Ekoloji 19, 73, 65-70 (2009)

# The Environmental Effect of a Land-Based Trout Farm on Yuvarlakçay, Turkey

**Ahmet Adem TEKİNAY[1], Derya GÜROY[1], Nazan ÇEVİK[2]**

[1]Çanakkale Onsekiz University, Faculty of Fisheries, Department of Aquaculture, 17100, Çanakkale-TURKEY

[2]Çanakkale Onsekiz Mart University, Bayramiç Vocational College, 17700, Çanakkale, TURKEY

*Corresponding author: atekinay@comu.edu.tr

**Abstract**
The objective of this study was to assess the environmental impact of one of the biggest flow-through rainbow trout farms located in South-Western Turkey between February and December 2006. The feeding water is obtained from the Yuvarlakçay Stream (Muğla, Turkey) at a mean flow rate of 2.86 Litre $s^{-1}$ per ton of the annual fish production (700 t $year^{-1}$) with drum filtration used for the effluent treatment of the farm. Bi-monthly sampling was conducted from the inlet and discharge water (before and after treatment) at the same hour of each sampling day. No significant differences in total nitrogen (TN), total phosphorus (TP), biochemical oxygen demand ($BOD_5$), and chemical oxygen demand (COD) were found in the effluent, although these parameters were found to have increased in the discharged water. The dissolved oxygen (DO) and pH of the effluent water were found to be significantly affected by the fish farming activities. The effluent treatment efficiencies were found to be 7.77% for TP, 8.67% for TN, 16.58% for $BOD_5$, and 13.16% for COD, respectively. The annual TP load of the trout farm after effluent treatment was found to be 5.68 kg P per ton of fish produced, and 5.30 kg P per ton of feed used, respectively. The average TP load without any effluent treatment determined via chemical and biological methods was 7.66 and 10.46 kg P per ton of fish produced, respectively.
**Keywords**: Environmental impact, phosphorus load, trout farming, water quality

**Yuvarlakçay Üzerinde Kurulu Olan Alabalık İşletmesinin Çevresel Etkisi**

**Özet**
Bu çalışmanın amacı, Türkiye'nin güney-batısında bulunan ve en büyük akarsu alabalık işletmelerinden biri olan işletmenin Şubat-Aralık 2006 tarihlerinde çevresel etkilerinin tespit edilmesidir. İşletmeye su Yuvarlakçay'dan (Muğla, Türkiye) yıllık üretilen alabalık (700 ton $yıl^{-1}$) ton başına 2.86 litre $s^{-1}$ olarak sağlanmakta ve işletmeden çıkan atık su tambur filtrasyona tabi tutularak atılmaktadır. Giren ve çıkan (arıtma öncesi ve sonrası) sudan iki ayda bir örnek alımı örnekleme günü aynı saatte gerçekleştirilmiştir. Toplam azot (TN), toplam fosfor (TP), biyokimyasal oksijen ihtiyacı ($BOİ_5$) ve kimyasal oksijen ihtiyacının (KOİ) istatistiksel olarak atık suda fark olmadığı tespit edilmiş, ancak bu parametrelerin atık suda arttığı gözlenmiştir. Atık sudaki çözünmüş oksijen (ÇO) ve pH balık yetiştiriciliği aktivitelerinden önemli ölçüde etkilendiği tespit edilmiştir. Atık su arıtma etkenliğinin sırasıyla TP için %7.77, TN için %8.67, $BOİ_5$ için %16.58 ve KOİ için %13.16'dır. Atık su arıtma sonrasında alabalık işletmesinin yıllık TP yükü 5.68 kg P/ton üretilen balık ve 5.30 kg P/ton kullanılan yem olduğu bulunmuştur. Atık su arıtması olmadan kimyasal ve biyolojik metotlar kullanılarak tespit edilen ortalama TP yükü sırasıyla 7.66 ve 10.46 kg P/ton üretilen balık olduğu bulunmuştur.
**Anahtar kelimeler**: Alabalık yetiştiriciliği, çevresel etki, fosfor yükü, su kalitesi

Tekinay AA, Güroy D, Çevik N (2009) The Environmental Effect of a Land-Based Trout Farm on Yuvarlakçay, Turkey. Ekoloji 19, 73, 65-70.

