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Research Article

Trophic status index and natural fisheries potential of some Iranian reservoirs

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Abstract

The Iran Water Resources Management Company constructs many dams to control surface water that provide a new potential for aquaculture activities. Trophic status index and natural potential for fish production were investigated in nine small dam reservoirs from northwest of Iran. Prediction of fish productivity was calculated based on phytoplankton biomass (using chlorophyll *a* concentration in water; $P_{Chl\text{-}a}$) and benthic macro invertebrate biomass (P_{BMI}). Average $P_{Chl\text{-}a}$ and P_{BMI} of reservoirs were estimated as 233.9±479.4 kg $ha^{-1}yr^{-1}$ and 14.76±19.18 kg $ha^{-1}yr^{-1}$ respectively. Concentrations of total phosphorus and total nitrogen varied between 0.023-0.345 and 0.42-3.58 mgl^{-1}, respectively. According to Carlson's transformed model (TSI_{PN}) the mesotrophic status was dominant in reservoirs in which TSI_{PN} varied between 38.7 and 51.2. The eutrophication trend seems to be very fast in these reservoirs because of high nutrient input by aquacultures activities. The usage of fertilizers and amounts of food for aquaculture proposes and expansions of exotic species decline the natural fisheries potential of these reservoirs. Maintenance of water quality and investigation of native species should be planned to preserve sustainable fisheries activities in these reservoirs.

Keywords: Natural potential, Trophic status index, Reservoirs, Iran

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Introduction

About 9% of the freshwater from rivers, lakes and groundwater of the world is withdrawn for human use (FAO, 2014). Rivers are known as main freshwater resources and about 65% of river runoff is under moderate to high threat (Vörösmarty *et al.*, 2010). Even though the negative impacts of dams on rivers and rural communities have been reported, dam development is continuing (FAO, 2014). Generally lakes act as sinks for pollutants flowing into them from their surrounding catchments and mostly the sources of water quality degradation in lakes have been linked to agricultural and urban land-use practices. Widespread land erosion in lake catchments transport the eroded materials containing sediment and nutrients into streams and lakes (Sharip *et al.*, 2014). The percentage of eutrophic lakes increase around the world because of discharge of untreated sewage (Liu *et al.*, 2010; Barki and Singa 2014; Behzadi *et al*., 2018; Nasrollahzadeh Saravi *et al*., 2019).

The Iranian territory includes 6 vast water catchment areas which are totally divided into 31 subareas. As a general approach, the Iranian Water Resources Management (IWRM, 2016) constructs many dams to control surface water. According to (IWRM, 2016), currently 647 dams are in use and 863 dams are either in different phases of construction or feasibility studies. These projects have been established to reserve of water for drinking, hydroelectric generation and agricultural purposes and about 123000 million m^3 of water will also be available for other purposes, particularly for recreational and aquaculture activities (IWRM, 2016). According to global fisheries production data in 2012 (FAO, 2014), 11.6 million tons of capture (12.7%) and 41.9 million tons of aquaculture (63%) fisheries were from the inland waters. In this regard, small freshwater reservoirs and the natural water bodies are economically important in Iran where annually about 52 thousand tons of fisheries production is harvested from these water bodies (IFO, 2015).

The Iranian Fisheries Organization enhances the fish production in these dam reservoirs through stocking of fry and fingerlings. Chinese carp including grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*) and common carp (*Cyprinus carpio*) have been released in most of the reservoirs. Besides, rainbow trout (*Oncorhynchus mykiss*) is also reared in cages in a few reservoirs (Table 2).

On the other hand, the main purpose of the fisheries organization is to maximize the fish production in the natural water bodies. Thus, in addition to annual fish exploitations, it is essential to estimate the potential of natural production for extensive fish culture in these water bodies. Currently, most of the Iranian dam reservoirs are used for extensive or semi-intensive fish cultures. The semi-intensive fish culture causes a significant impact on

the natural environment of reservoirs, leading to halting of aquaculture development. Moreover, a few of these reservoirs have been established for drinking water purposes which are the main limitations for fisheries activities.
The estimation of the trophic status of these dam reservoirs will generate fundamental knowledge for aquaculture and fisheries programs. A trophic state shows the biological response to nutrient enrichment of the water bodies, since the changes in nutrient levels cause changes in algal biomass and productivity of the water bodies (Carlson, 1977).

The fisheries and recreational situation of the reservoirs are related to trophic state indices (TSI). TSI is the main subject for ecological investigations of lakes in worldwide (Havens *et al.*, 1999; Liu *et al.*, 2010; Frumin and Khuan 2011; Jarosiewicz *et al.*, 2011; Sharip *et al.*, 2014; Li *et al.*, 2017) that it is calculated basis on different variables such as secchi depth (SD), chlorophyll a (Chla), total phosphorus (TP), total nitrogen (TN). This index also prioritizes the different levels of protection and the restoration efforts in water bodies that are used for fishery proposes (RMB, 2012).

The morphoedaphic index as an estimator of potential fish yield in lakes is the simplest method for reservoirs managers who must make decisions on the basis of minimal field data (Ryder 1965; Jenkins and Oglesby, 1982). Other factors that influence fisheries potential and production of freshwater invertebrate are climatic situations and nutrient levels (Henderson *et al.*, 1973; Plante and Downing, 1989).

Study of Downing *et al.* (1990) showed that fish production did not correlate with the morphoedaphic index and closely correlated with primary productivity. Furthermore, Bays and Crisman (1983) observed that total zooplankton biomass significantly regressed with increasing trophic state while the fish community is also changed. According to O'Reilly *et al.* (2003) decrease of primary productivity by about 20%, implies a roughly 30% decrease in fish yields. The development of lake trophic indices has provided a means of setting standards using lake total phosphorus, chlorophyll *a* (Chl-a) and productivity (Gowen, 1994).

