annual average nutrient concentrations in the receiving stream reach and data on the total annual discharges in the conveyance channel. We neglected the other nutrient sources to estimate the specific loading from aquaculture activities and assumed the modeled nutrients as conservative. Accordingly, average annual concentration, discharge, and mass-balance were:

$$C = L / Q_1 \quad (1)$$

$$L = L_f P_f \quad (2)$$

$$L_{1,2,3} = Q_{1,2,3}\, C \quad (3)$$

$$L_{1,2,3} = Q_{1,2,3}\, (L_f P_f / Q_1) \quad (4)$$

where L is the total annual loading into the receiving stream reach from fish production (kg yr^{-1}), L_f is the estimated waste loads per fish mass (kg t^{-1} of fish produced), P_f is the total annual fish production (t yr^{-1}), C is the average annual concentration of TSS, TN and TP (kg m^{-3}), $L_{1,2,3}$ are the total annual mass fluxes in the receiving stream (L_1) reach and conveyance channel after Regulators 1 (L_2) and 2 (L_3), respectively (kg yr^{-1}), $Q_{1,2,3}$ are the total annual flow rates in the receiving stream reach and conveyance channel after Regulators 1 and 2, respectively (m^3 yr^{-1}).

RESULTS

Effluent characteristics

The concentrations of the monitored parameters in the inflows and outflow of Farms I to IIII are presented in Table 2. The production rates of the farms had significant impacts on the concentrations of the monitored parameters in the effluents. The ΔCs for most of the parameters were significantly different in the Farm III effluent compared with effluents of the other farms, except that the ΔC for TAN was different from Farm I only. The ΔCs for TSS and COD were comparable among the farms (Table 3).

The correlations between the ΔCs and the annual production rates were very strong for DO and SAT ($p < 0.001$; $r^2 = 0.88$ and $r^2 = 0.85$, respectively), whereas there were significant but weaker correlations ($p < 0.05$; $r^2 = 0.15$ to 0.60) for BOD, COD, and the nutrient fractions.

The effect of trout culture on effluent water quality was manifested by a significant decrease in DO and SAT, and an increase ($p < 0.05$) in suspended solids, BOD, COD, and nutrient concentrations compared with the inflow (Fig. 2). The mean decreases in DO and SAT were 24 and 23%, respectively, while the increases in the other parameters ranged between 8 and 65%.

The mean ratios of effluent TAN in DIN and TN were within the ranges of 60 to 75% and 24 to 44%, respectively. The ratios of NO_3-N/TN and TON/TN were 10 to 17% and 21 to 26%, respectively, with NO_2-N constituting only a little part. The effluent SRP within TIP ranged between 42 and 84%, whereas TOP represented most of the TP, with ratios between 66 and 78% (Table 4).

Waste loads

The concentration of nitrogen and phosphorus fractions in the effluents displayed differences among the monitored farms. Therefore, the estima-

Table 2. Mean (SD) concentrations (C) and ranges of the monitored parameters in the inflows and outflows of 3 trout *Oncorhynchus mykiss* farms. DO: dissolved oxygen; SAT: oxygen saturation; TSS: total suspended solids; BOD: 5 d biochemical oxygen demand; COD: chemical oxygen demand; TAN: total ammonia nitrogen; NO_2-N: nitrite nitrogen; NO_3-N: nitrate nitrogen; TON: total organic nitrogen; TN: total nitrogen; SRP: soluble reactive phosphorus; TIP: total inorganic phosphorus; TOP: total organic phosphorus; TP: total phosphorus