## INTRODUCTION

Production of rainbow trout (*Oncorhynchus mykiss*) in Turkey commenced in the early 1970s as a land-based operation using water abstracted from rivers and it has significantly increased from 28500 tons in 1997 to 61073 tons in 2007 (Anonymous 2008). This expansion in rainbow trout production in land-based farms as well as cage farms in dammed lakes has led to fears that a significant amount of nitrogen and phosphorus from trout farms are discharged into the rivers which in turn drain into lakes or seas. However, there is a lack of information about the environmental effects of rainbow trout farming in Turkey, although numerous publications

Geliş: 03.02.2009 / Kabul: 16.05.2009

have been published about this issue for decades in various countries (Bergheim and Selmer-Olsen 1978, Bergheim et al. 1984, Phillips et al. 1985, Foy and Rossel 1991, Enell 1995, Kelly et al. 1996, Boaventura et al. 1997, Cripps and Bergheim 2000, Lekang et al. 2000, Bergheim and Brinker 2003, True et al. 2004, Maillard et al. 2005, d'Orbcastel et al. 2008). Furthermore, increasing concerns on the environmental impact of fish farming have driven many goverments to adopt regulatory procedures (Tacon and Forster 2003, Boyd 2003, Bergheim and Brinker 2003). In this context, effluent treatment facilities, including physical, chemical, and biological techniques, have been constructed in many freshwater fish farms to control the Nitrogen (N) and Phosphorus (P) concentrations being discharged into the surrounding waters (Cripps and Bergheim 2000, Bergheim and Brinker 2003, Sindilariu 2007). In addition, better feeding management, reduction in excessive nutrients in feed, and the improved physical and chemical quality of feed also resulted in decreasing effluent loading from the salmonid culture by 50 - 70% since 1980s (Bergheim and Cripps 1998).

The assessment of the environmental impact of fish farms might be determined by using chemical or biological methods (Cho et al. 1991). The chemical method includes monitoring of the physico-chemical parameters of the inlet and outlet water samples, while the fish production and feed used in the farm are taken into account in the biological method (Cho et al. 1991, Anonymous 2004).

In this study, the chemical quality of the effluent from one of the biggest flow-through trout farms in Turkey was characterized. The P loading from this farm was also estimated by using both chemical and biological approaches and the efficiency of the effluent treatment of the trout farm was evaluated.

## MATERIALS AND METHODS

### Description of the Farm

The monitored farm is located outside of Beyobası on the Yuvarlakçay stream in the South-Western part of Turkey. This is a mountain spring, discharging into Köyceğiz Lake which in turn drains into the Mediterranean Sea (Fig. 1).

The Yuvarlakçay stream flows at a high velocity through a narrow bed because of the topographic character of the area. Only the sampled trout farm is operated on the Yuvarlakçay stream and it has many features of a modern farm. Trout production is realized in concrete raceways which are designed so that water flows by gravity through three raceways. The fish farm has been operating since 1986 and the effluent treatment has been accomplished by drum filtration since 1992. The trout are grown from the larval stage to about 250-400 g. Table 1 presents details of its production capacity, food conversion ratio (FCR) and water capacity within the farm. Extruded feed is used on the farm throughout the production period. The average proximate composition of the grow-out feed (4, 6, 8 mm size) which comprises approximately 80% of the total consumption is as follows: moisture: 9.3%, protein: 45.0%, fat: 22.5%, ash: 9.95% and phosphorus: 1.35%.