Nutrient concentration and primary production level are significant factors in determining community production of higher trophic levels (Henderson *et al.*, 1973). Fish productivity which is derived from primary productivity is higher in eutrophic water in comparison to oligotrophic, mesotrophic and hypereutrophic waters. Sometimes, it is higher in mesotrophic than that in eutrophic waters due to lower energy conversion efficiency (Li and Mathias 1994). Considering the high correlation between annual phytoplankton production and fish production, the efficiency of phytoplankton conversion into fish production is higher in oligotrophic lakes than hyper-eutrophic ones (Downing *et al.*, 1990).

Preparation of the lake data on water quality enabled lake managers to ecosystem improvements. Thus, in this study, the natural fisheries production potential of nine small dam reservoirs in relation to their trophic status was estimated. These reservoirs are located in the northwest of Iran. Although they are generally within the temperate zone, due to their topological and altitudinal differences, their locations ranged from semi-arid areas with very cold weather to semi-humid areas with warm weather.

Material and methods

The nine reservoirs are located in northwest of Iran within two provinces Eastern Azarbaijan (Fig. 1; Alkhalaj, Arasbaran and Ardalan) and Zanjan (Fig 1; Golabar, Khandaghloo, Mirzakhanloo, Shovier, Taham and Todebin). A brief description of all dams including the nearest city to dam, the input river, surface area, maximum depth, the altitude of region, range of temperature and the period of ice cover have been presented in Table 1. The dynamic ratio in each reservoir was calculated as the square root of surface area divided by mean depth (Håkanson, 1982).

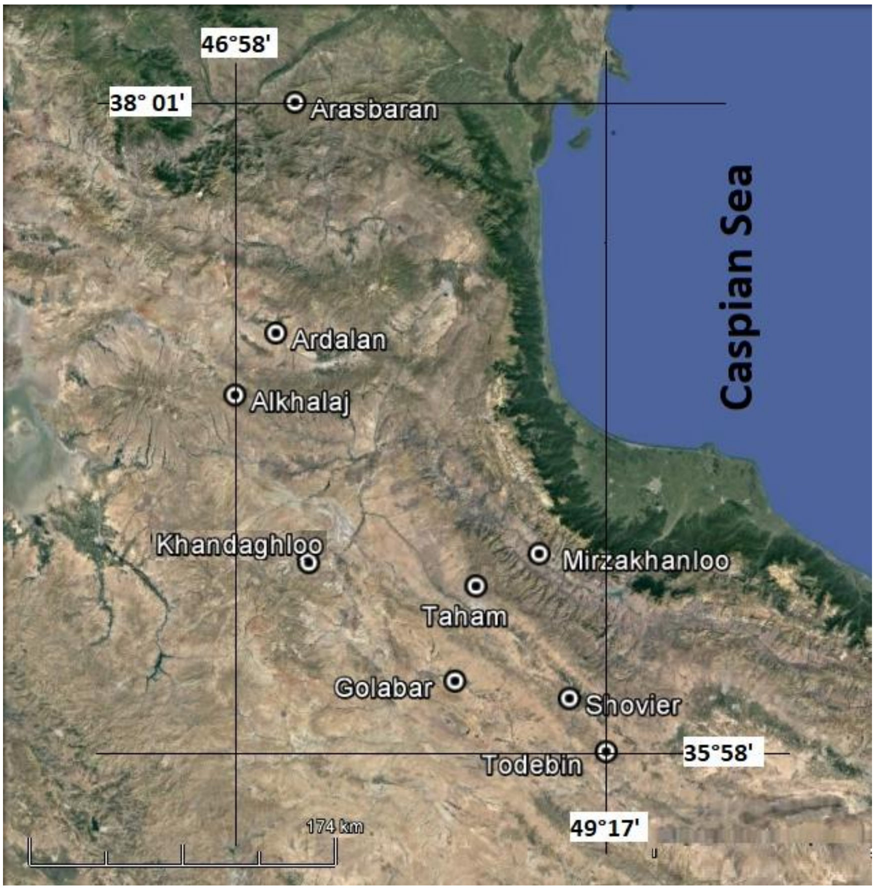

Figure 1: Location of reservoirs in the northwest of Iran.

The study was conducted in 3-6 stations in different reservoirs during 2007-2010 (Table 1). Benthic macro invertebrates were sampled three times in each station using a bottom sampler (Van-Veen grab; area covered was 400 cm²). The collected samples were washed and sieved (mesh size of 500 µm) with water and transferred to the laboratory where they were recognized with identification keys (Pennak, 1953; Macan, 1968). The number of macro invertebrates was counted to determine their density ($n.m^{-2}$) and their wet weight was measured after drying on blotter paper to determine biomass ($g.m^{-2}$). A part of substrate was sampled for estimation of total organic matter (TOM) and particle size of sediment was determined by loss-on-ignition method (Astm, 2000) and sieving methods (Gee and Or, 2002), respectively.

Furthermore the water samples were collected using Nansen water sampler of 1.71 liter (Hydro-Bios, Germany, TPN; Transparent Plastic Nansen water sampler, No: 436201). The water samples were collected from surface to 2 meter depths and were deep frozen for analyses of inorganic nutrients. Total phosphorus (TP) and total nitrogen (TN) were digested by persulfate method (APHA, 2005). Ascorbic acid method was used and absorption was read at 880 nm in a spectrophotometer for TP. Cadmium reduction method was used for TN and absorption was detected at 543 nm (APHA, 2005).