Parameter	Inflow (C_{in})						Outflow (C_{out})					
	Farm I		Farm II		Farm III		Farm I		Farm II		Farm III	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
DO (mg l^{-1})	10.3 (0.8)	9.4–11.8	10.4 (0.8)	9.3–11.7	10.7 (0.6)	10.0–12.0	9.6 (1.1)	7.2–11.2	9.3 (0.8)	8.0–10.4	6.5 (0.6)	5.5–7.6
SAT (%O_2)	100 (9.2)	90 –117	101 (8.4)	89–115	103 (8.9)	92–118	94 (12.8)	69–114	92 (10.1)	79–106	62 (5.6)	53–74
TSS (mg l^{-1})	2.8 (2.7)	0.0 –9.6	5.2 (6.3)	0.0–21.2	5.8 (5.1)	0.0–14.2	8.3 (7.8)	0.0–23.2	8.2 (7.2)	0.0–25.2	9.9 (7.8)	0.0–22.0
BOD (mg l^{-1})	5.8 (0.6)	5.1–7.4	5.6 (0.6)	4.3–6.2	5.5 (0.9)	4.4–7.9	6.3 (0.8)	5.3–8.0	6.3 (0.7)	4.9–7.9	6.2 (0.9)	5.1–8.5
COD (mg l^{-1})	9.5 (0.7)	8.9–10.5	7.6 (1.3)	6.0–9.6	7.4 (1.4)	6.0–9.7	15.8 (2.9)	12.3–18.8	14.4 (4.9)	6.3–20.4	20.2 (8.3)	12.6–31.3
TAN (µg l^{-1})	98 (132)	0–371	116 (128)	0–358	81 (105)	0–255	147 (161)	0–520	298 (302)	0–760	350 (388)	0–1252
NO_2-N (µg l^{-1})	6 (7)	0–17	8 (9)	0–29	3 (2)	0–8	14 (12)	1–40	14 (14)	0–50	29 (44)	0–135
NO_3-N (µg l^{-1})	400 (225)	60–829	404 (201)	162–749	434 (200)	24–741	516 (245)	174–970	508 (276)	188–1138	529 (218)	300–1054
TON (µg l^{-1})	148 (111)	22–321	234 (236)	19–742	155 (118)	18–432	277 (144)	23–500	376 (310)	35–1147	387 (213)	37–825
TN (µg l^{-1})	654 (219)	386–1044	784 (229)	423–1178	674 (236)	257–995	980 (332)	585–1539	1278 (433)	724–1831	1375 (551)	813–2377
SRP (µg l^{-1})	18 (15)	0–44	30 (30)	0–94	21 (13)	6–41	38 (25)	7–79	47 (48)	12–149	80 (65)	12–234
TIP (µg l^{-1})	56 (29)	23–101	67 (56)	15–161	54 (25)	21–93	85 (40)	27–152	112 (105)	28–319	136 (81)	33–257
TOP (µg l^{-1})	105 (67)	6–189	102 (90)	4–249	134 (123)	1–428	236 (186)	6–639	212 (193)	14–565	225 (185)	9–535
TP (µg l^{-1})	161 (80)	36–251	169 (102)	33–349	179 (141)	32–496	320 (221)	39–777	323 (255)	42–867	354 (247)	42–781

tions of emissions using the nutritional and hydrological methods showed some variability (Table 5). Despite a high, negative bias at Farm I, the predicted and measured TSS concentrations in the effluents were highly similar. The measured TN concentrations were in the range from 297 to 857 µg l^{-1} at the farms, whereas the predicted values were between 319 and 703 µg l^{-1}. TP concentrations by prediction and measurement in the effluents of Farms I and II were close, which was not the case at Farm III. However, overall predictions were well correlated with measurements for all 3 parameters (Fig. 3).

Aside from an overestimation of measured TP for Farm III, the load estimations based on the nutritional and hydrological methods for suspended solids and nutrients from trout culture activities were almost the same for the 3 farms. Estimated TSS loads by both methods overlapped at 278 kg t^{-1} of fish produced. An estimation of TN load of 44.3 kg t^{-1} of fish by the nutritional method was slightly higher than that by the hydrological method. The nutritional and hydrological methods estimated TP loads as 8.4 and 8.8 kg t^{-1} of fish produced, respectively (Table 6).

