Evaluation of the primary production and maximum fish production in Salman Farsi Reservoir, Fars Province, Iran

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Abstract

Primary production in water bodies corresponds to their fish production capacity. Aquaculture planning for water resources is conducted based on specific geographical conditions and their internal and external factors. Understanding the fish production capacity of lakes enables predictions for exploitation (fishing) and restoration of reserves. This research aims to estimate the primary production of the Salman Farsi Reservoir, Fars Province, on the Ghare Aghaj River, to evaluate fish production capacity and plan aquaculture development. Sampling was conducted to measure dissolved oxygen, water temperature, pH, conductivity, transparency, total phosphorus, total nitrogen, and chlorophyll-a in three transversal sections along the side, surface, and deep areas of the open water, with three repetitions in four seasons during 2023 – 2024. Trophic conditions were estimated using Trophic Status Index (TSI) models. Total production of the lake was calculated using the Brämick-Lemke and Koeschel models, while fish production was calculated using the Brämick-Lemke and Downing models. The annual average of dissolved oxygen, transparency, electrical conductivity, pH, total phosphorus, total nitrogen, and chlorophyll-a concentration in the lake was 8.2 ppm, 4.1 meters, 1387 µS/cm, 8.3, 0.174 ppm, 4.50 ppm, and 1.38 ppm, respectively. The average TSI based on transparency, phosphorus, chlorophyll-a, and Carlson's index was 40, 78, 33, and 50. The initial production size in the lake was estimated 292 gC.m-²y-1. Fish production capacity was calculated based on primary production at 39 Kg.ha-1.y-1 and based on phosphorus at 33 Kg.ha-1.y-1, with an average of 36 Kg.ha-1.y-1. Considering the 2000-hectare livable area for fish in the lake, the total fish production this year was estimated at 71.8 tons. Under current lake conditions, the allowable fishing size was estimated to be 7 to 11 tons of fish per year. Determining the production capacity and trophic level can help maximize exploitation while minimizing ecological impacts and potential risks associated with restocking and fishing, such as the introduction of excessive juvenile fish into the lake.

Keywords: Primary production, Chlorophyll, Total phosphorus, Fish production, Fars Province

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Introduction

For the proper exploitation and management of production, release, and fishery in reservoirs, it is essential to predict the size of the annual harvest (Henderson *et al*., 1973). Reservoirs, as artificial water bodies created by damming rivers, serve multiple purposes, including water supply, flood control, and hydropower generation (Adeloye, 2012). However, they also play a critical role in supporting aquatic ecosystems and fisheries. To ensure sustainable exploitation and effective management of reservoir resources, understanding the annual harvest size is essential.

Properly managing fish production, stocking, and harvest requires accurate predictions. By estimating the annual harvest size, fisheries managers can optimize resource utilization. If the harvest is too small, the reservoir's potential remains untapped, affecting food security and livelihoods. Conversely, an excessive harvest could deplete fish populations, disrupt ecological balance, and compromise long-term sustainability. Reservoir ecosystems are complex, with interconnected food webs. Fish populations depend on primary production (such as phytoplankton and algae) and secondary production (zooplankton and other prey). Predicting the annual harvest helps maintain ecological balance (Jager and Smith, 2008). Managers can adjust stocking rates, fishing quotas, and habitat enhancements based on these predictions, ensuring healthy fish populations while preserving other aquatic life.

Reservoir fisheries contribute to local economies and cultural heritage as well. Predicting the annual harvest informs policies and regulations. It guides decisions on fishing seasons, gear types, and allowable catch. By balancing economic gains with ecological sustainability, reservoirs can support both livelihoods and biodiversity (Cael and Seekell, 2023; Ho *et al*., 2019). Primary production is the fundamental process that sustains life in lakes (Pierson, 2012). Through photosynthesis, aquatic plants, including phytoplankton and submerged macrophytes, convert inorganic nutrients (such as carbon dioxide and minerals) into organic matter. This organic material serves as the base of the food web, supporting other organisms. The availability of nutrients significantly influences primary production in freshwater ecosystems. Among these nutrients, phosphorus (P) and nitrogen (N) play crucial roles (Shuvo *et al*., 2021; Theng *et al*., 2023). Phosphorus is often the limiting nutrient in lakes, and its concentration affects the growth of algae and other primary producers (Chislock *et al*., 2013). When phosphorus levels are sufficient, phytoplankton assimilate more nitrogen, leading to increased primary production.

Fish production in freshwater lakes is intricately tied to primary production. Phytoplankton and other primary producers serve as the primary food source for zooplankton, which, in turn, are consumed by fish. The energy flow from primary producers to fish sustains entire aquatic food chains (Lapointe *et al*., 2014).

In past years, in collaboration with Fars Fisheries, carp fingerlings were released into the reservoir as part of stock restoration efforts. However, this release occurred without knowledge of the lake's production capacity. If the population regeneration rate falls below the natural production capacity of the lake, the water resource will not be optimally utilized. Conversely, if it exceeds the lake's production capacity, it could disrupt the ecosystem cycle. Therefore, understanding the lake's production capacity and estimating the harvestable fish capacity are crucial for effective lake aquaculture planning.

