

PORTRAYING FISHERIES AND ECOLOGICAL STATUS OF A MEDITERRANEAN LAKE

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Background. Gaps of knowledge in lentic systems and discrepancies in official fishery statistics biased fisheries state and inhibits the development of conservation strategies. For that reason the integration of conventional (official data from fisheries landings) and unconventional (fishermen knowledge) sources of data, accompanied with the use of historical archives will outline the framework of the monitoring of freshwater resources. The presently reported study integrated local ecological knowledge of fishers, historical data, field surveys and scientific data to present better management options for a Mediterranean lentic system (Volvi Lake, northern Greece).

Materials and methods. On-the-spot interviews were conducted with the professional fishers of Volvi Lake (northern Greece) in parallel with field surveys of environmental parameters during 2014–2015 and complemented with archival freshwater-related information.

Results. The results of the presently reported study point to commercial fisheries as a declining activity, with little scope for a future, due to internal and external threats. This diagnostic can probably be generalized beyond the case study to other freshwater ecosystems in Europe, where decreasing fisheries productivity due to overfishing, habitat loss, and pollution, coupled with low economic productivity has led to an increased marginalisation of freshwater fisheries.

Conclusion. The reported difficulties of freshwater fisheries could be bypassed through creation of fishers' typology regarding their dependence on fisheries. Upgrading the methodological approach followed by the official reporting system in freshwaters might also facilitate the fulfilment of the requirements of the EU Water Framework Directive.

Keywords: fisheries typology, expert judgement, long-term changes, anoxia, Volvi Lake, Greece

INTRODUCTION

European lakes constitute an important part of the European natural heritage and comprise economic drivers for the local communities. However, the anthropogenic pressures imposed on their catchment areas, including habitat loss and degradation, species invasions, pollution, climate change, and over-exploitation of the resources (Freyhof and Brooks 2011, Arthington et al. 2016, Markovic et al. 2017), trigger environmental concerns regarding the sustainability of the fisheries they support.

Although the managerial measures developed for the European lakes (Anonymous 2000) target a good conservation status (Hering et al. 2010), catch and effort data of the freshwater fisheries statistics are often poor and/or under-estimated due to the misreported or/and non-declared catches provided by fishers, as well as due to illegal fishery (Bobori and Economidis 2006).

In the absence of data, unconventional data sources, such as fishers' ecological knowledge and historical archive material are increasingly being used to fulfil long-term gaps

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and to expand baselines (Eckert et al. 2018, Giovos et al. 2019, Tiralongo et al. 2019). Despite its potential biases (Thurstan et al. 2016), fishers' ecological knowledge, which represents a lifetime of accumulated ecological observations, is used as a source of complementary empirical data in marine and freshwater environments (for review see Hind 2015) and offers the opportunity to preserve local knowledge of previously abundant and/or ecologically important species. Historical retrospective can be complementary used to validate scientific knowledge and empower scientists and managers on better ecosystem management (Sáenz-Arroyo et al. 2005). This mixture of methodologies has already been successfully applied for assessing cod spawning grounds (DeCelles et al. 2017), changes in fish diversity (Rosa et al. 2014), and conservation threats to vulnerable reef fish species (Castellanos-Galindo et al. 2011) in marine and lagoon ecosystems. However, such studies are generally lacking for European (Prespa Lake: Catsadorakis et al. 2018, Greek freshwaters: Perdikaris et al. 2017) and worldwide (Hallwass et al. 2013, Leeney and Poncelet 2016) inland aquatic ecosystems. For instance, in the Brazilian Amazon, data originating from local fishers' knowledge confirmed changes in the abundance of several fish species after the construction of a local dam (Hallwass et al. 2013).