More precise estimations of nutrient loads also reflected annual loading values. Estimates of annual TN fluxes into the stream were 230 and 233 t yr^{-1} and into the Mediterranean Sea 125 and 127 t yr^{-1}, as assessed by the hydrological and nutritional methods, respectively. Estimates of annual TP fluxes were 46 and 44 t yr^{-1} into the stream and 25 and 24 t yr^{-1} into the Mediterranean Sea, respectively (Table 7).

Table 3. Changes (mean ± SD) in parameter concentrations between inflow and outflow of 3 rainbow trout *Oncorhynchus mykiss* farms. Values within the same rows not sharing a common superscript letter were significantly different ($p < 0.05$, Student's t-test). Abbreviations as in Table 2

Parameter	Farm I	Farm II	Farm III	p
DO (mg l^{-1})	-0.6 ± 0.3^a	-1.1 ± 0.4^b	-4.3 ± 0.8^c	<0.001
SAT (%O_2)	-4.4 ± 3.9^a	-8.8 ± 4.1^a	-40.6 ± 8.8^b	<0.001
TSS (mg l^{-1})	2.3 ± 1.2	3.3 ± 1.5	4.5 ± 3.3	0.219
BOD (mg l^{-1})	0.4 ± 0.2^a	0.4 ± 0.2^a	0.7 ± 0.3^b	0.011
COD (mg l^{-1})	6.3 ± 3.2	9.3 ± 2.5	14.2 ± 7.0	0.137
TAN (µg l^{-1})	72 ± 75^a	189 ± 176^{ab}	275 ± 183^b	0.037
NO_2-N (µg l^{-1})	7 ± 6^a	8 ± 6^a	39 ± 48^b	0.045
NO_3-N (µg l^{-1})	31 ± 28^a	55 ± 74^a	147 ± 114^b	0.029
TON (µg l^{-1})	77 ± 49^a	93 ± 82^a	225 ± 153^b	0.049
TN (µg l^{-1})	297 ± 132^a	432 ± 201^a	857 ± 342^b	0.002
SRP (µg l^{-1})	12 ± 13^a	15 ± 13^a	63 ± 32^b	0.005
TIP (µg l^{-1})	14 ± 14^a	35 ± 34^a	86 ± 64^b	0.028
TOP (µg l^{-1})	54 ± 11^a	62 ± 24^a	165 ± 79^b	0.016
TP (µg l^{-1})	66 ± 44^a	101 ± 60^a	230 ± 77^b	0.008