The trophic status index (TSI) of reservoirs was calculated through the following equation ‘1’; a combination model of nutrient variables and chlorophyll *a* concentration based on Walker's regression (Walker Jr, 1984) and the Carlson's transformed model (Carlson 1991).

$$(1) \quad TSI_{(PN)} = 9.81(-0.7 + 1.25\log\left[P^{-2} + \left[\frac{N-150}{12}\right]^{-2}\right]^{-0.5}) + 30.6$$

Where, P= total phosphorus ($\mu g.L^{-1}$) and N= total nitrogen. For chlorophyll *a* determination a distinct water volume (depending on suspended material) was filtered through a Whatman GF/C filter paper (FM 10175), using slight vacuum. The chlorophyll from filter paper was extracted in 96% ethanol (UCB, 2005; Wasmund *et al.,* 2006). The absorbance of extracted solvent was spectrophotometrically read and the chlorophyll *a* concentration was calculated by equation ‘2’ as microgram per litter (UCB, 2005).

Table 1: Characteristic of the dam reservoirs studied (temperature range based on daily averages for each month) and the sampling schedule.

		Taham	**Shevir**	**Mirzakanlo**	**Todebin**	**Khandaglo**	**Golabar**	**Ardalan**	**Alkhalaj**	**Arasbaran**
Characteristic of lake	Distance to City	15 Km to Zanjan	13 Km to Khoramdareh	20 km to Abbar	13 km to Abhar	25 Km to Mahneshan	55 km to Ijroud	34 km to Sarab	15 km to BostanAbad	26 Km to Kaleybar
	Altitude (m)	1900	1750	560	1980	1620	1910	1640	1890	550
	Area (h)	317	17	12	30	110	986	154	33	180
	Max depth (m)	65	15	11	15	25	30	16	12	33
	Volume (million CM)	87.7	1.8	1.4	8	5	116	4.5	2.5	23.7
	Temperature Range (oC)	-2.6-23.7	-1.3-23.6	6.6-28.5	-2-22.5	-1.2-26.8	-3.2-24.2	-5.1-21	-6.4-22	1.1-23.8
	Ice cover period (Day)	111	61	28	94	75	133	135	124	39
Sampling date and number of station	**Fill out by the river**	**Taham**	**Shovir**	**Siahvaroud**	**Todebin**	**PariChai**	**Sejasroud**	**AlanChi**	**ShahrChi**	**SilinChi**
	Feb. 2007	+								
	Jun.	+								
	Aug.	+								
	Sep.	+	+	+						
	Oct.	+	+	+						
	Nov.	-								
	Feb. 2008		-	+						
	May		+	+						
	Jul.		+	+	+					
	Aug.		+	+						
	Sep.				+					
	Oct.		+	+	+					
	Dec.				+					
	Mar. 2009				+					
	Apr.				+					
	Jun.				+					
	Jul.				+					
	Aug.				+					
	Nov.				+	+				
	Dec.					+	+			
	Mar. 2010						+	+	+	+
	Apr.					+	+			
	Jun.					+	+	+	+	+
	Aug.					+	+	+	+	+
	Oct.					+	+			
	N. of Station	6	3	3	3	3	4	4	4	4

The algal biomass was estimated by multiplying the chlorophyll *a* content by a factor of 67 (APHA, 2005).

(2) Chl*a* (µg/L) = $\frac{29.6(665^{b}-665^{a})v_1}{V_2 \times L}$

Where:

b -absorption before acidification,

a -absorption after acidification,

v_1 - volume of solvent used to extract sample in ml,

v_2 - volume of water filtered in L,

L- path length of spectrophotometer cuvette in cm.

Prediction of fish productivity was based on algal biomass ($P_{Chl\text{-}a}$) and benthic macro invertebrate biomass (P_{BMI}), calculated using equation '3' (Li and Mathias, 1994);

(3) Fish productivity = $\frac{B \times \frac{P}{B} \times Uf}{FCR}$

Where B = biomass of food organism (alga and benthos)

P/B = ratio of production to standing biomass of food organisms that according to Li and Mathias (1994) was considered for alga=55 and for benthos=4

U*f* = food utilization coefficient was 20% and 25% for alga and benthos, respectively (Li and Mathias, 1994).

FCR= food conversion ratio was considered 30 and 5 for alga and benthos, respectively (Li and Mathias, 1994).

Results

The chlorophyll *a* varied between 2.3 and 268.1 µgL^{-1} in different reservoirs which the highest level was observed in Khandaghloo and followed by Shovier (Fig. 2). According to chlorophyll *a*, the algal biomass ranged between 0.15 and 17.96 mgl^{-1} in the surveyed reservoirs.

A low diversity of macro invertebrates was observed in the investigated lakes. Larvae of Chironomidae from insects of Diptera had the widest distribution of all taxa and occurred in all reservoirs. Tubificidae from Haplotaxida worms was also widely distributed in all lakes. While chironomidae and tubificidae had the dominant biomass in all reservoirs with an average of 63.2 % and 29.6 %, respectively, hirudinea showed the highest biomass (61.8%) in Taham reservoir (Table 2). Biomass of macro benthos varied between 0.06 and 29.5 gm^{-1} in the investigated reservoirs. It was low in Arasbaran, Mirzakhanloo and Khandaghloo reservoirs while it was high in Shovier and Todebin reservoirs (Table 2, Fig. 2).

The mean potential production of reservoirs based on algal biomass ($P_{Chl\text{-}a}$) and benthic macro invertebrate biomass (P_{BMI}) are illustrated in Table 2. $P_{Chl\text{-}a}$ of reservoirs to planktivouros extensive fish culture ranged from 28.4 to 3292.3 kg ha^{-1}yr^{-1} during the study (average 233.9±479.4 kg ha^{-1}yr^{-1}), while P_{BMI} of reservoirs ranged between 0.12 and 59.14 kg ha^{-1}yr^{-1} (average 14.76±19.18 kg ha^{-1}yr^{-1}). Nutrient concentration including T_P and T_N varied from 0.023-0.345 mg L^{-1} and 0.42-3.58 mg L^{-1}, respectively.