Numerous studies have been conducted globally to measure primary production and its relationship with fish production (Sreenivasan, 1969; John *et al*., 1990; Nielsen and Richardson, 1996; Khalil, 1998; Brämick and Lemcke, 2001; Hakanson and Boulion, 2001; Gomes *et al*., 2002; Krishnarao *et al*., 2002; Chattopadhyay and Banerjee, 2008; Darchambeau *et al*., 2014; Rajashekhar and Baburrao, 2011). These studies are limited in Iran due to the nascent nature of aquaculture in water reservoirs. However, research has been conducted in the Karkheh, Shahid Abbaspur (Masjed Solaiman), Karun 3, Marun, and Dez reservoirs (Khalafe-Nilsaz, 2008, 2010), and Haft Barm Lake, Fars (Zamanpoore, 2023).

This study investigates the fish production capacity within the Salman Farsi Reservoir, focusing on key parameters such as the Trophic Status Index (TSI), primary production capacity, and maximum sustainable fish production, using data on transparency, total phosphorus, and chlorophyll-a levels in the plankton community. Understanding these capacities provides valuable insights into ecological dynamics and ecosystem functioning. By leveraging this knowledge, we can enhance resource management practices. Specifically, safeguarding water quality against potential threats and establishing a suitable range for aquaculture operations allows us to determine the optimal scale for aquaculture development.

Materials and methods

Study area

The Salman Farsi Reservoir is located in Fars province, south of Shiraz, on the Ghare Aghaj River, which originates from the Zagros Mountains in the Karzin Gorge. Access to the site is via a 13-kilometer-long special asphalt road branching off from the 12-kilometer road from Ghir to Firuzabad. The distance from the dam site to Shiraz is about 200 kilometers, and from the cities of Firuzabad and Jahrom, it is about 75 and 100 kilometers, respectively. The area of the reservoir lies between 28° 30′ N to 28° 45′ N and 53° 15′ E. Based on the shape of the lake and how different parts of the lake are connected to each other, three transversal sections were chosen along the length of the lake in riverine, transitional, and lacustrine sections (Table 1, Fig. 1). In each section, three stations, including littoral, surface, and deep open water (limnetic) areas, were selected.

Table 1: Geographical points of selected cross-sections of the main parts of the Salman Farsi Lake.

Sections	Lattitude	Longitude
Riverine	28°32'11.3"N	53°07'41.6"E
Transitional	28°33'10.7"N	53°08'01.8"E
Lacustrine	28°35'10.3"N	53°08'50.6"E

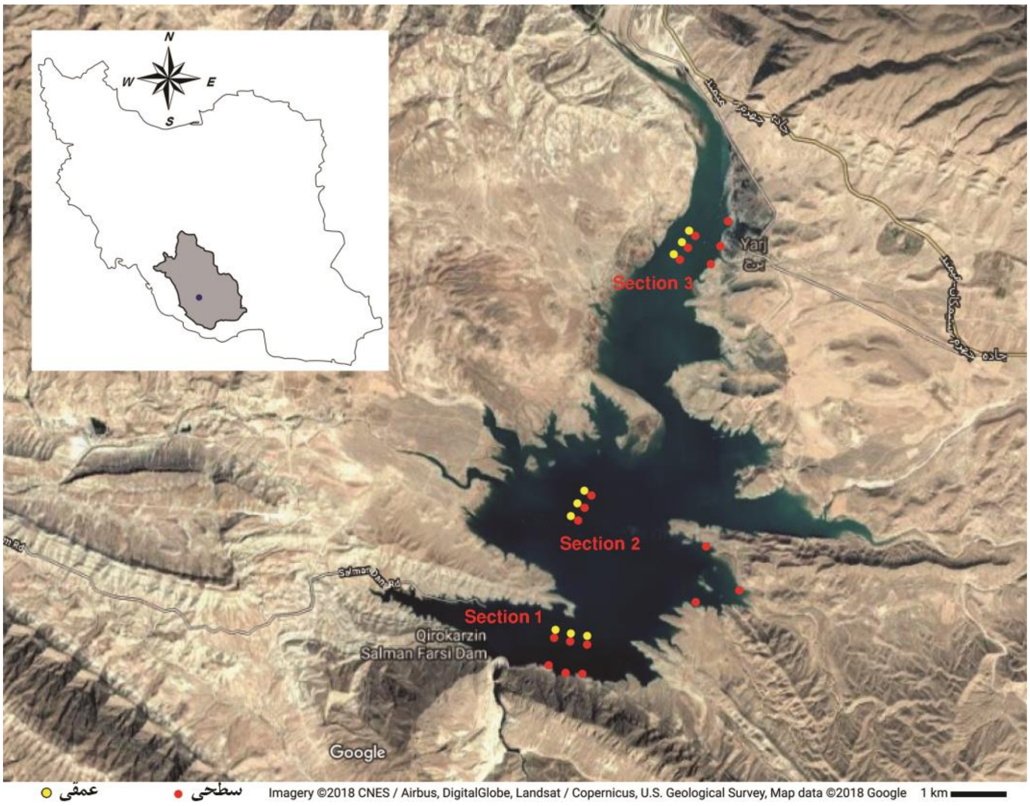

Figure 1: Geographical location of Salman Farsi Reservoir and the sampling locations (lake sections: Section 1: Lacustrine; Section 2: Transitional; Section 3: riverine).

Sampling at each of these stations was done with three repetitions at distances of approximately 100 meters from each other (Stockner *et al*., 2001).