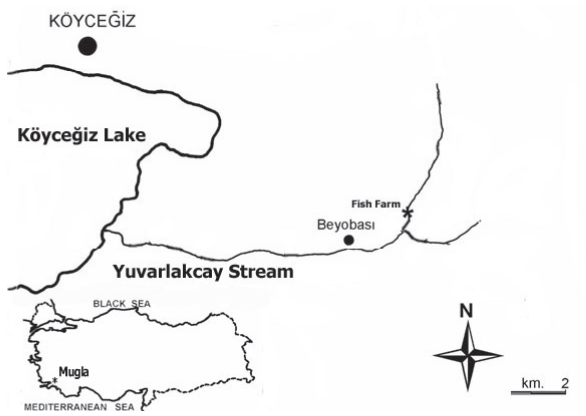


**Fig 1**. Location of the farm.

### Water Quality Monitoring

Bimonthly sampling was conducted from February to December 2006 from the inlet and discharge water (before and after treatment) at the same hour of each sampling day. Water samples for chemical analysis were collected from the middle of the water column in triplicate using prewashed polyethylene bottles and were carried to the laboratory at +4°C and analyzed within 24h.

### Analytical Methods

Water temperature, pH and dissolved oxygen (DO) were measured in situ via a 567 YSI probe. Total phosphorus (TP) and total nitrogen (TN) of the water samples was measured according to Strickland and Parsons (1972). Biological oxygen demand ($BOD_5$) and chemical oxygen demand (COD) of water samples and the proximate analysis of feed and fish samples (moisture, protein, fat and ash) were determined according to the Association of Official Analytical Chemists (Anonymous 2000).

**Table 1**. Characteristics of the sampled trout farm.

| Parameter | Units | | |
|---|---|---|---|
| Production capacity | tons year$^{-1}$ | | 700 |
| Feed used | tons year$^{-1}$ | | 750 |
| Feed Conversion Ratio | kg feed fed per kg fish produced | | 1.07 |
| Water flow rate | m$^3$ sec$^{-1}$ | Average flow | 2 |
| | | Low flow | 1.6 |

**Calculations**

**Phosphorus Load Determination**

The annual TP load of the farm was determined by chemical and biological methods. In the chemical method, the TP load was calculated by using the inlet and outlet water (as treated and untreated forms) TP values. In the biological method, the TP load was estimated according to the method suggested by the OSPAR Commission (Cho et al. 1991, Anonymous 2004).

TP load = 0.01 x (I x Ci - P x Cf)

where TP load: total phosphorus discharge to water body (tons/year); I: feed used (tons/year); Ci: phosphorus content in feed (%); P: production (tons/year); Cf: phosphorus content in produced organisms (%).

**Effluent Treatment Efficiency Determination**

The effluent treatment efficiency of the drum filtration system was determined by using the data of the sampled effluent water before and after treatment:

Treatment Efficiency (%) = [(Concentration of the parameter before treatment - Concentration of the parameter after treatment) / Concentration of the parameter before treatment] X 100

**Statistical Analysis**

The collected data was subjected to one-way analysis of variance ($p<0.05$) using the statistical software package Statgraphics (Statgraphics Centurion) (Zar 2001). Differences between the means of the inlet and effluent discharged before and after treatment were determined by the Tukey's HSD procedure.

## RESULTS AND DISCUSSION

The physico-chemical parameters of water at the farm inlet and effluent before and after treatment are presented in Table 2, 3, 4 and summarized in Table 5. Changes in temperature, TP, TN, $BOD_5$ and COD concentrations between the inlet and effluent water samples were insignificant ($p>0.05$), while the DO and pH values of the inlet were significantly reduced in the effluent water ($p<0.05$)(Table 2).