Table 2: Results of benthos composition, mean potential productions ($P_{chl\text{-}a}$ and P_{BMI}) and trophic state in the dam reservoirs. Chinese carps; *Cyprinus carpio, Hypophthalmichthys molitrix, Ctenopharyngodon idella, Aristichthys nobilis* others: Aa; *Alburnus alburnu,* Abi; *Alburnoides bipunctatus,* Abr; *Abramis brama,* Af; *Alburnus filippi,* Al; *Astacus leptodactylus,* Bb; *Barbatula bergiana,* Bl; *Barbus lacerta,* Cc; *Capoeta capoeta,* Hh; *Huso huso,* Om; *Oncorhynchus mykiss,* Rf; *Rutilus frisii,* So; *Squalius oriantalis.*

Reservoir	Silt & Clay (<0.06 mm)	TOM	Fish native species	Composition of benthos	Chinese carp fish yield (tons)	Other released Species	Dynamic ratio	TN/TP	$P_{chl\text{-}a}$ ($kg.h^{-1}.y^{-1}$)	P_{BMI} ($kg.h^{-1}.y^{-1}$)	TSI_{PN}	TSI attribute
Alkhalaj	% 87	6.4 ± 1.8	Abr, Af, Cc, So, Bb	Chironomidae 51.7% Tubificidae 34.5 % Lumbriculidae 13.8%	5	Al	0.02	11.3	99.7	1.14	41.5	Meso trophy
Arasbaran	% 90	7.6 ± 2.5	Bl, Bb	Chironomidae 64.9 % Tubificidae 29.7 % Lumbriculidae 5.7 %	8.5	Hh	0.03	19.7	88.2	0.74	43.7	Meso trophy
Ardalan	% 78	4.9 ± 1.0	Aa	Chironomidae 84.6 % Tubificidae 15.4 %	32	Al	0.05	11.5	76	2.7	43.3	Meso trophy
Golabar	% 97	7.8 ± 0.7	Abi, Aa, Af, Bl, Cc, So	Chironomidae 54.7 % Tubificidae 45.3 %	662	Hh, Om	0.17	27.5	113.3	2.7	42.9	Meso trophy
Khandaghloo	% 90	9.7 ± 6.3	Cc	Chironomidae 55.8 % Tubificidae 44.2 %	165	Rf, Ali	0.02	15.6	1010	0.94	47.3	Meso-Eeutrophy
Mirzakhanloo	% 74	3.2 ± 0.9	Cc	Chironomidae 69.5 % Tubificidae 30.4 %	5.8		0.005	15.4	151	0.81	43.9	Meso trophy
Shovier	% 96	4.3 ± 1.6	Cc, So	Chironomidae 57.9% Tubificidae 35% Gammaridae 3.5% Ephemeroptera 3.5%	15.3		0.006	6.6	320.5	42.8	46.1	Meso-Eutrophy
Taham	% 52	4.9 ± 1.2	Abi, Af, So, Cc	Chironomidae 3.7% Tubificidae 29.8% Gammaridae 1 % Gastropoda 5.5% Hirudina 61.8%			0.03	17.5	167.1	22.3	39.2	Oligo trophy
Todebin	% 95	5.0 ± 1.5	Cc	Chironomidae 66.5% Tubificidae 2.6% Gastropoda 23.4% Naididae 7.5%	20	Om	0.01	18.8	84.8	31.1	46.6	Meso trophy

These parameters had the lowest values in Taham and higher levels in Khandaghloo and Todebin reservoirs (Fig. 2). Consequently the trophic status index (TSI_{PN}) is also following the nutrient levels in the lakes (Table 2). The range of TSI_{PN} was between 38.7 and 51.2 in Taham and Khandaghloo reservoirs, respectively.

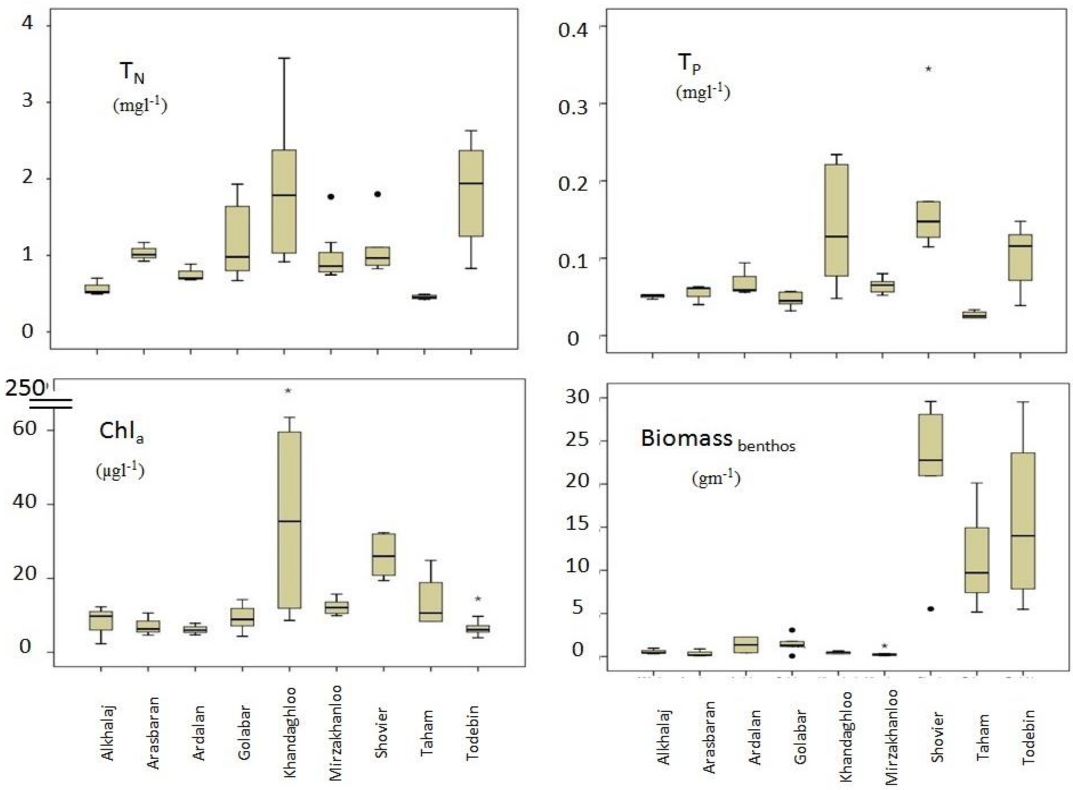

Figure 2: Fluctuations of Chl-a, benthic biomass and nutrient levels in the studied dam reservoirs in Eastern Azarbaijan and Zanjan Provinces.