Sampling and measurements

Sampling was performed seasonally from May 2023 to February 2024 between the 10th and 20th of each month from 0800 to 1400. A total of 108 samples were collected. Water samples were taken with a modified Dussart flask and kept in 1-liter bottles in a cool box. Factors such as dissolved oxygen, water temperature, pH, and electrical conductivity were measured and recorded on-site. Dissolved oxygen and water temperature were measured with a digital portable oxygen meter (Hach HQ40d Multimeter), and air temperature was measured with a mercury thermometer. A Secchi disk was used to measure transparency in deep stations. The disk was slowly lowered into the water, and when it reached the limit of visibility, the water depth was read from the length of the rope.

The persulfate method was used to measure total phosphorus. The unfiltered water was heated and acidified to convert all forms of phosphorus to orthophosphate. Orthophosphate ions were measured using a spectrophotometer (HACH DH-2400). The nitrogen obtained from the Kjeldahl method (organic nitrogen and ammonium) was added to the amounts of nitrite and soluble nitrate to obtain total nitrogen (Rus *et al*., 2012). Chlorophyll sampling was done from the trophic layer (from below the surface down to a depth of 100 cm). The chlorophyll content of the samples was extracted in the laboratory with 90% acetone, and the absorbance was read at wavelengths of 630, 647, and 664 nm (Greenberg *et al*., 2005).

Calculation models

Trophic status index (TSI) models (Carlson, 1977) were used to assess the trophic conditions of the reservoir based on the biomass of phytoplankton. Algal biomass was estimated using Secchi depth and total phosphorus. This index was obtained for each of the mentioned variables from the following relationships:

$TSI(SD) = 60-14.41\ In(SD)$ (m)

$TSI(TP) = 14.42\ In(TP) + 4.15$ (µg/L)

$TSI(Chl) = 9.81 \ln Chlorophyll + 30.6$ (µg/L)

Carlson’s $TSI = [TSI(TP) + TSI(CA) + TSI(SD)]/3$

Where, the index value is less than 30, the lake is oligotrophic, where it is 30 - 50, it is mesotrophic, where it is 50 - 70, it is eutrophic, and where it is >70, it is hypertrophic.

Estimation of the total primary production of the lake

Using these results, the primary production of the lake, the trophy status and the fish production capacity were estimated. Primary production ($gCm^{-2}.y^{-1}$) was measured based on Equation 1 for normal stratified lakes (Koeschel *et al*., 1981; Brämick and Lemcke, 2003):

Eq. 1 $PP = 148.\ IogTP - 39.6$

PP: primary production ($gCm^{-2}.y^{-1}$), TP: total phosphorus (µg/L)

Fish production capacity, the ability to produce fish in the lake, was estimated in two models of Brämick and Lemke (2003) based on primary production (Eq. 2), and Downing *et al*. (1990) based on total phosphorus (Eq. 3).

Eq. 2 $\log_{10}FP = 0.332 + 0.531\log_{10}TP$

FP: Fish production ($Kg.ha^{-1}.y^{-1}$), TP: total phosphorus (µg/L)

Eq. 3 $FP = 6.315 \times 2.71828^{(0.0062\times PP)}$

FP: Fish production ($Kg.ha^{-1}.y^{-1}$), PP: primary production ($gCm^{-2}.y^{-1}$)

Estimation of fish biomass (standing crop)

Using Downing's model (Downing *et al*., 1990), the total fish population of the lake was predicted from fish production (Eq. 4).

Eq. 4 $\log_{10}FB = (\log_{10}FP + 0.42)/1.084$

FB: Fish biomass ($Kg.ha^{-1}$), Fish production ($Kg.ha^{-1}.y^{-1}$)

By multiplying the size of fish production and fish population by the livable area of the lake for fish, it was possible to estimate the total production and productivity of the lake. The management of Salman Reservoir reported the total area of the lake to be 2500 hectares this year. With the help of the Google Earth system, very shallow marginal parts were calculated to be approximately 500 hectares. Therefore, in this study, the livable area of the lake for fish was taken as 2000 hectares.

To determine the difference between stations and sections in the changes of chemical factors, the comparison of the average data between the stations and the analysis of the data were done using Analysis of Variance (ANOVA) in SPSS 19. The t-test with two independent populations was used to compare the two stations.

Results

The annual average of physical factors, including dissolved oxygen, transparency, electrical conductivity, and pH of the lake were 8.2 ppm (SE=0.2), 1.4 m (SE=0.1), 1387 μScm-1 (SE=11), and 8.3 (SE=0.1), respectively. The annual average of the measured chemical factors including total phosphorus, total nitrogen, and chlorophyll-a were 0.174 ppm (SE=0.003), 4.50 ppm (SE=0.11), and 1.38 ppm (SE=0.06), respectively (Figs. 2 and 3).

The highest seasonal average of trophic status index (TSI) based on transparency was in spring (42) and the lowest in autumn (38) and winter (39) ($p<0.01$). The annual average of the trophic status based on the transparency between the three sections was 40 (SD=3), where the differences were not significant. The TSI based on total phosphorus was slightly lower in spring, but its difference was not significant compared to other seasons. The lowest mean monthly phosphorus-based TSI was in spring (77) and the highest in summer (79).

The average annual TSI based on phosphorus was 78. The average seasonal trophic state based on chlorophyll in summer (28.4) was lower than autumn (34.5) and spring (34.7) ($p < 0.05$). Its annual average was 32.7 (SD = 4.7). Results of the trophic status index based on transparency, total phosphorus, and chlorophyll-a are presented in Table 2.

