

The Application of a Phosphorus Budget Model Estimating the Carrying Capacity of Kesikköprü Dam Lake

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Abstract: The aim of this study was to estimate the carrying capacity of Kesikköprü Dam Lake, Ankara, where cage farms for the intensive culture of rainbow trout are located. For this purpose Dillon and Rigler's phosphorus budget model was applied in a series of steps and the carrying capacity of the lake was found to be 3335 tonnes per year. This estimated value was about 10 times higher than the present production level of the lake. It seems possible to orientate the fish culture in cages in inland waters by using the phosphorus budget model recommended in this study.

Key Words: Cage fish culture, rainbow trout (*Oncorhynchus mykiss*), carrying capacity, phosphorus load, Kesikköprü Dam Lake.

Kesikköprü Baraj Gölü'nün Taşıma Kapasitesinin Tahmininde Fosfor Bütçe Modelinin Uygulanması

Özet: Bu çalışmanın amacı, kafeslerde entansif gökkuşağı alabalığı yetiştiriciliğinin yapıldığı Kesikköprü Baraj Gölü'nün (Ankara) taşıma kapasitesini tahmin etmektir. Bu amaçla, Dillon ve Rigler'in fosfor bütçe modeli göle uygulanmış ve gölün taşıma kapasitesi 3335 ton/yıl bulunmuştur. Tahmin edilen bu değer, gölün şu anki kapasitesinin yaklaşık olarak on katından fazladır. Bu çalışmada önerilen fosfor bütçe modelinin kullanımı ile içsularda kafeslerde balık yetiştiriciliğini yönlendirmek olası görülmektedir.

Anahtar Sözcükler: Kafeslerde balık yetiştiriciliği, gökkuşağı alabalığı (*Oncorhynchus mykiss*), taşıma kapasitesi, fosfor yükü, Kesikköprü Baraj Gölü.

Introduction

In recent years there has been a rapid increase in the number of fish farms which employ floating net cages to rear trout, principally rainbow trout (*Oncorhynchus mykiss*), in freshwater systems in Turkey (1).

It is reported in various studies that because of intensive fish farming there may be variations in the trophic level of the water. The negative impact of aquaculture derives mainly from particulate and dissolved nutrients from animal excretion and uneaten feed (2,3).

The determination of the location and the overall working capacity of the project as per the carrying capacity of the environment are very important factors in reducing the ecological effects and the risks that may emerge (4). The phosphorus budget model that was first established by Vollenweider, and then developed by Dillon and Rigler, is widely used in estimating phosphorus

concentration, which is the basic restrictive element in lakes, and further, these total phosphorus estimations are used by limnologists to determine the nutrition levels of lakes, as well as for estimating the biomass and productivity of all the biological components of the lakes and pools (5,6). It has been reported that the Dillon and Rigler model gave favourable results when applied and tested both in shallow and deep lakes, as well as in the reservoirs of both warm and tropical areas. It is also reported that the model may successfully be used to estimate the carrying capacity of inland waters where intensive fish raising is carried out (7).

Beveridge (7) produced a model of the impact of the cage culture of salmonids, based on previous work on the relation between the phosphorus loading of lakes and resulting chl-a levels; the model predicts the capacity of a lake to produce fish while keeping water quality within acceptable limits.

The concept of nutrient (phosphorus) loading is the amount of nutrient added to the unit area of the lake in a unit time. In other words, it shows the relation between the amount of nutrient that enters the water body, and the reaction of the system to this input. Vollenweider has stated that the concept of nutrient loading may initially be applied on elements such as nitrogen and phosphorus which determine the eutrophication spectrum and productivity of the lake, and, among these elements, phosphorus is of greater importance than nitrogen in controlling eutrophication (8).

The aim of this study was to estimate the carrying capacity of Kesikköprü Dam Lake, where cage farms for intensively cultured rainbow trout are located. For this purpose Dillon and Rigler's phosphorus budget model was applied in a series of steps.