While the TSI showed meso-eutrophy status in most of the lakes, it ranged between oligotrophic status in Taham and eutrophic status in Khandaghloo most of the time (Table 2). While there was a positive correlation between log productivity and TSI_{PN}, no significant slope (Spearman's correlation coefficient = 0.26, $p>0.05$) was observed.

Discussion

There have been many attempts to estimate potential fish production from different models such as primary production, algal biomass, total phosphorus, climate and morphoedaphic indices (Leach *et al.*, 1987). These models showed that macro-zoobenthos was a good predictor for fish yield and reported the potential fish yield from 0.75 to 8.77 8 $kgha^{-1}yr^{-1}$ for some lakes. In this study the P_{BMI} varied from 0.74 to 42.8 $kgha^{-1}yr^{-1}$ (Table 2). The Chironomid midge larvae and Oligochaeta tubificidae were widely distributed in all reservoirs while Oligochaeta families, Lumbriculidae and Naididae, were found in a few reservoirs and Hirudinea showed the highest proportion in Taham reservoir (Table 2). Because of our sampling method, relatively few numbers of organisms such as Gammaridae, Ephemeroptera and Gastropoda were encountered in the sediment. These taxa belong to groups that are not normally associated with soft sediments and generally occur on rocks, stones, and aquatic plants (Merritt *et al.,* 2008). Furthermore, according to tolerance values of macro-invertebrates, the Gammaridae and Ephemeroptera are considered to be more sensitive to environmental stress than Chironomidae and Tubificidae (Llansó and Dauer, 2002; Mandaville, 2002).

The cumulative biomass of chironomidae and tubificidae had no significant correlation with total organic matter (Pearson correlation= -0.41; $p>0.05$) and grain size (Pearson correlation= 0.3; $p>0.05$) of sediments. The sediment texture was generally silt and clay from 52% to 97% of substrate texture (Table 2).

The lowest total organic matter in sediment was observed in Mirzakhanloo that can be due to the new structure of the reservoir, which caused the low benthic biomass. The highest total organic matter observed in Khandaghloo was due to high utilization of fertilizers (Abdolmalaki, 2015), that can be a limiting factor for benthic development.

Moreover the oxycline formed in most lakes around 7 meter depths (Table 2) may decrease oxygen in deepest layers to zero. The oxycline not only eliminates the organisms in the anoxic conditions in the deepest parts but can also be a risk for fishes (Wanink *et al.,* 2001; Broszeit *et al.,* 2013; Keister and Tuttle, 2013) especially for cage culture in these reservoirs, following a sudden upwelling of hypoxic water. For instance, massive fish kills associated with sudden deoxygenation of the water were observed frequently in Lake Victoria (Wanink *et al.,* 2001).

Although the hydro-chemical parameters were mostly within the standard range of the water quality, the climate situations restrict different kinds of aquaculture activities in these reservoirs (Mirzajani, 2010; Abedini, 2014; Abdolmalaki, 2015; DaghighRoohi, 2015; Babaei, 2016; Mirzajani, 2016a, 2016b). Regarding extensive warm water fish culture, long periods of cold weather and prolonged ice cover (Table 1) are the main restrictions for algal growth ($P_{chl\text{-}a}$) that decrease the growth period of fish. This situation is observed particularly in Ardalan and Alkhalaj reservoirs (Table 2). Furthermore, sometimes high temperatures (above 30ºC) cause problems in many lakes particularly in Mirzakhanloo (Table 1). The general temperature range for warm water fish species is between 23-32ºC (Swann, 1997). Special management is needed to use the available short time for aquaculture activities for example to determine the appropriate time and the best size for fish release. Another severe restricting factor on aquaculture, observed in a few reservoirs such as Ardalan, Alkhalaj, Shovier and Mirzakhanloo reservoirs, was the high turbidity resulting from the transfer of substrate by wind. Wind had a direct influence on the water quality of lakes by resuspension of sediments into the water column, typically in low-elevation flat regions and act upon as a function of their mean depth and surface area (James *et al.*, 2009). In all studied reservoirs the dynamic ratio was below than 0.8 (Table 2), expected to be influenced by wind-induced waves (Håkanson, 1982). Although turbid shallow lakes often have sufficient amounts of P and N to support algae growth, but algal biomass do not increase due to poor light conditions (Havens *et al.*, 1999).

In the reservoirs investigated, a part of the natural potential is utilized by the native fishes and the fishes released annually by the Iranian Fisheries Organization. While this production is based on Chinese carp as a commercial fish (Table 2), other noncommercial exotic species such as *Carassius gibelio*, *C. auratus*, *Hemiculter leucisculus* and *Pseudorasbora parva* are omitted from a portion of this potential.

After the expansion of exotic species, the native species such as *Squalius oriantalis* (Mirzajani and Abbasi, 2008) and *Capoeta capoeta* have drastically decreased in most Iranian ecosystems. These species could be good candidates for aquaculture improvement (Abdolmalaki, 2002; Mirzajani and Abbasi 2008). These two species formed the main production in Taham reservoir with about 500 tons fish yields annually (archives data of Zanjan Fisheries Authority).