Carlson's trophy index was obtained by averaging three trophy indices calculated based on transparency (SD), total phosphorus (TP) and chlorophyll (Chl). Its maximum size was in May and its minimum was in August. The seasonal average of Carlson's trophy index in Salman Lake in the research year was 50.34 (Table 3).

The size of the total primary production in the lake was estimated to be 292 $gCm^{-2}.y^{-1}$. Its maximum and minimum were reached in winter (294 $gCm^{-2}.y^{-1}$) and summer (245 $gCm^{-2}.y^{-1}$). The average fish production capacity in the lake in 2023-2023 was estimated 39 $Kg.ha^{-1}.y^{-1}$ based on the primary production, and 33 $Kg.ha^{-1}.y^{-1}$ based on the total phosphorus (Table 4).

Assuming the correctness of both methods, the average sizes obtained from both models were 35.90 $Kg.ha^{-1}.y^{-1}$.

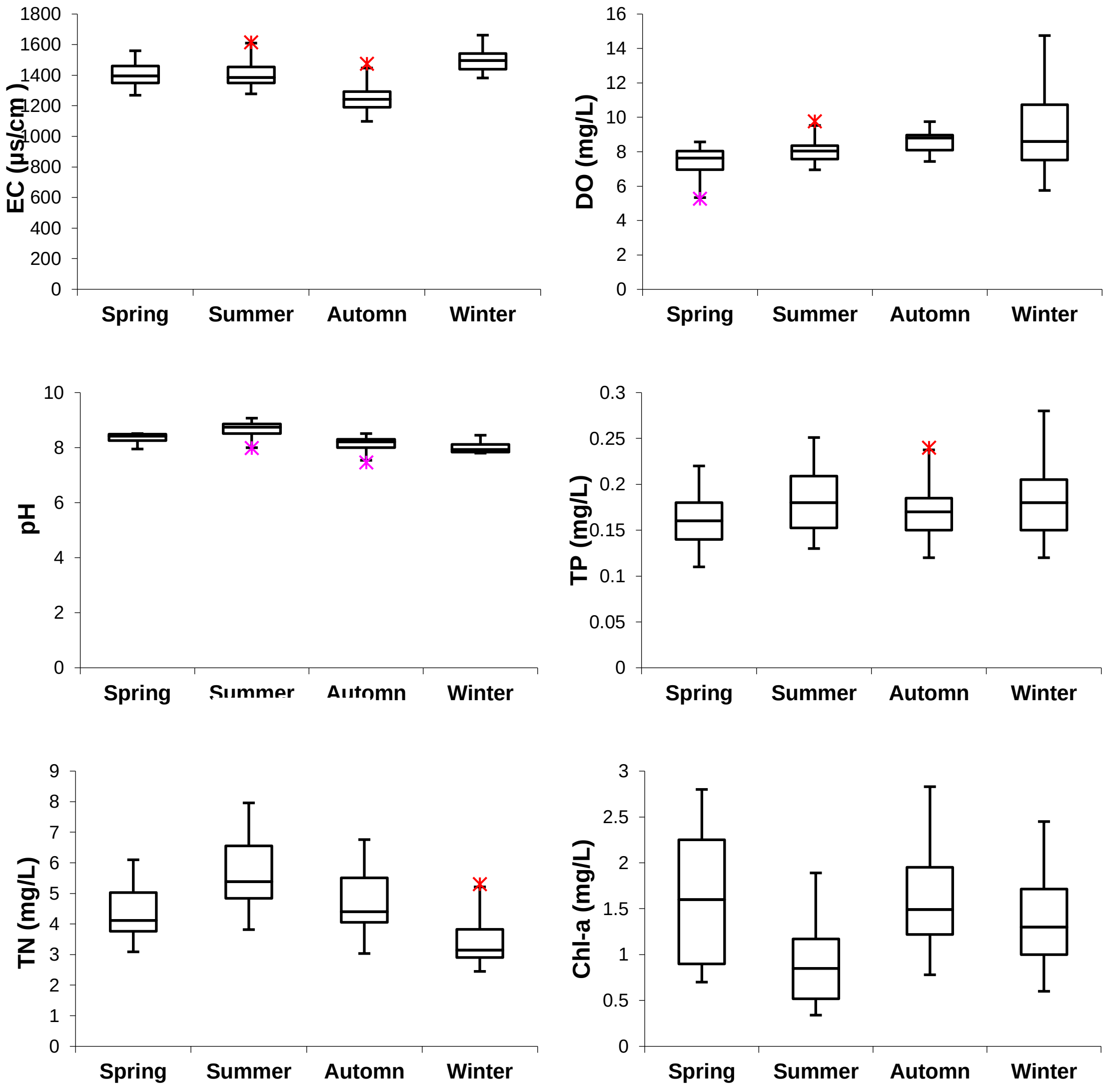

Figure 2: Box Plot diagrams of electrical conductivity, dissolved oxygen, water pH, total phosphorus, total nitrogen, and chlorophyll-a concentration of Salman Farsi Reservoir water in 2023-2024.