**Table 2**. Water quality parameters of the farm inlet.

| Parameter | Feb | Apr | Jun | Aug | Oct | Dec | Mean±SE |
|---|---|---|---|---|---|---|---|
| Temp. (°C) | 14 | 14.5 | 14.92 | 15.5 | 14.71 | 13.67 | 14.55±0.27 |
| pH | 8.06 | 8.63 | 8.2 | 8.27 | 8.23 | 8.58 | 8.33±0.09 |
| DO (mg l$^{-1}$) | 7.8 | 8.7 | 8.1 | 7.8 | 8.2 | 7.5 | 8.02±0.17 |
| $BOD_5$ (mg l$^{-1}$) | 3.12 | 3.04 | 3.68 | 4.16 | - | - | 3.50±0.26 |
| COD (mg l$^{-1}$) | 31.2 | 15.2 | 18.4 | 20.8 | 47.2 | 14.4 | 24.53±4.59 |
| TP (mg l$^{-1}$) | 0.1695 | - | 0.3617 | 0.2408 | 0.1701 | 0.0466 | 0.198±0.051 |
| TN (mg l$^{-1}$) | 0.0734 | 0.512 | 0.4902 | 0.3824 | 0.7682 | 0.1932 | 0.403±0.101 |

**Table 3**. Water quality parameters at the farm outlet before treatment.

| Parameter | Feb | Apr | Jun | Aug | Oct | Dec | Mean±SE |
|---|---|---|---|---|---|---|---|
| Temp. (°C) | 14.4 | 15.3 | 15.3 | 17.7 | 14.7 | 13.4 | 15.14±0.76 |
| pH | 7.90 | 8.11 | 7.85 | 7.84 | 7.97 | 8.14 | 7.97±0.05 |
| DO (mg l$^{-1}$) | 8.6 | 6.1 | 6.6 | 6.9 | 5.8 | 7.3 | 6.88±0.41 |
| $BOD_5$ (mg l$^{-1}$) | 3.84 | 3.52 | 3.04 | 4.80 | 6.24 | 4.80 | 4.37±0.47 |
| COD (mg l$^{-1}$) | 38.4 | 17.6 | 30.4 | 24.0 | 62.4 | 9.6 | 30.4±6.73 |
| TP (mg l$^{-1}$) | 0.2555 | 0.2715 | 0.3115 | 0.2631 | 0.3143 | - | 0.283±0.012 |
| TN (mg l$^{-1}$) | 1.004 | 0.5264 | 0.617 | 0.5011 | 0.4659 | - | 0.623±0.098 |

**Table 4**. Water quality parameters at the farm outlet after treatment.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Temp. (°C) | 14.1 | 14.4 | 17.5 | 18.07 | 14.93 | 13.6 | 15.43±0.58 |
| pH | 7.97 | 7.97 | 7.5 | 7.78 | 8.04 | 8.18 | 7.91±0.09 |
| DO (mg l$^{-1}$) | 8.6 | 5.5 | 6.5 | 5.8 | 5.2 | 7.5 | 6.52±0.53 |
| $BOD_5$ (mg l$^{-1}$) | 3.04 | 3.68 | 2.72 | - | 5.6 | 3.2 | 3.65±0.51 |
| COD (mg l$^{-1}$) | 30.4 | 36.8 | 27.2 | 4.8 | 56 | 3.2 | 26.40±6.73 |
| TP (mg l$^{-1}$) | 0.2237 | 0.1843 | 0.4021 | 0.2498 | 0.2452 | - | 0.261±0.037 |
| TN (mg l$^{-1}$) | 1.1000 | 0.4812 | 0.4732 | 0.4652 | 0.6637 | 0.2334 | 0.569±0.119 |

**Table 5**. Summary of the water quality parameters of the inlet, and effluent before and after treatment (Mean±SE) (Table 2-3-4)*

| Parameters | Inlet | Outlet before effluent treatment | Outlet after effluent treatment |
|---|---|---|---|
| Temperature (°C) | 14.55±0.27 | 15.14±0.76 | 15.43±0.58 |
| pH | 8.33±0.09$^b$ | 7.97±0.05$^a$ | 7.91±0.09$^a$ |
| DO (mg l$^{-1}$) | 8.02±0.17$^b$ | 6.88±0.41$^a$ | 6.52±0.53$^a$ |
| $BOD_5$ (mg l$^{-1}$) | 3.50±0.26 | 4.37±0.47 | 3.65±0.51 |
| COD. (mg l$^{-1}$) | 24.53±4.59 | 30.4±6.73 | 26.40±6.73 |
| TP (mg l$^{-1}$) | 0.198±0.051 | 0.283±0.012 | 0.261±0.037 |
| TN (mg l$^{-1}$) | 0.403±0.101 | 0.623±0.098 | 0.569±0.119 |

*Means on the same row that do not share a common superscript letter are significantly different ($p<0.05$).