Materials and Methods

Materials

Kesikköprü Dam is 110 km south-east of Ankara, 25 km downstream of the Hirfanlı Dam; it was built over the Kızılırmak River in 1996. The dam is located between lat 39° 23' N and long 33° 25' E, and is 785 m above sea level. The dam lake is of the soil-rock filling type; it has a surface area of 6.50 km² and a volume of 95.00 hm³. It was built for the purposes of water supply and energy production. Water flows from Hirfanlı Dam to Kesikköprü Dam (9).

In this study, the total phosphorus values of the water samples taken from a research station 60 m from cage-

fish farm number V are used (Figure). This rainbow trout cage farm of 55-t capacity started production in 1996. The farm consisted of floating cages, each 5 x 5 x 5 m. The fish were fed a commercial pelleted diet. The crude protein and phosphorus content of the feed were 46% and 1.1%, respectively. The capacities of the other farms, numbers I, II, III and IV, are 50 t, 30 t, 40 t and 40 t, respectively.

Methods

Dillon and Rigler's phosphorus budget model for the assessment of carrying capacity was described in a series of steps as follows:

1. Measure the steady-state total-P concentration. In temperate waters this is best determined at the time of spring overturn, when the waters are well mixed.

2. The development capacity of lake or reservoir for intensive cage culture is the difference between the productivity of the water body prior to exploitation and the final desired/acceptable level of productivity.

3. The capacity of the water body for intensive cage fish culture is the difference, Δ[P], between [P] prior to exploitation, [P]_i, and the acceptable [P] once fish culture is established, [P]_f.

$$\Delta[P] = [P]_f - [P]_i \tag{1}$$

ΔP is related to P loadings from the fish cages, L_{fish}, the size of the lake, A, its flushing rate and the ability of the water body to handle the loadings.

$$\Delta P = L_{fish} (1 - R_{fish}) \bar{z} \rho \tag{2}$$

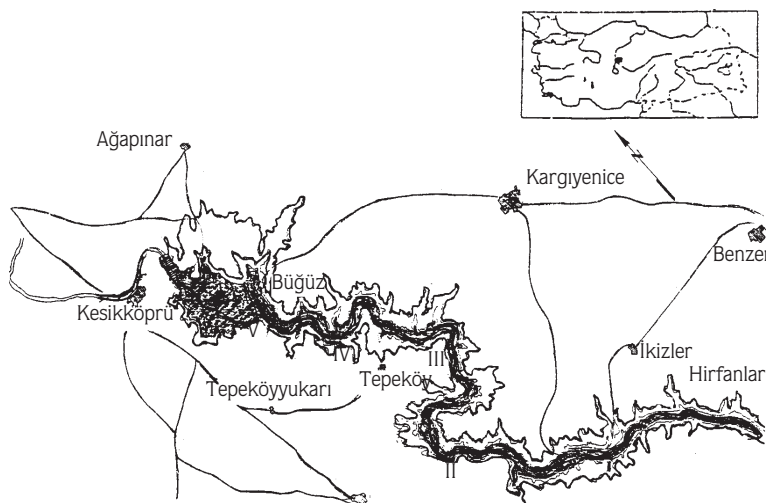


Figure. Location of the five cage trout farms in Kesikköprü Dam Lake (V: selected fish farm).

$$L_{\text{fish}} = \Delta[P] \bar{z}\rho / (1 - R_{\text{fish}}) \quad (3)$$

R_{fish} is the most difficult parameter to estimate. At least 45-55% of the total-P wastes from cage rainbow trout are likely to be permanently lost to sediments as a result of solids deposition and calculated as

$$R_{\text{fish}} = x + [(1 - x) R] \quad (4)$$

where

x: the net proportion of total-P lost permanently to the sediments as a result of solids deposition (0.45-0.55)

R: Phosphorus retention coefficient

$$R = 1/1 + 0.747 \rho^{0.507} \quad (5)$$

ρ = Flushing rate (y^{-1})

4. Acceptable total-P loading, L_a is estimated by multiplying L_{fish} and lake surface area.

5. Intensive cage fish production ($t y^{-1}$) can be estimated by dividing L_a by the average total-P wastes per tonne of fish production.

Results

The characteristics of Kesikköprü Dam Lake and the selected cage-fish farm are shown in Tables 1 and 2, respectively.