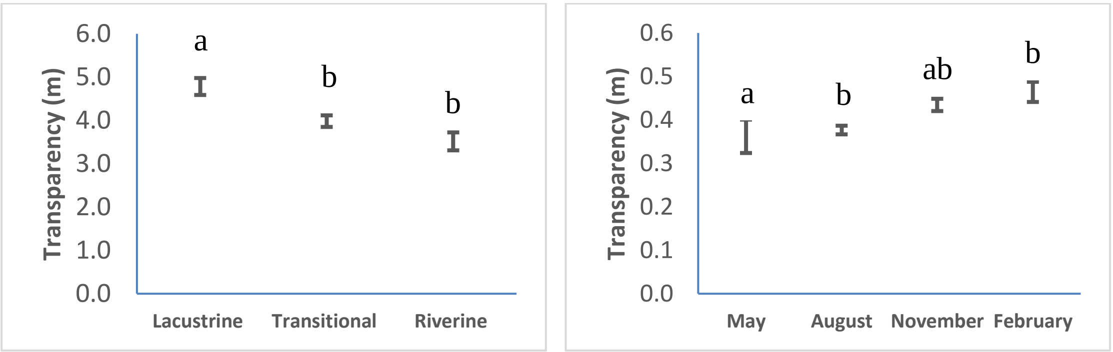

Figure 3: Changes of transparency (Secchi depth) of Salman Farsi Reservoir in 2023-2024 between the lake sections (top), and selected months of the year (bottom). Different alphabetic signs indicate statistically significant differences (*p*<0.05).

Table 2: Data of the Trophic State Index (Mean ± SD) based on transparency (Secchi depth), total phosphorus, and chlorophyll-a, in Salman Farsi Reservoir in 2023-2024.

TSI criteria	Lake zone	Months			
		May	August	November	February
Transparency	Lacustrine	36.6 (±0.4)	40.5 (±0.8)	37.7 (±1.4)	35.4 (±0.8)
	Transitional	42.7 (±0.7)	40.3 (±0.8)	39.1 (±0.5)	38.7 (±1.0)
	Riverine	47.0 (±0.7)	42.0 (±1.5)	39.8 (±1.5)	39.9 (±0.4)
Total phosphorus	Lacustrine	75.3 (±2.1)	76.8 (±2.1)	76.2 (±0.2)	75.8 (±1.4)
	Transitional	76.7 (±1.3)	78.6 (±2.5)	78.0 (±1.4)	80.5 (±1.5)
	Riverine	78.2 (±1.6)	80.1 (±2.3)	78.5 (±1.8)	79.3 (±1.0)
Chlorophyll-a	Lacustrine	31.9 (±3.4)	25.5 (±3.7)	31.8 (±2.5)	33.5 (±3.7)
	Transitional	33.6 (±5.7)	26.9 (±5.8)	34.2 (±3.5)	31.4 (±4.0)
	Riverine	39.3 (±1.3)	32.8 (±2.3)	37.6 (±1.9)	35.6 (±2.4)

Table 3: Data of the Trophic State Index based on transparency (Secchi depth, SD), total phosphorus, TP, and chlorophyll-a, Chl, and Carlson's TSI in Salman Farsi Reservoir in 2023-2024.

	May	August	November	February	Mean	SD
SD TSI	42.1	40.9	38.9	38.0	40.0	1.9
TP TSI	77.3	79.0	78.1	78.9	78.3	0.8
Chl TSI	34.7	28.4	34.5	33.5	32.7	2.9
Carlson's TSI	51.4	49.4	50.5	50.1	50.3	0.8

Table 4: Estimation of primary production and fish production in Salman Farsi Reservoir in 2023-2024.

	May	August	November	February	Mean	SD
PP (gCm^{-2}.y)	287.3	294.9	291	294.4	291.9	3.6
FP (Kg.ha^{-1}.y^{-1})	37.5	39.3	38.3	39.2	38.6	0.9
FP (Kg.ha^{-1}.y^{-1})	31.9	34.1	32.9	33.92	33.2	0.9

The estimation of the total fish population of the lake with the Downing model showed its value in the year of the study to be 66.38 Kg.ha^{-1}. Based on this estimate, if the living area of the lake is taken as 2000 hectares for the fish population, the total size of fish produced in the lake is 71.8 tons, and the size of the fish population in the whole lake is 132.8 tons.

Discussion

The annual average of dissolved oxygen in the reservoir was 8.3 mg/L, similar to the findings of previous research in this lake. This factor was recorded in 2016-2017 as 8.2 mg/L (Zamanpoore *et al.*, 2019). The annual average of dissolved oxygen in Darudzen Lake was 7.6 mg/L in 2010-2011 (Zamanpoore and Qaed-Abdi, 2016), and 9.5 mg/L in 2019 (Zamanpoore *et al*., 2022). Parham *et al.* (2007) reported the average dissolved oxygen in Karkheh Reservoir as 9.6 mg/L. The annual average transparency of the Salman Reservoir in this study was 1.4 m, while in 2016-2017 it was measured as 3.5 m (Zamanpoore *et al.*, 2019). Measurements in Dorudzen Lake showed an annual average of 2.1 m in 2010-2011 (Zamanpoore and Qaed-Abdi, 2016), and 5.8 m in 2019