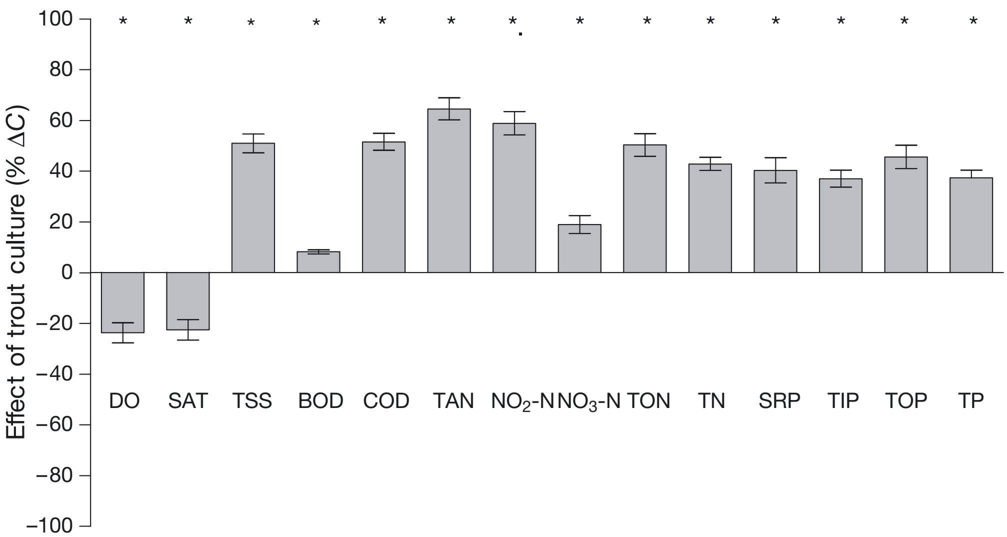

Fig. 2. The relative effect (mean ± SE) of rainbow trout *Oncorhynchus mykiss* culture on the effluent water quality. Asterisks indicate a significant ($p < 0.05$) farm effect. DO: dissolved oxygen; SAT: oxygen saturation; TSS: total suspended solids; BOD: 5 d biochemical oxygen demand; COD: chemical oxygen demand; TAN: total ammonia nitrogen; NO_2-N: nitrite nitrogen; NO_3-N: nitrate nitrogen; TON: total organic nitrogen; TN: total nitrogen; SRP: soluble reactive phosphorus; TIP: total inorganic phosphorus; TOP: total organic phosphorus; TP: total phosphorus

DISCUSSION

Effluent characteristics

Determined ranges and mean nutrient increases in effluents in our study are broadly consistent with the summarized data for several rainbow trout *Oncorhynchus mykiss* farms (Stewart et al. 2006, Sindilariu 2007, Aubin et al. 2009, Sindilariu et al. 2009, Tello et al. 2010). Effluent characteristics are also in concordance with the results of previous research on flow-through rainbow trout farms in the same region as our study (Tekinay et al. 2009, Bilgin Yıldırım & Pulatsü 2011).

Table 4. Mean ratios of nutrient concentrations in the effluents. Abbreviations as in Fig. 2

Ratio	Farm I	Farm II	Farm III
TAN/DIN	0.66	0.75	0.60
TAN/TN	0.24	0.44	0.32
NO_2-N/TN	0.02	0.02	0.05
NO_3-N/TN	0.10	0.13	0.17
TON/TN	0.26	0.21	0.26
SRP/TIP	0.84	0.42	0.73
SRP/TP	0.18	0.15	0.27
TIP/TP	0.22	0.34	0.32
TOP/TP	0.78	0.66	0.68

Table 5. Predicted and measured suspended solids and nutrient concentrations in the effluents of the farms (I to III). Abbreviations as in Fig. 2

Parameter	Predicted			Measured			Bias (%)		
	I	II	III	I	II	III	I	II	III
TSS (mg l^{-1})	2.0	3.3	4.4	2.3	3.3	4.5	−12.5	0.0	−2.3
TN (µg N l^{-1})	319	527	703	297	432	857	6.9	18.0	−21.9
TP (µg P l^{-1})	60	99	133	66	101	230	−10.0	−2.0	−72.9

It is well known that the nutrient concentrations in trout farm effluents are highly variable (e.g. Sindilariu 2007) and the effluent water quality is highly affected by farm management practices such as stocked fish size, stocking density, feed quality, feeding techniques, frequency of cleaning, etc., as well as temporal variations such as influent water quality and flow rate (e.g. Axler et al. 1997). Ammonia nitrogen can form 53 to 69% of total nitrogen wastes in the effluent of rainbow trout farms (Kajimura et al. 2004), but the ratio may increase up to 79% in some instances (Dalsgaard & Pedersen 2011). The ratios of TAN/TN in effluents in our study were unexpectedly lower than the literature values, suggesting that nitrification of ammonia and temporal variations in the samplings most likely played a significant role, as reported previously (Papatryphon et al. 2005, Dalsgaard & Pedersen 2011).