The levels of DO varied between 7.5 and 8.7 mg l$^{-1}$ at farm inlet during the monitoring period and the lowest DO in the effluent after treatment was observed in October (5.2 mg l$^{-1}$). This value was found to be close to the limit of DO concentration for fish farm effluents (5 mg l$^{-1}$) as recommended by the Global Aquaculture Alliance (Boyd and Gautier 2000). Reduction in DO concentrations in the farm effluent, due to fish farming activities, was in accordance with previous findings (Boaventura et al. 1997, Pulatsu et al. 2004, McDaniel et al. 2005). However, Kazancı and Dügel (2000) previously reported that DO levels in the Yuvarlakçay stream before and after the fish farm ranged between 8.77 and 9.50 mg l$^{-1}$ , respectively. The difference in DO concentrations of effluent water between this result and above mentioned study may be due to the elevation of fish production capacity from 1992 to 2006.

In contrast to Boaventura et al. (1997) and Pulatsu et al. (2004), there was a significant decrease in the mean pH values in the effluent water compared to the receiving water ($p<0.05$) (Table 2). This is supported by Kazancı and Dügel (2000) who measured the pH value in a decreasing manner in Yuvarlakçay but they did not report whether such decrease in pH values were significant.

The mean $BOD_5$ values of the inlet, and the effluent before treatment and after treatment displayed an increasing trend during the sampling period with a maximum value of 6.24 mg $l^{-1}$ measured in October at the outlet of the farm before effluent treatment. However, the elevation rates of the $BOD_5$ in the effluents were not significantly different ($p>0,5$). This is in contradiction with the findings of Boaventura et al. (1997), Pulatsu et al. (2004) and Maillard et al. (2005) who reported that the impact of trout farm effluents on the $BOD_5$ of the receiving water was significant ($p<0.05$). As the suspended solids and dissolved nutrient composition in effluent increases, COD values in the effluent increase due to aquaculture activities (Pillay 2004). This was observed in the present study, however the increase in COD values in the effluent compared to the receiving water was not confirmed statistically ($p\geqslant0.05$)(Table 2).

Similar to $BOD_5$ and COD results, TP and TN values in the discharged water increased. However, there was no statistical difference in the TP or TN concentrations among the mean inlet and effluent before and after treatment ($p\geqslant0.05$) (Table 5). Depending on the farm production capacity, feeding level and feed composition, the TP or TN values determined in this study were in accordance with earlier studies in which the effluent TP and TN were reported to be within the ranges of 0.06-0.591 mg $l^{-1}$ and 0.17-2.2 mg $l^{-1}$, respectively (Boaventura et al. 1997, Pulatsu et al. 2004, Maillard et al. 2005, Sindilariu 2007).

In this investigation, the maximum TN, $BOD_5$, and COD value as well as the minimum DO values were observed in the effluent before and after treatment during the October sampling expedition, when the fish biomass was found at its maximum for the production season. This is in compliance with the fact that as the fish biomass increases, the level of excretory products of fish lead to a decrease in effluent DO concentration and an increase in the $BOD_5$, COD, and TN in the effluent (Pillay 2004, Maillard et al. 2005).

The calculated and estimated TP load of the farm is given in Table 6. Different TP loads of fish farms were previously reported as ranging from 4.8 to 25.6 kg per ton of fish produced (Foy and Rosell 1991, Enell 1995, Kelly et al. 1996, Bergheim and Cripps 1998, Pulatsu et al. 2004, d'Orbcastel et al. 2008). The calculated TP load of the fish farm after effluent treatment in this study was found to be quite near the values ranging between 4.8 and 6.0 kg P per ton of fish produced as determined by researchers' investigations about trout farms in Europe (Enell 1995, d'Orbcastel et al. 2008). On the other hand, the total TP load without any effluent treatment was found to be near the values determined for the fish farming facilities on the Karasu stream, Turkey. The study on the TP load of trout farms upon the Karasu stream has revealed that the TP ranged between 6.25 and 14.5 kg per ton fish produced (Pulatsu et al. 2004).