(Zamanpoore *et al*., 2022). Mohammadi *et al*. (2017) reported the one-year average transparency in Golbalag Reservoir (Kurdistan) as 0.5 m. The annual average electrical conductivity of the lake was 1387 µS/cm. The measurements of 2016-2017 in the same lake showed the electrical conductivity as 873 µS/cm (Zamanpoore *et al*., 2019). In comparison, in Dorudzan Lake, this factor was measured at 720 µS/cm (Zamanpoore and Qaed-Abdi, 2016) and 722.2 µS/cm (Zamanpoore *et al*., 2022). In Golbalag Reservoir, the annual average electrical conductivity was measured as 1462 µS/cm (Mohammadi *et al*., 2017). The annual average pH of the lake was 8.3. This factor was reported as 7.9 in 2016-2017 (Zamanpoore *et al*., 2019). In Dorudzan Reservoir, the annual average pH was 8.2 in 2010-2011 (Zamanpoore and Qaed-Abdi, 2016) and 8.0 in 2019 (Zamanpoore *et al*., 2022). The annual average of total phosphorus in the lake water was 0.174 ppm. This factor has not been reported in the past from this lake. However, the concentration of phosphate ions in 2016-2017 in Salman Reservoir was 0.36 ppm (Zamanpoore *et al*., 2019). In the water of Dorudzan Lake, the one-year average of phosphate ions was 0.20 ppm in 2010-2011 (Zamanpoore and Qaed-Abdi, 2016), and 0.13 ppm in 2016-2017 (Zamanpoore *et al*., 2022). Mohammadi *et al*. (2017) reported the one-year average amount of total phosphorus in Golbalag Reservoir (Kurdistan) as 0.71 ppm. In the reservoir, which is an open system, the main source of phosphate ions is rural and agricultural wastewater (Hamid *et al*., 2020). After the end of the spring precipitations, which dilute the water and reduce the concentration of substances, the reduced inflow of the river carries substances washed from the upstream watershed into the lake, increasing its concentration inside the lake. With autumn precipitations, the lake water is diluted again, and the concentration decreases. This interpretation is confirmed by the results of the three sections, which showed that the amount of phosphate ions was higher in the riverine section closest to the entrance of the river flow.

The average amount of total nitrogen was 4.50 ppm. The total averages of ammonium, nitrite, and nitrate in the same lake in 2016-2017 were 1.16 ppm (Zamanpoore *et al*., 2019). The annual average concentration of nitrate ion in the water of Dorudzen Reservoir in Zamanpoore and Qaed-Abdi (2006) was 0.44 ppm in 2010-2018, but in Zamanpoore *et al*. (2022) it was recprded as 4.1 ppm during 2019-2028. Mohammadi *et al*. (2017) reported the annual average of total nitrogen in Golbalag Reservoir as 2.3 ppm. The annual average of chlorophyll-a concentration was 1.38 ppm. The size of this factor in the reservoirs of the country where it has been measured is reported to be close to each other. For example, it was 1.9 ppm in Dorudzen Reservoir (Zamanpoore *et al*., 2022). In Golbalag Reservoir, the annual average chlorophyll-a concentration was 1.09 ppm (Mohammadi *et al*., 2017), and Roohi *et al*. (2019) reported a one-year average chlorophyll concentration in Azad Reservoir, Sanandaj, of 3.5 ppm.

The lake’s trophic index, based on Carlson’s method with indices calculated by transparency, total phosphorus, and chlorophyll-a, was 50.34. It is evident that fish production in lakes depends on the size of its primary production (Brämick and Lemcke, 2001), which in turn depends on the nutrients that reach it from outside the lake or are released inside it from the bacterial decomposition of organic matter (from the death of plants and animals). Based on this, different lakes can be categorized into low (oligotrophic), medium (mesotrophic), and high (eutrophic) production rates.

In the analysis of chlorophyll density, lakes with a chlorophyll concentration of 10 – 500 μgL^{-1} are considered to be eutrophic (Leith and Whittaker, 1975). Since the annual average of chlorophyll-a in the lake was 50 μgL^{-1}, this lake can be considered eutrophic. Carlson and Simpson (1996) attribute a chlorophyll-a concentration range of 20 μgL^{-1} to 156 μgL^{-1} as true or complete lake trophicity; therefore, the lake trophicity is known to be complete by their criterion as well. On the other hand, analysis based on transparency, with clarity depths of 2 – 4 m, indicates mesotrophic status of lakes. On this basis, Salman Lake, having an average annual transparency depth of 1.4 m, is placed in the upper range of the middle trophic status. Ultimately, trophic estimations based on the total phosphorus levels are slightly different. Stratified lakes whose summer total phosphorus are recorded less than 6 μgL^{-1} are categorized in the oligotrophic group (Carlson and Simpson, 1996). While the annual average total phosphorus concentration of the lake was 0.174 μgL^{-1} in this reseach, Salman Lake might be put in the group of oligotrophic lakes, according to Carlson and Simpon (1996). The model of Leith and Whittaker (1975) also considers the range of less than 1 μgL^{-1} – 5 μgL^{-1} in very low trophy (ultra-oligotrophic). However, the lake transparency data is not consistent with this result. In such a situation, Carlson's multi-factor index is used to make a correct judgment about the state of the trophic status of the lake.