The relatively high NO_3-N/TN ratios observed further support the impact of nitrification. High standard deviations in TAN concentrations in the present investigation could primarily be due to farm management practices and changes of

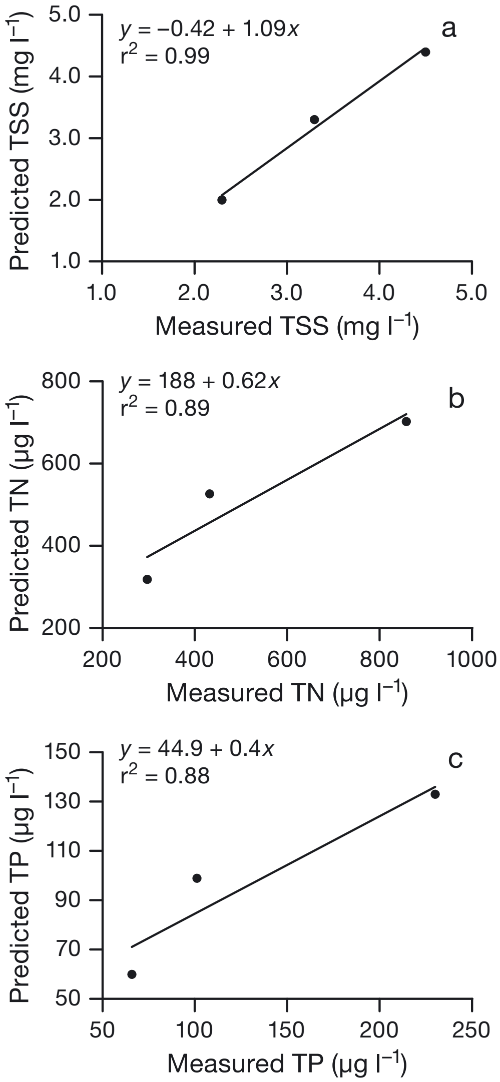

Fig. 3. Relationships between measured (mean annual) and predicted concentrations of (a) total suspended solids (TSS), (b) total nitrogen (TN), and (c) total phosphorus (TP) in effluents of the 3 rainbow trout *Oncorhynchus mykiss* farms studied. *y*: predicted concentrations; *x*: measured concentrations

sampling time during the day, as suggested by Papatryphon et al. (2005), Roque d'Orbcastel et al. (2008), and Aubin et al. (2011). Although urea, amino acids, and nitrogen excretion via the gills and/or skin and mucus may comprise a considerable amount of the soluble fraction of organic nitrogen (Kajimura et al. 2004), both soluble and particulate fractions may reach up to 36% of TN (Foy & Rosell 1991). Because we did not determine these fractions separately, our TON values are indirectly consistent with the range of the TON/TN ratio published by Foy & Rosell (1991).

In contrast to earlier findings reporting that 60% of TP loading was in the form of SRP (Foy & Rosell

Table 6. Mean estimates of suspended solids and nutrient loads. Predicted: based on nutritional method; Measured: based on hydrological method. Abbreviations as in Fig. 3

	Load (kg t^{-1} of fish produced)		
	TSS	TN	TP
Predicted	278	44.3	8.4
Measured	278	43.9	8.8

Table 7. Estimations of annual nutrient flux (t yr^{-1}) into the Eşen Stream at the Çaygözü site and Mediterranean Sea using a simplified mass-flux equation. Predicted: loading data (*L*) for mass-flux calculation based on load value from the nutritional mass-balance method; Measured: *L* for mass-flux calculation based on load value from the hydrological mass-balance method. L_1: mass flux into the receiving stream reach from aquaculture activities; L_2: mass flux into the conveyance channel by Regulator 1; L_3: mass flux into Fethiye Bay after Regulator 2; TN: total nitrogen; TP: total phosphorus

	Nutrient flux (t yr^{-1})					
	L_1		L_2		L_3	
	TN	TP	TN	TP	TN	TP
Predicted	233	44	195	37	127	24
Measured	230	46	193	39	125	25

1991), our findings are closer to the data of Roque d'Orbcastel et al. (2008), who found a 31.2% SRP of TP in trout farm effluent. The TOP/TP ratios were between 66 and 78%, indicating that the majority of phosphorus wastes in the monitored farm effluents was in the organic fraction, presumably in the particulate fraction organically bound in fecal and unconsumed feed materials.