While comparing the TP loads determined by the chemical and biological methods it was observed that the biological method overestimated the TP load. Other researchers have also found that there might be overestimation between the biological and chemical methods for the TP loading (in terms of kg P per ton of fish produced) determination (Cho et al. 1991, Papatryphon et al. 2005, d'Orbcastel et al. 2008). The determination of TP loads of fish farms via the chemical method is usually expensive and also time consuming, because in the chemical method regular water quality monitoring as well as water flow rate measurements should be conducted. On the other hand, the biological method for farm TP loading determinations appears to be easier, less expensive and time saving, provided that there is enough and reliable information about the fish production, feed consumption, feed composition, and digestible coefficients of feed used (Anonymous 2004, Papatryphon et al. 2005, d'Orbcastel et al. 2008).

In this study, the effluent treatment efficiencies were determined as 7.77% for TP, 8.67% for TN, 16.58% for $BOD_5$ and 13.16% for COD, respectively. These findings were in accordance with the previous results with the only exception that the COD treatment efficiency was lower in our study

**Table 6**. Calculated and Estimated TP loads of the trout farm*.

| | kg P/ton fish | Kg P/ton feed |
|---|---|---|
| Calculated TP load of the farm before effluent treatment | 7.66 | 7.15 |
| Calculated TP load of the farm after effluent treatment | 5.68 | 5.30 |
| Estimated TP load of the farm | 10.46 | 9.77 |

*P content of fish was assumed to be 0.4% on dry basis (Anonymous 2004)

than the values in literature. The treatment efficiencies were reported in the ranges of 6-79%, 5-28%, 5-49%, and 23-30% for TP, TN, $BOD_5$, and COD respectively for different effluent treatment facilities, including drum or belt filters and settling basins depending on the water flowing rate and effluent content (Bergheim and Brinker 2003, Sindilariu, 2007).

## CONCLUSION

The present study demonstrated that effluent treatment of the trout farm by means of drum filters helped reduce the discharged organic matter, although the differences in concentrations between the inlet and the effluent water of the farm were insignificant ($p>0.05$). In this context, the sampled farm can be regarded as a good example considering the rest of the trout farms in Turkey because of the use of high quality extruded feed (i.e: FCR: 1.1) and using a solid waste removal technique since 1992. The Ministry of Agriculture and Rural Affairs in Turkey has recently been introducing some regulations for the environmental assessment of fish farming. These developments are promising, but monitoring the inlet and effluent of the farms for TP, TN, $BOD_5$ and suspended solids, and limitations on the use of water and feed should be applied to determine and control the impact of aquaculture facilities in Turkey which currently is in the process of joining the European Union. The rainbow trout industry of Turkey, must also demonstrate a sustainable responsibility on the efficient use of water since the declared objective of The Water Framework Directive of the EU is that all the waters within EU are returned to a 'good status' by 2015.

## ACKNOWLEDGEMENTS

This study was sponsored by the Scientific and Technical Research Council of Turkey (TÜBİTAK) (Project No 105Y090). Emrah Deveciler, Müge Gezen, Soner Bilen, Selçuk Berber and Füsun Yurdabak are acknowledged for their support.

## KAYNAKLAR

Anonymous (2000) Official methods of analysis of AOAC International. Edited by William Horwitz, Association of Official Analytical Chemists, 17th Edition. Washington.

Anonymous (2004) HARP-NUT Guideline 2: Quantification and reporting of nitrogen and phosphorus discharges/losses from aquaculture plants. OSPAR Commission. Reference Number 2004-2.

Anonymous (2008) TURKTSTAT, Official statistics of the Turkish Statistical Institute.

Bergheim A, Brinker A (2003) Effluent treatment for flow through systems and European environmental regulations. Aquacultural Engineering 27, 61-77.