Calculation of Carlson's multifactorial index is a method of judging between different factors. The average annual trophic index was 40 based on transparency, 78 based on total phosphorus, and 33 based on chlorophyll. The use of Carlson's index for the lakes’ trophic status in the Salman Lake shows that the situation caused by phosphorus concentration can affect the judgment. Lakes with a trophic index of less than 30 are in the oligotrophic, with an index of 40 to 50 in the mesotrophic, and with indices of 50 to 70 in the eutrophic group. The calculated three-factor index for this lake was 50, which reflects the boundary conditions between moderate and high trophicity. In mesotrophic conditions, the lake water should be as clear as medium, but in eutrophic conditions, a large population of aquatic plants should be seen (Carlson and Simpson, 1996). Our observation in the lake indicates that the water was relatively clear during the survey, and the population of aquatic plants in the lake periphery was very sparse and scattered, so the second possibility can be ruled out, and it is more correct to consider the lake as medium-to-high trophy.

The estimate of primary production in the lake was 292 $gCm^{-2}.y^{-1}$ (Table 4), which indicates a high level, and is the result of increased trophism of the lakes. Primary productivity in water bodies is the end result of photosynthesis in primary producers, the basis of ecosystem functioning, as it makes chemical energy and organic matter available to the entire living community (Chislock *et al*., 2013). This measure depends on factors such as light, temperature, nutrients, and the extent of the lake. Besides these, the two main factors regulating light and nutrients, i.e., the amount of light penetration and the depth of water mixing, may also have an effect on production. The presence of phytoplankton and their pigments, suspended organic and mineral detritus, and colored organic matter dissolved in the water column affects light penetration and, as a result, primary production.

Primary production has been reported to range from 2 to 290 $gCm^{-2}.y^{-1}$ in temperate lakes of the world, and from 30 to 2500 $gCm^{-2}.y^{-1}$ in tropical lakes (Leith and Whittaker, 1975), indicating that production amounts in this lake is more than temperate lakes. Southern Iran is part of the subtropical geographical region and its climate cannot be considered temperate or tropical, therefore, the finding that the production in this lake is slightly more than the range of world temperate lakes seems to be relevant and acceptable. The average primary production capacity in the Karkheh Reservoir was 156 $gCm^{-2}.y^{-1}$ (0.42 $gCm^{-2}d^{-1}$), and the measured primary production was 93 $gCm^{-2}.y^{-1}$ (Khalfa-Nilsaz, 2008). The average primary production in the lake of Shahid Abbaspur reservoir (Masjed Solaiman), Karun 3, Marun, and Dez was estimated to be 77 $gCm^{-2}.y^{-1}$ (Khalfa-Nilsaz, 2010). The initial production in these lakes was less than that of the Salman Reservoir, which is acceptable considering that the Salman Lake is lower in latitude and closer to subtropical conditions. On the other hand, the initial production capacity in Azad Reservoir, Sanandaj, was 324 $gCm^{-2}.y^{-1}$ (Roohi *et al*., 2019), and in Velasht Lake in the west of Mazandaran it was 241 $gCm^{-2}.y^{-1}$ (Hedayatifard *et al*., 2011). The trophic status of Azad Reservoir was reported as meso-eutrophic (TSI=40), which is less than Salman Reservoir (50), while its primary production estimate (324 $gCm^{-2}.y^{-1}$) is higher than Salman (292 $gCm^{-2}.y^{-1}$). Roohi *et al*. (2019) used the method of converting chlorophyll-a concentration to planktonic biomass, to estimate the production potential, assuming that 15% of the energy of each trophic level reaches the next level. Mohammadi *et al*. (2017) used the same method -although with a different model- with the assumption that chlorophyll-a is 1.5% of the organic matter of the algae, and the organic matter of the algae is also 10% of its biomass.

The fish production capacity in the lake in 2023 estimated by averaging the results of the primary production model (Brämik and Lemke, 2003) and the total phosphorus model (Downing, 1990) was 35.90 $Kg.ha^{-1}.y^{-1}$, which is proportionate with the estimation of Velasht lake (28.2 $Kg.ha^{-1}.y^{-1}$), as the primary production in Salman is 292 $gCm^{-2}.y^{-1}$, and in Velasht was 241 $gCm^{-2}.y^{-1}$ (Hedayatifard *et al*., 2010). In comparison, Khalafe Nilsaz (2008) estimated the average fish production capacity in Karkheh Reservoir to be 103 $Kg.ha^{-1}.y^{-1}$, which is nearly three times that of Salman dam lake. The average production of fish in Shahid Abbaspur Reservoir, Karun 3, Marun, and Dez was 20 $Kg.ha^{-1}.y^{-1}$ (Khalafe Nilsaz, 2010) and in the Azad Lake was 218 $Kg.ha^{-1}.y^{-1}$ (Roohi *et al*., 2019). The lowest production was 162 $Kg.ha^{-1}.y^{-1}$ in the minimum lake area, while the highest production was 237 $Kg.ha^{-1}.y^{-1}$ in the maximum water level. The average fish production capacity in Golbalag Reservoir (Kurdestan) was also 138.4 $Kg.ha^{-1}.y^{-1}$ (Mohammadi *et al*., 2017), about 4 times that of Salman.

Roohi *et al*. (2019) converted the estimated biomass of algae into the biomass of fish (and only planktivorous fish) by estimating the conversion percentage (citing Vollenweider, 1974) to calculate fish production. Mohammadi *et al*. (2017) used another model, the algal biomass was converted into zooplankton biomass, and then into fish biomass. These two methods are both based on the estimation of energy transfer efficiency, in which it is assumed that all algal biomass is converted into zooplankton biomass in the first place, and in the second place all planktonic biomass is converted into fish biomass. Second assumption is that the percentage of energy transfer is constant at each stage. However, the method used in this research is derived from experimental models obtained from practical research on world lakes (Koeschel *et al*., 1981; Brämik and Lemke, 2003), and the difference in methods may be the main reason for the difference in estimates. This estimation difference was seen most with that of Karkheh Reservoir. In this lake, although the size of the initial production is less than that of Salman and Velasht (nearly half of them) the estimate of fish production in it was about three times.