Waste loads

There were strong correlations between predicted and measured concentrations of TSS, TN, and TP in the effluents of the monitored farms. Our predicted TN and TP loads were within the range of those presented by Bureau et al. (2003) and Roque d'Orbcastel et al. (2008), who recorded 40.8 to 71 kg N and 7.5 to 15.2 kg P t^{-1} of fish produced. Our predicted TSS loads were in close agreement with those reported by Bureau et al. (2003), who found 240 to 318 kg TSS t^{-1} of fish produced for land-based salmonid farms, but higher than those by Roque d'Orbcastel et al. (2008), who reported a load of 147.5 kg TSS t^{-1} of fish produced for rainbow trout. The inconsistency of TSS prediction with the latter study could be due to differences in the feed conversion ratio (FCR; 1.1 versus 0.85) and the assumed nutrient digestibility coefficients. Indeed, an improvement in the FCR could result in huge decreases in waste loads, as observed by Bilgin Yıldırım & Pulatsü (2011).

There are many sources of uncertainties associated with the hydrological and nutritional methods. The primary uncertainties originate from the sampling process, especially its location in time and space for the hydrological method and its input data for nutrient-balance modeling (Aubin et al. 2011). Because of the above-mentioned temporal variations in solids transport and farm management, estimating quantitative waste outputs by hydrological or nutritional methods may lead to erroneous loading rates (Papatryphon et al. 2005, Sindilariu 2007, Roque d'Orbcastel et al. 2008). However, Papatryphon et al. (2005) suggested that, considering the nature of the nutrient emissions, the potential measurement error, and the variability associated with the environment and the farms, the differences between predictions and measurements may not seem important.

Therefore, despite the uncertainties, nutritional mass-balance modeling as a cost-efficient solution to estimate the release of waste can provide both fish farmers and authorities with valuable information on the environmental impacts of aquaculture farms, both active or soon to be activated (Aubin et al. 2011). Papatryphon et al. (2005) also suggested that nutritional mass-balance modeling should be the preferred method of environmental impact assessments for predicting nutrient emissions in various forms. Our study showed that a nutritional mass-balance method based on very simple inputs that are easily accessible, such as average annual feed use and fish production, as well as feed specifications, is capable of providing reliable estimations for suspended solids and nutrient loads, without seasonal data. Doubtless to say, an integration of more frequent observations in feed use and farm management practices will further increase the precision of the method. Yet the simple approach outlined in the present study can still help authorities during basin-scale planning of production for land-based operations.

High river-borne organic matter and nutrient inputs have been recognized as important sources of coastal eutrophication (Mallin et al. 1993, Rahm et al. 1996). This is particularly significant for an oligotrophic system like the Mediterranean Sea. Along the eastern Mediterranean coast, diffuse discharges from intensive cultivation practices and point discharges from urban waste water are the most significant sources of organic matter and nutrients carried to the sea by rivers and streams (Ludwig et al. 2009). Karakassis et al. (2005) calculated the contribution of a 100 000 t yr^{-1} cage-aquaculture production to the total annual anthropogenic TN and TP loadings into the eastern Mediterranean as <8% using a mass-balance method similar to ours. This volume of production generated 12×10^3 t N yr^{-1} and 2×10^3 t P yr^{-1} in annual loadings or 120 and 20 kg t^{-1} of fish produced, respectively. But the loads into the eastern Mediterranean from flow-through trout fish farming at the studied site were 28.4 to 28.9 kg N and 5.5 to 5.7 kg P t^{-1} of fish produced. Although our estimations on TN and TP loads are almost a quarter of the estimations for marine cage farms by Karakassis et al. (2005), the results of the present study show that land-based trout farms may be considered significant aquacultural sources of nutrient flux into the coastal ecosystem.