The archived data from Zanjan and Eastern Azarbaijan Fisheries authorities showed that about 74 to 1577 kg $ha^{-1}yr^{-1}$ with an average of 690 ± 555 $kgha^{-1}yr^{-1}$ is harvested from these reservoirs (Table 2). Our estimations varied from 79 to 1011 (average 244 ± 299 $kgha^{-1}yr^{-1}$). Thus a total production of 934 kg $ha^{-1}yr^{-1}$ is acceptable for the utilized Iranian reservoirs. In other words, the total extensive fish farm production can be doubled to 100 thousand tons, which will further increase by introducing the crayfish, *Astacus leptodactylus*. This production can further be increased with cage culture that is currently being practiced in some reservoirs to rear rainbow trout and sturgeon fishes (Table 2) although no official data related to fish farming in cages is available. While the preservation of water quality is important to have sustainable fish yields in the reservoirs, the usage of high amounts of food or fertilizer can change the water quality and trophic levels.

According to the National Fish Habitat Initiative (NFHI, 2016) the best predictor of lake production is age of reservoir; older reservoirs are less likely to produce fish compared to younger lakes. As a matter of fact, prolonged changes in nutrient levels cause changes in the productivity of water bodies (Carlson, 1977). Regarding TSI, although the mesotrophic status is dominant in the majority of investigated reservoirs, this index indicated higher trophic levels in several reservoirs, particularly in Khandaghloo, Shovier and Todebin (Table 2). Actually, fish farmers utilize the fertilizers or feeds in these reservoirs. The useless of fertilizers in Shovier not only had no effective role in production ($P_{chl\text{-}a}$) but also increased the TSI. In this reservoir is observed the nitrogen limitation where the TN/TP ration was below 10 (Table 2).

In situations of high phosphorus loading, the planktonic utilization of nitrogen can deplete nitrogen supplies (Jarosiewicz *et al.,* 2011). A higher TN/TP ratio>10 facilitated proliferation of numerous algal groups and a lower TN/TP ratio <10, as a N-limited conditions, supported a proliferation of nitrogen-fixing cyanobacterial genera (Dash *et al.,* 2015). The ratio TN/TP in mesotrophic reservoirs Alkhalaj and Ardalan was about 11.4 (Table 2) that suggests both TN and TP limitation for phytoplankton growth. TN/TP ratio in Todebin is desirable for algal growth but due to temperature limitation, the rainbow trout (*Oncorhynchus mykiss*) is the main target for aquaculture. TSI was high in Todebin because the fishes in cages are fed intensively even in winter when there is not good condition for their consumption. Conversely the lowest TSI is observed in Taham, which is conserved very well because of drinking water purposes. Excessive nutrient enrichment leads to algal blooms that may result in hypoxic conditions when these algae die and decompose in lakes, leading to an anoxic environment and fish mortality (Leng, 2009).

Although these reservoirs located in a small geographical scale, they have some differentiation in natural factors (Table 1). While the anthropogenic impacts are considered as the main factors, the natural factors can also have important roles in Lake Eutrophication. Using data from 103 lakes across China, the natural factors together accounted for 13-58% of the variance in eutrophication parameters. While TSI were negatively related to elevation, lake depth, and lake volume, the climate variables had weak correlations (Liu *et al.,* 2010).

The role of the wind was mentioned above regarding to area and depth of the reservoirs. As the sediment phosphorus would strongly resuspend by wind wave or fish disturbance in shallow lakes, all successful cases to control eutrophication in different lake depths worldwide came from deep lakes (Liu *et al.,* 2010). Lakes located in higher elevation region suffered relatively little industrial and urban pollution. The low TSI in Taham partly resulted from these low antropogenic impacts.

We observed non-significant positive correlation between productivity and TSI. Downing *et al.* (1990) reported fish community production varied between 1.2 to 398 $kgha^{-1}yr^{-1}$ for 20 lakes in a wide range of geographic locations. They also found a non-linear relationship between fish production and total phosphorous but conversion of phytoplankton into fish production was higher in oligotrophic lakes than in hyper-eutrophic lakes. The positive relation between primary production and fish yield has also been reported based on food-chain in tropical African lakes (Henderson *et al.,* 1973). It seems that the eutrophication trend and aging process are very fast in these reservoirs due to high nutrient input and high value of sedimentation caused by aquaculture activities and river discharges, respectively. It can be predicted that the natural potential will decline in these situations.

Since the water quality degradation in lakes have been linked to their surrounding catchments (Sharip *et al.*, 2014), the rehabilitation management of eutrophic lakes should be included both external and internal actions such as reductions of external point and nonpoint source nutrient loads and the bio-manipulation of food webs and sediment management (James *et al.*, 2009). The phosphorus control is critical to mitigating lake eutrophication. While the excessive P loading in lakes increase the surplus amounts of P in water and sediments, the N limitation is observed. A common goal of lakes management programs is to restore P-limited conditions (Havens *et al.*, 1999). The aeration is another method to restoration of eutrophic lakes. With an artificial aeration, the eutrophic lakes from aquaculture nutrient enrichment rapidly returned to an oligo-mesotrophic statues (Axler *et al.*, 1998). Sediment dredging, as a mechanical technique, increases the depth and volume of the lakes and improves lake water quality and decrease the trophic state index (Sebetich and Ferriero, 1997).

In this study although the natural potential of reservoirs are somehow using by exotic commercial species, the native species such as *Squalius oriantalis*, *Capoeta capoeta*, *Rutilus frisii* and sturgeon species showed a good potential for fisheries activities. Thus, we suggest that the fisheries authorities consider financially supporting investigations on artificial breeding and feeding of native species instead of planning the introduction of exotic species. This approach limits not only the utilization and expansion of exotic species but it also promotes conservation of native species.