Table 1. Morphometric, hydrologic and phosphorus budget parameters of Kesikköprü Dam Lake (* values of 2000).

	Symbol	Values
Drainage area (km^2)	A_d	354
Surface area (km^2)	A_o	6.5
Lake volume (10^6m^3)	V	95
Mean depth (m)	\bar{z}	14.62
Total outflow (10^6m^3)	Q	2155
Flushing rate (y^{-1})*	$\rho = Q/V$	22.68
Water replenishment time (y)*	$t_w = 1/\rho$	0.04
Phosphorus retention coefficient*	R	0.21

Table 2. Characteristics of the selected cage-fish farm.

	Values
Total biomass (kg)	55,300
Total feed (kg)	65,800
Phosphorus content (%)	1.10
Feed conversion ratio (FCR)	1.24
Phosphorus load from feed	753.50
Mean P fish retention	0.22
Phosphorus content of fish biomass	121.66

The results of this study are presented below according to the above-described steps:

1. The average phosphorus concentration of the water samples was $[P] = 53.10 \text{ mg/m}^3$ in April 2000 (the activities of cage-fish farm number V as reported in another study (10) did not influence this station).

2. 60 mgm^{-3} is chosen as the value for maximum acceptable $[P]_f$ in temperature inland water bodies used for the culture of rainbow trout (7).

3. Determine $\Delta[P]$;

$$\begin{aligned} \Delta[P] &= [P]_f - [P]_i \\ &= 6.90 \text{ mg/m}^{-3} \end{aligned}$$

$$L_{\text{fish}} = \Delta P \bar{z}\rho / 1 - R_{\text{fish}}$$

x is assumed to be 0.5

Thus, R is calculated from equation (5),

$$R = 0.21$$

Thus, using equation (4) R_{fish} is calculated as 0.61.

$$\bar{z} = 14.62 \text{ m (Table 1)}$$

$$\rho = 22.68 \text{ y}^{-1} \text{ (Table 1)}$$

$$\begin{aligned} L_{\text{fish}} &= (6.90 \times 14.62 \times 22.68) / (1 - 0.61) \\ &= 5866.44 \text{ mg m}^{-2} \text{ y}^{-1} \\ &\cong 5.87 \text{ g m}^{-2} \text{ y}^{-1} \end{aligned}$$

4. Since the dam lake has a surface area of $6.5 \times 10^6 \text{ m}^2$, the total acceptable loading, L_a , is

$$\begin{aligned} L_a &= 5.87 \times 6.5 \times 10^6 \\ &= 38.15 \times 10^6 \text{ g/y}^{-1} \end{aligned}$$

5. The tonnage of fish that can be produced, assuming a P loading of 11.44 kg t^{-1} . This value is calculated as below for selected cage-fish farm:

P content of commercial trout pellet: 1.10%

1 tonne feed contains 11.0 kg P

FCR = 1.24 therefore P_{food} : 13.64 kg

P content of trout = 0.22% wet weight of fish = 2.2 kg t fish⁻¹

Therefore,

$$\begin{aligned} \text{P losses to the environment} &= 13.64 - 2.2 \\ &= 11.44 \text{ kg t} \\ &\text{fish produced}^{-1} \end{aligned}$$

$$\begin{aligned} \text{Carrying capacity of lake} &= 38.15 \times 10^6 / 11.44 \\ &= 3335 \text{ t y}^{-1} \end{aligned}$$

Discussion

There have been several models and methods developed for estimating the effects of carrying capacity of inland waters where intensive fish raising is performed, and the influences of the cages where fish are cultured on the recipient waters. In this study, the Dillon and Rigler model was taken as the baseline, and the carrying capacity of Kesikköprü Dam Lake was estimated to be 3335 t y⁻¹. This result is about 10 times higher than its present fish production level.

The results of this study showed that the calculated values from this model can be used as a pre-development

guide to the carrying capacity of lakes. However, the effects of and changes in the cage-fish farm should be checked with actual observed values to increase the reliability of the models.

The determination of the environment and sustainability of fish culture helps in estimating the results of the environmental effects of production. In this sense, it seems possible to orientate the production activities in inland waters by adopting the model recommended in this research.

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