Bergheim A, Cripps SJ (1998) Effluent management: overview of the European experience. In: Libey GS, Timmons MB (eds), Recirculating Aquaculture. Economics, Engineering, Management. Proceedings of the 2nd International Conference, 16-19 July 1998, Roanoke, 233-244.

Bergheim A, Hustveit H, Kittelsen A, Selmer-Olsen A (1984) Estimating pollution loadings from Norwegian fish farms. II. Investigations 1980-1981. Aquaculture 36, 157-168.

Bergheim A, Selmer-Olsen AR (1978) River pollution from a large trout farm in Norway. Aquaculture 14, 267-270.

Boaventura R, Pedro AM, Coimbra J, Lencastre E (1997) Trout farm effluents: characterization and impact on the receiving streams. Environmental Pollution 95, 379-387.

Boyd CE (2003) Guidelines for aquaculture effluent management at the farm level. Aquaculture 226, 101-112.

Boyd CE, Gautier D (2000) Effluent composition and water quality standards. Global Aquaculture Advocate 3, 61-66.

Cho CY, Hynes JD, Wood KR, Yoshida HK (1991) Quantification 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), Proceedings of the 1st International Symposium on Nutritional Strategies in Management of Aquaculture Waste, 26 June 1990, Guelph, Canada, 37-50.

Cripps SJ, Bergheim A (2000) Solids management and removal for intensive land-based aquaculture production systems. Aquaculture Engineering 22, 33-56.

d'Orbcastel ER, 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.

Enell M (1995) Environmental-impact of nutrients from Nordic fish farming. Water Science and Technology 31, 61-71.

Foy RH, Rosell R (1991) Loadings of nitrogen and phosphorus from a Northern Ireland fish farm. Aquaculture 96, 17-30.

Kazancı N, Dügel M (2000) An evaluation of the water quality of Yuvarlakçay Stream, in the Köceğiz-Dalyan protected area, SW Turkey. Turkish Journal of Zoology 24, 69-80.

Kelly LA, Stellwagen J, Bergheim A (1996) Waste loadings from a freshwater Atlantic salmon farm in Scotland. Water Resources Bulletin 32, 1017-1025.

Lekang OI, Bergheim A, Dalen H (2000) An integrated wastewater treatment system for land-based fish-farming. Aqucultural Engineering 22, 199-211.

Maillard VM, Boardman GD, Nyland JE, Kuhn DD (2005) Water quality and sludge characterization at raceway-system trout farms. Aquacultural Engineering 33, 271-284.

McDaniel NK, Sugiura SH, Kehler T, Fletcher JW, Coloso RM, Weis P, Ronaldo P, Ferraris RP (2005) Dissolved oxygen and dietary phosphorus modulate utilization and effluent partitioning of phosphorus in rainbow trout (*Oncorhynchus mykiss*) aquaculture. Environmental Pollution 138, 350-357.

Papatryphon E, Petit J, Hayo V, Kaushik SJ, Claver K (2005) Nutrient-balance modeling as a tool for environmental management in aquaculture: the case of trout farming in France. Environmental Management 35, 161-174.

Phillips MJ, Beveridge MCM, Ross LG (1985) The environmental of salmonid cage culture on inland fisheries: present status and future trends. Journal of Fish Biology 27 (Suppl.A), 123-127.

Pillay TVR (2004) Aquaculture and the environment. 2nd Ed. Blackwell Publishing, Oxford.

Pulatsu 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. Turkish Journal of Fisheries and Aquatic Sciences 4, 9-15.

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

Strickland JDH, Parsons TR (1972) A practical handbook of seawater analysis. 2nd Ed. Fisheries Research Board of Canada, Bulletin 167, Ottawa.

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

True B, Johnson W, Chen S (2004) Reducing phosphorus discharge from flow-through aquaculture I: facility and effluent characterization. Aquacultural Engineering 32, 129-144.

Zar JH (2001) Biostatistical analysis. 4th Ed. Prentice-Hall Inc., Upper Saddle River, New Jersey.