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References

Abdolmalaki, S., 2002. General fisheries investigation of Maco and Mahabad reservoir. Iranian Fisheries Research Organization, Bandar Anzali.

Abdolmalaki, S., 2015. The survey of Khandaghloo dam reservoir of Mahneshan city of Zanjan province.

Iranian Fisheries Research Organization, Bandar Anzali.

Abedini, A., 2014. Limnological study of Arasbaran lake in East Azarbaijan province in order to aquaculture development. Iranian Fisheries Research Organization, Bandar Anzali

APHA, 2005 Standard Methods for Examining of Water and Waste Water vol 17th edition. Washington D.C.

Astm, D., 2000. 2974 standard test methods for moisture, ash, and organic matter of peat and other organic soils. *American Society of Testing and Materials*.Doi: 10(**1520**), D2974

Axler, R., Yokom, S., Tikkanen, C., McDonald, M., Runke, H., Wilcox, D. and Cady, B., 1998. Restoration of a mine pit lake from aquacultural nutrient enrichment. *Restoration Ecology*, 6, 1-19. DOI:10.1046/j.1526-100x.1998.00612.x

Babaei, H., 2016. study of Golabar dam reservoir in Zanjan province. Iranian Fisheries Research Organization, Bandar Anzali.

Barki, D.N. and Singa, P., 2014. Assessment of trophic state of lakes in terms of Carlson's trophic state index Assessment 3.

Bays, J. and Crisman, T., 1983. Zooplankton and trophic state relationships in Florida Lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, 40, 1813-1819. DOI:10.1139/f83-210

Behzadi, S., Kamrani, E., Kaymaram, F., Ranjbar, M., 2018. Trophic level, food preference and feeding ecology of *Rachycentron canadum* (Linnaeus, 1766), in Hormuzgan Province waters (northern Persian Gulf and Oman Sea). *Iranian Journal of Fisheries Sciences*, 17(**1**), 179-193. DOI: 10.22092/IJFS.2018.115608

Broszeit, S., Davenport, J., Bredendieck, K., Harman, L. and McAllen, R., 2013. Seasonal oxygen-driven migration of mobile benthic fauna affected by natural water column stratification. *Estuarine, Coastal and Shelf Science*, 125, 36-42. DOI:10.1016/j.ecss.2013.03.020

Carlson, R.E., 1991. Expanding the trophic state concept to identify non-nutrient limited lakes and reservoirs Enhancing the states's lake management programs: 59-71.

Carlson, R.E., 1977. A trophic state index for lakes. *Limnology and Oceanography*, 22, 361-369. DOI:10.4319/lo.1977.22.2.0361

DaghighRoohi, J., 2015. Study of Ardalan and Alkhalaj dam reservoirs in Eastern Azerbaijan province in order to Aquaculture. Iranian Fisheries Research Organization, Bandar Anzali.

Dash, P., Silwal, S., Ikenga, J.O., Pinckney, J.L., Arslan, Z. and Lizotte, R.E., 2015. Water quality of four major lakes in Mississippi, USA: Impacts on human and aquatic ecosystem health. *Water*, 7, 4999-5030. DOI:10.3390/w7094999

Downing, J.A., Plante, C. and Lalonde, S., 1990. Fish production correlated with primary productivity, not the morphoedaphic index. *Canadian Journal of Fisheries and Aquatic Sciences*, 47, 1929-1936. DOI:10.1139/f90-217

FAO, 2014. The state of world fisheries and aquaculture. Rome

Frumin, G. and Khuan, Z.Z., 2011. Trophic status of fresh-water lakes in China Russian. *Journal of General Chemistry*, 81, 2653-2657. DOI:10.1134/S1070363211130044.

Gee, G.W. and Or, D., 2002. 2.4 Particle-size analysis. *Methods of Soil Analysis Part 4*, 255-293.

Gowen, R., 1994. Managing eutrophication associated with aquaculture development. *Journal of Applied Ichthyology*, 10, 242-257. DOI:10.1111/j.1439-0426.1994.tb00164.x

Håkanson, L., 1982. Lake bottom dynamics and morphometry: the dynamic ratio. *Water Resources Research*, 18, 1444-1450. DOI:10.1029/WR018i005p01444

Havens, K.E., Carrick, H.J., Lowe, E.F. and Coveney, M.F., 1999. Contrasting relationships between nutrients, chlorophyll a and Secchi transparency in two shallow subtropical lakes: Lakes Okeechobee and Apopka (Florida, USA). *Lake and Reservoir Management*, 15, 298-309. DOI:10.1080/07438149909354125.

Henderson, H., Ryder, R. and Kudhongania, A., 1973. Assessing fishery potentials of lakes and reservoirs. *Journal of the Fisheries Board of Canada*, 30, 2000-2009. https://doi.org/10.1139/f73-324

IFO, 2015. Annual report of Iranian fisheries organization in 2013-2014. Iranian Fisheries Organization.

IWRM, 2016. The characteristic dams in Iran. Iranian water resources management.

James, R.T., Havens, K., Zhu, G. and Qin, B., 2009. Comparative analysis of nutrients, chlorophyll and transparency in two large shallow lakes (Lake Taihu, PR China and Lake Okeechobee, USA). *Hydrobiologia*, 627, 211-231. DOI:10.1007/s10750-009-9729-5

Jarosiewicz, A., Ficek, D. and Zapadka, T., 2011. Eutrophication parameters and Carlson-type trophic state indices in selected. *Pomeranian lakes Limnological Review*, 11, 15-23. DOI:10.2478/v10194-011-0023-3.

Jenkins, R.M. and Oglesby, R.T., 1982. The morphoedaphic index—concepts and practices: The morphoedaphic index and reservoir fish production transactions of the American Fisheries Society, 111,133-140.