In the presently reported study, an exhaustive gathering of environmental, biological, and historical data, complemented with interviews with active professional fishers was used to portray fisheries and environmental status of the second largest natural lake in Greece (Volvi Lake, northern Greece). Volvi Lake has rich fish fauna (21 native fish species have been reported in the lake's catchment) (Bobori and Psaltopoulou 2012), which it supports a long-standing traditional fishery and a large fisheries-dependent community. Critical issues of the study were to: (a) describe the profile of inland fishers, (b) identify where fisheries' management has seen increasing discord between user groups and managers, (c) describe the ecological status of the lake, and (d) extend baseline of historical fisheries data. These issues fulfil one of the requirements of the EU Water Framework Directive

(Anonymous 2000) for defining reference conditions in freshwater systems based on a combination of conventional and non-conventional monitoring methods (Voulvoulis et al. 2017), such as expert judgement and historical information to improve fisheries management.

MATERIALS AND METHODS

Study area. Volvi Lake (northern Greece) (Fig. 1) is the second-largest natural lake in Greece (surface area: 68 km², mean depth: 13.5 m, maximum depth: 23.5 m) and together with the adjacent Koronia Lake is part of a National Wetland Park of international significance (Ramsar Convention). It is also included in the NATURA 2000 network and protected under the Directives 2009/147 (Anonymous 2010) and 92/43 (Anonymous 1992). Lake's water quality and the trophic status and food web are affected by various anthropogenic pressures, i.e., agricultural runoff, animal husbandry effluents (Gantidis et al. 2007), and the accidental or deliberate introduction of non-native fish species (Bobori and Economidis 2006, Bobori et al. 2019).

Interviews. The on-the-spot interview survey was conducted during August–October 2014 targeting on the local professional fishers operating in Volvi Lake. Contact details of the licensed fishers were provided by the local fishery office, which is responsible for issuing fishing licences and monitoring the fishing activity in the lake. The interviews were carried out privately (as one-to-one sessions, to prevent influences by others, especially by the fisherman's colleagues), in Greek by one person, ensuring that questions were presented identically to minimize sampling bias, and they took place around the fishers' mooring/landing sites and frequently on board of their own vessel.

In total, 74 licensed professional fishers (65 men and 9 women) operated in Volvi Lake and owned 65 licensed fishing vessels, according to the records provided by the local fishery office. Efforts were made to interview all the licensed fishers and the spotted illegal ones. Before starting the interview, fishers were informed that their participation was optional and their personal data would remain confidential.

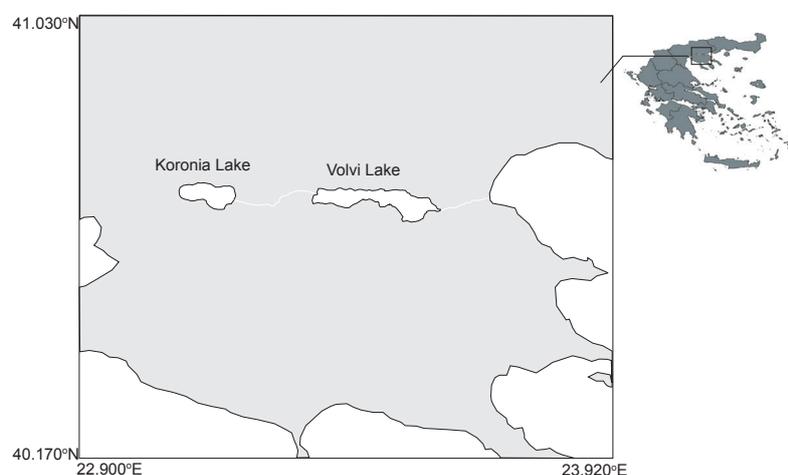


Fig. 1. The studied Volvi Lake (northern Greece)

Fishers were asked about issues related to (a) fishing operation, (b) problems faced on operational and marketing issues, and (c) demographic features. It should be noted that questionnaires were designed to be compatible with those used in socio-economic surveys conducted in other Greek lakes (Roussi-Dimitriou et al. 1997) and coastal waters (Tzanatos 2006), to facilitate comparisons.