CONCLUSIONS

The results of the present study showed that farm effluents have decreased DO and SAT values and increased TSS, BOD, COD, and nutrients compared with farm inflows. Estimations of the nutritional and hydrological mass-balance methods were well correlated with each other. The nutritional mass-balance modeling for capacity planning and basin-scale management of land-based aquaculture at a stage of environmental impact assessment seems to be a useful decision tool because of its cost efficiency and simple applicability. It was also possible to predict nutrient loading into the ultimate receiving coastal ecosystem using a simplified mass-flux model. Future studies and efforts should be focused on the determination of nutrient discharges from a variety of sources, together with aquaculture contribution to prepare a coastal zone management plan.

Acknowledgements. This study was supported by grants from The Scientific and Technical Research Council of Turkey (TUBITAK, Project No. 107Y084). We thank the fish farmers who collaborated with us on this study. The authors also thank Ramazan Uysal, Faruk Pak, Gazi Uysal, Ö. Aybike Topçuoğlu, and Gül Tunç Karaağaç for their invaluable help with data collection and laboratory analysis, and Prof. Dr. Ayşe Muhammetoğlu, Assoc. Prof. Yılmaz Emre and Prof. Dr. Ahmet Alp for his suggestions on this article.

LITERATURE CITED

APHA (American Public Health Association) (1998) Standard methods for the examination of water and wastewater, 20th edn. APHA, Washington, DC

Aubin J, Papatryphon E, van der Werf HMG, Chatzifotis S (2009) Assessment of the environmental impact of carnivorous finfish production systems using life cycle assessment. J Clean Prod 17:354–361

Aubin J, Tocqueville A, Kaushik SJ (2011) Characterisation of waste output from flow-through trout farms in France: comparison of nutrient mass-balance modelling and hydrological methods. Aquat Living Resour 24: 63–70

Axler RP, Tikkanen C, Henneck J, Schuldt J, Mcdonald ME (1997) Characteristics of effluent and sludge from two commercial rainbow trout farms in Minnesota. Prog Fish-Cult 59:161–172

Bilgin Yıldırım HB, Pulatsü S (2011) Evaluation of the effluent characteristics in land-based trout farms (Fethiye, Muğla) within the frame of legal arrangements. Ekoloji 20(81):48–54 (in Turkish)

Bureau DP, Gunther SJ, Cho CY (2003) Chemical composition and preliminary theoretical estimates of waste outputs of rainbow trout reared in commercial cage culture operations in Ontario. N Am J Aquaculture 65:33–38

Cho CY, Bureau DP (2001) A review of diet formulation strategies and feeding systems to reduce excretory and feed wastes in aquaculture. Aquacult Res 32:349–360

Cho CY, Hynes JD, Wood KR, Yoshida HK (1991) Quantitation of fish culture wastes by biological (nutritional) and chemical (limnological) methods; the development of high nutrient dense (HND) diets. In: Cowey CB, Cho CY (eds) Nutritional strategies and aquaculture waste. Proceedings of the 1st International Symposium on Nutritional Strategies in Management of Aquaculture Waste, University of Guelph, p 37–50

Cox BA (2003) A review of currently available in-stream water-quality models and their applicability for simulating dissolved oxygen in lowland rivers. Sci Total Environ 314:335–377

Dalsgaard AJT, Pedersen PB (2011) Solid and suspended/dissolved waste (N, P, O) from rainbow trout (*Oncorhynchus mykiss*). Aquaculture 313:92–99

Deniz H (2010) Turkey: best practices in aquaculture management and sustainable development. In: Advancing the aquaculture agenda workshop proceedings. OECD, Paris, p 183–193

Foy RH, Rosell R (1991) Fractionation of phosphorus and nitrogen loadings from a Northern Ireland fish farm. Aquaculture 96:31–42

Frier JO, From J, Larsen T, Rasmussen G (1995) Modelling waste output from trout farms. Water Sci Technol 31: 103–121

James A (1993) An introduction to water quality modeling, 2nd edn. Wiley, New York, NY