The amount of production and abundance of fish in the lakes is dependent on primary production, which itself is affected by various factors such as temperature, water level, wind, turbidity and flow, and biological factors such as initial population size and food abundance (Brämik and Lemke, 2003). Factors such as water level, meteorological factors including light intensity, photoperiod, rainfall, and the water cycle (input and output) also greatly affect the amount of primary production in lake and stream waters (Oglesby, 1977). Therefore, to compare and find the reason for the difference between the size of fish production in different ecosystems, biotic and abiotic factors should be considered simultaneously. As a comparison, the production capacity of fish is reported in various water bodies in Karnataka, India, as 100–200 $Kg.ha^{-1}.y^{-1}$ (Krishnarao *et al*., 2002), and 50-70 $Kg.ha^{-1}.y^{-1}$ in Lake Cochibulka in Nicaragua (Hooker *et al*., 2001), while in Borulos Lake, Greece, the fish production capacity was as high as 1260 $Kg.ha^{-1}.y^{-1}$ (Khalil, 1998).

Some of these differences may also be obtained by using the estimation methods. The assessment of fish stock and their production capacity in inland waters is performed by various methods depending on the quality of available input data and the accuracy of the desired result. Estimation of fish production performance in older methods was based on the amount of primary production during the algal growth period (by measuring water chlorophyll or by directly measuring primary production). However, in newer methods, the primary production is measured from the amount of total phosphorus in the water (Theng *et al*., 2023), which is the main limiting factor for algal growth (Downing *et al*., 1990). For example, the primary production capacity of Azad Dam (Mohammadi *et al*., 2017; Roohi *et al*., 2019), estimated much higher than our findings, was based on the measurement of chlorophyll-a, an estimation based on the percentage of chlorophyll constituting the algal biomass. Therefore, one of the important reasons for the difference in the estimation of production in different ecosystems may be the heterogeneity of the methods used.

In interpreting the findings of fish production based on performance analysis models (auxiliary variables of primary production such as chlorophyll-a and phosphorus), it is necessary to look at the local conditions of each lake and even different parts within each lake. For example, the production in the northern and western sub-sections of Lake Manzala was low (ca. 70 $Kg.ha^{-1}.y^{-1}$), in the eastern part of the lake was medium (ca. 190 $Kg.ha^{-1}.y^{-1}$), and in the southern part of the lake was very high (ca. 2000 $Kg.ha^{-1}.y^{-1}$) (Bishai and Khalil, 1990). The interesting point is that the fish production of Manzala Lake during 1920 – 1929 was low (similar to the present northern and western parts), while during 1962 – 1966 it was medium (like the present eastern part). In current years, the average production of open water fish in different parts of Manzala Lake is about 600 $Kg.ha^{-1}$, which is also considered in the category of high enrichment. These transformations were related to physical and chemical conditions, especially the input of nutrients from rivers (Bishai and Khalil, 1990). This comparison shows that even in one lake, the production function may be very diverse in time and place scale. Therefore, the difference between different lakes can clearly be acceptable.

With the estimate of 2000 hectares of livable area of the lake for the fish population, the total size of fish produced in the lake in 2023 – 2024 was 71.8 tons, and the total size of the standing crop of fish population in the lake was estimated to be 132.8 tons. In optimistic interpretations, it is said that 15% of the fish stock can be harvested, but in more precise cases 10% of the lake's production is allowed to be harvested (Downing *et al*., 1990), so a size between 7.2 and 10.8 tons of fish can be harvested in Salman Farsi Reservoir to meet sustainability criteria.

Based on the fishermen's experiences with potential harvests in recent years, this estimate may seem conservative. The reason lies in the fishing practices themselves (Goldsworthy *et al*. 2024). Unfortunately, fishing in the province's lakes has not been based on such estimates until now. Instead, management has primarily relied on quotas for the number of fishermen and fishing days. Consequently, it is speculated that stakeholders have exerted excessive pressure on the fish reserves. By utilizing more accurate scientific estimates, as demonstrated in this research, and implementing a fish population monitoring program, annual population assessments, and studies of population dynamics, it is expected that production and harvest will reach a balanced state, leading to sustainability for the lake and its surrounding community.

Conclusion

The estimates from this research indicate a significant potential for fish production in the lake, which could have important implications for ecological balance, food security, and economic benefits. The findings highlight the importance of understanding the dynamics of primary production and its relationship with fish production capacity in the lake. Further research is necessary to comprehend the underlying factors driving the observed seasonal variations in primary production and their effects on fish populations. Additionally, comparing and validating different estimation methods can enhance our understanding of the lake ecosystem and optimize fish production strategies. It appears that excessive fishing pressure in recent years, resulting from management based on quotas for the number of fishermen and harvest days, has contributed to reduced production. Overall, these findings provide essential foundations for future research aimed at sustainable management and conservation of lake aquatic resources and offer valuable information for decision-making processes related to aquaculture policies and practices.

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