Keister, J.E. and Tuttle L.B., 2013. Effects of bottom-layer hypoxia on spatial distributions and community structure of mesozooplankton in a sub-estuary of Puget Sound, Washington, USA. *Limnological Oceanography*, 58, 667-680. DOI:10.4319/lo.2013.58.2.0667

Leach, J., Dickie, L., Shuter, B., Borgmann, U., Hyman, J. and Lysack, W., 1987. A review of methods for prediction of potential fish production with application to the Great Lakes and Lake Winnipeg. *Canadian Journal of Fisheries and Aquatic Sciences*, 44, 471-485. DOI:10.1139/f87-348

Leng, R., 2009. The impacts of cultural eutrophication on lakes: A review of damages and nutrient control measures Writing 20: Freshwater systems and society, Professor Sandra Cook.

Li, S.F. and Mathias, J., 1994. Freshwater fish culture in China. Elsevier.

Li, S., Bush, R.T., Mao, R., Xiong, L. and Ye, C., 2017. Extreme drought causes distinct water acidification and eutrophication in the Lower Lakes (Lakes Alexandrina and Albert). *Australia Journal of Hydrology*, 544, 133-146. DOI:10.1016/j.jhydrol.2016.11.015

Liu, W., Zhang, Q., Liu, G., 2010. Lake eutrophication associated with geographic location, lake morphology and climate in China. *Hydrobiologia*, 644, 289-299. DOI:10.1007/s10750-010-0151-9

Llansó, R.J. and Dauer, D.M., 2002. Methods for calculating the Chesapeake Bay benthic index of biotic integrity prepared for the Chesapeake Bay Benthic Monitoring Program Accessed November, 22, 2010.

Macan, T., 1968. A guide to freshwater invertebrate animals Longman.

Mandaville, S., 2002. Benthic macroinvertebrates in freshwaters: Taxa tolerance values, metrics, and protocols vol 128. Citeseer,

Merritt, R., Cummins, K. and Berg, M., 2008. An Introduction to the Aquatic Insects of North America. Fourth Edition edn. Kendall/Hunt publication company.

Mirzajani, A. and Abbasi, K., 2008. The largest European Chub Leuciscus cephalus from Iran. Tehran

Mirzajani, A., 2010. Limnological study of Taham lake in Zanjan province in order to aquaculture possibility. Iranian Fisheries Research Organization, Bandar Anzali.

Mirzajani, A., 2016a. Study of Shovier and Mirzakhanlo dam reservoirs in Zanjan province in order to aquaculture possibility. Iranian Fisheries Science Research Institute, Bandar Anzali.

Mirzajani, A., 2016b. Study of Todebin dam reservoir in Zanjan province in order to aquaculture possibility. Iranian Fisheries Research Organization, Bandar Anzali

Nasrollahzadeh Saravi, H., Pourang, N., Foog, S., Makhlough, A., 2019. Eutrophication and trophic status using different indices: A study in the Iranian coastal waters of the Caspian Sea. *Iranian Journal of Fisheries Sciences***.** 18 (3), 531-546. DOI: 10.22092/ijfs.2018.117717

NFHI, 2016. Habitat Management: Thinking Big.3

O'Reilly, C.M., Alin, S.R., Plisnier, P.D., Cohen, A.S. and McKee,

B.A., 2003. Climate change decreases aquatic ecosystem productivity of Lake Tanganyika. *Africa Nature*, 424, 766-768. DOI:10.1038/nature01833

Pennak, R.W., 1953. Freshwater Invertebrates of the United States. The Ronald press company, New York

Plante, C. and Downing, J.A., 1989. Production of freshwater invertebrate populations in lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, 46, 1489-1498. DOI:10.1139/f89-191

RMB, E.L., 2012. Otter Tail County Lakes Assessment. Otter Tail County Soil and Water Conservation District Minnesota Board of Soil and Water Resources.

Ryder, R.A., 1965. A method for estimating the potential fish production of north-temperate lakes. *Transactions of the American Fisheries Society*, 94, 214-218. DOI:10.1577/1548-8659(1965)94[214:AMFETP]2.0.CO;2

Sebetich, M.J. and Ferriero, N., 1997. Lake restoration by sediment dredging Internationale Vereinigung für theoretische und angewandte Limnologie. *Verhandlungen*, 26, 776-781. DOI:10.1080/03680770.1995.11900822

Sharip, Z., Zaki, A.T., Shapai, M.A., Suratman, S. and Shaaban, A.J., 2014. Lakes of Malaysia: Water quality, eutrophication and management Lakes & Reservoirs. *Research and Management*, 19, 130-141. DOI:10.1111/lre.12059

Swann, L., 1997. A fish farmer's guide to understanding water quality. Aquaculture Extension, Illinois-Indiana Sea Grant Program.

UCB, 2005. University of Colorado Boulder. Chlorophyll a (Chl a) by Spectrophotometry with Ethanol Extraction (260903). http://www.colorado.edu/geography/class_homepages/geog_1011_sm06/Field%20Data_2004_2005/Chlorophyll%20and%20macroinv/Methodology/Bio412ChlaProtocol.doc.

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Reidy Liermann C. and Davies P. M., 2010. Global threats to human water security and river biodiversity. *Nature*, 467, 555-561.DOI:10.1038/nature09440

Walker Jr, W.W., 1984. Trophic state indices in reservoirs. Lake and reservoir management. 1, 435-440. DOI:10.1080/07438148409354552

Wanink, J.H., Kashindye, J.J., Goudswaard, P.K. and Witte, F., 2001. Dwelling at the oxycline: does increased stratification provide a predation refugium for the Lake Victoria sardine Rastrineobola argentea? *Freshwater Biology*, 46, 75-85. DOI:10.1111/j.1365-2427.2001.00644.x

Wasmund, N., Topp, I. and Schories, D., 2006. Optimising the storage and extraction of chlorophyll samples. *Oceanologia*, 48, 125-144.