Kajimura M, Croke SJ, Glover CN, Wood CM (2004) Dogmas and controversies in the handling of nitrogenous wastes: the effect of feeding and fasting on the excretion of ammonia, urea and other nitrogenous waste products in rainbow trout. J Exp Biol 207:1993–2002

Karakassis I, Pitta P, Krom MD (2005) Contribution of fish farming to the nutrient loading of the Mediterranean. Sci Mar 69:313–321

Kelly LA, Stellwagen J, Bergheim A (1996) Waste loadings from a freshwater Atlantic salmon farm in Scotland. Water Res Bull 32:1017–1025

Kırkağaç MU, Pulatsü S, Topçu A (2009) Trout farm effluent effects on water sediment quality and benthos. CLEAN-Soil, Air, Water 37:386–391

Ludwig W, Dumont E, Meybeck M, Huessner S (2009) River discharges of water and nutrients to the Mediterranean and Black Sea: major drivers for ecosystem changes during past and future decades? Prog Oceanogr 80:199–217

Mallin MA, Paerl HW, Rudek J, Bates PW (1993) Regulation of estuarine primary production by watershed rainfall and river flow. Mar Ecol Prog Ser 93:199–203

Papatryphon E, Petit J, Van Der Werf HM, Sadasivam KJ, Claver K (2005) Nutrient balance modelling as a tool for environmental management in aquaculture: the case of trout farming in France. J Environ Manag 35:161–174

Pulatsü S, Rad F, Köksal G, Aydın F, Karasu-Benli AÇ, Topçu A (2004) The impact of rainbow trout farm effluents on water quality of Karasu Stream, Turkey. Turk J Fish Aquat Sci 4:9–15

Rahm L, Conley D, Sandén P, Wulff F, Stålnacke P (1996) Time series analysis of nutrient inputs to the Baltic Sea and changing DSi:DIN ratios. Mar Ecol Prog Ser 130: 221–228

Rodrigues AMP (1995) Biological and nutritional approach to the environmental impact of trout culture in Portugal. Water Sci Technol 31:239–248

Roque d'Orbcastel E, Blancheton JP, Boujard T, Aubin J, Moutounet Y, Przybyla C, Belaud A (2008) Comparison of two methods for evaluating waste of a flow through trout farm. Aquaculture 274:72–79

Sindilariu PD (2007) Reduction in effluent nutrient loads from flow-through facilities for trout production: a review. Aquacult Res 38:1005–1036

Sindilariu PD, Brinker A, Reiter R (2009) Waste and particle management in a commercial, partially recirculating trout farm. Aquacult Eng 41:127–135

Stewart NT, Boardman GD, Helfrich LA (2006) Treatment of rainbow trout (*Oncorhynchus mykiss*) raceway effluent using baffled sedimentation and artificial substrates. Aquacult Eng 35:166–178

Subasinghe R, Soto D, Jia J (2009) Global aquaculture and its role in sustainable development. Rev Aquac 1:2–9

Tacon AGJ, Forster IP (2003) Aquafeeds and the environment: policy implications. Aquaculture 226:181–189

Taşeli BK (2009) Influence of land-based fish farm effluents on the water quality of Yanıklar Creek. Int J Environ Res 3:45–56

Tekinay AA, Güroy D, Çevik N (2009) The environmental effect of a land-based trout farm on Yuvarlakçay, Turkey. Ekoloji 19:65–70

Tello A, Corner RA, Telfer TC (2010) How do land-based salmonid farms affect stream ecology? Environ Pollut 158:1147–1158

TURKSTAT (2012) Production quantity of aquaculture products. Turkish Statistical Institute. Available at: www.turkstat.gov.tr/PreIstatistikTablo.do?istab_id=696 (accessed 18 April 2012)

Editorial responsibility: Tim Dempster, Trondheim, Norway

Submitted: August 1, 2012; Accepted: January 30, 2013
Proofs received from author(s): March 23, 2013