Ecological state. Abiotic (e.g., temperature and O₂ concentrations) as well as biotic (e.g., chlorophyll *a* concentrations) parameters were estimated based on a seasonal monitoring fieldwork, which covered an extensive network of sampling sites throughout the entire lake and conducted from October 2014 to August 2015 (see Moutopoulos et al. 2018 for more sampling details). Temperature and dissolved oxygen were measured across the water column (HACHQ40D instrument) to determine the thermal profile of the water column and the presence of hypoxic/anoxic layers in the water column. Phytoplankton biomass was estimated by samples taken at the depth 2 m. Seasonal chlorophyll *a* concentrations were determined spectrophotometrically (Strickland and Parsons 1972). Estimation of phytoplankton biomass was performed assuming the euphotic layer of 10 m, carbon to chlorophyll *a* ratio of 40 and carbon to phytoplankton wet weight ratio of 0.1, according to Jones (1979).

Historical perspective. A thorough search was conducted in archives to collect information (i.e., scientific literature, bulletins, theses, record books, and magazines) on Greek freshwater fisheries from the early 20th century. The development of datasets included digitisation (from paper copies), quality control of the digitisation process, taxonomic and geographic standardisation, data integration, and graphical analysis.

In Greece, the monitoring of inland fisheries statistics was firstly established in 1928 by the General Statistical Service of Greece (GSSG, now Hellenic Statistical Authority). Catches per species for Volvi Lake during 1928–1939 were estimated by the ratio of Volvi catches' for all species combined reported in 1939 (Ananiadis 1948) to total catches of northern Greece (Anonymous 1934–1940) and then, this ratio was multiplied by the annual catches reported for 1928–1939 for all lakes and species combined reported from northern Greece (Anonymous 1934–1940). Catches per species for the period 1928–1939 were estimated from the species composition data reported for the study lake during 1947–1949 (Tsakakis 1950) assuming that the species composition pattern in post-war years has not changed when compared with the pre-war ones, because fishing intensity remained almost stable in terms of number of fishers/vessels and gears used (Anonymous 1934–1939, Tsakakis 1950).

Organised inland fishery during 1940–1945 was non operational due to the Second World War, whereas during 1946–1960 only sparse catch data for the Greek freshwater systems had been published (Serbetis 1948, Tsakakis 1950). Landing data for Volvi Lake were available for the 1946–1948 period, whereas: (a) for the year 1949 total catches were estimated from the landing per surface area provided by Tsakakis (1950) (i.e., 4–8 kg·km⁻²), (b) for the period

1950–1955 data were estimated based on the ratio of the Volvi catches' to the total northern Greek inland catches reported by Tsakakis (1950) for the year 1948 (19.4%) and (c) for the period 1956–1960 landing data were estimated based on the ratio of Volvi catches' in 1961 to the total Greek inland catches in the same year, which was reported by FAO. During 1961–2016 annual species catches from Volvi Lake were reported by the local fishery office.

Data analysis. Descriptive statistics were applied, providing percentage contribution, mean and standard deviation (SD) values of several resulting parameters. Comparisons were performed using one- and two-way ANOVA parametric tests. Whenever a significant difference was detected ($P < 0.05$), a Tukey post-hoc pairwise comparison test was used to detect the responsible factors (Zar 2010).

RESULTS

Socio-economic features and fishing typology of lake fisheries. In total, 29 out of the 74 licensed fishers participated in the survey, whereas six out of 74 stated that they have stopped fishing, due to serious health problems. The remaining registered fishers refused to participate and stated that they were occasionally engaged in fisheries, especially during winter, holding a professional fishing license only for subsistence purposes. Unlicensed fishers operating in the lake were also identified (approximately 15 persons), but they refused to be interviewed. More than 60% of the interviewed fishers were older than 60 years, with high fishing experience (>25 years) (Fig. 2A), but with only primary educational level (Fig. 2B). Less than 1/3 of the interviewed fishers (27.6%) were fully dependent on the fishery, whereas the others were mostly retirees or farmers (Fig. 2C). A high percentage of the interviewed fishers (72.8%) stated that their father was engaged either exclusively or occasionally in fisheries (combined with other agricultural activities) (Fig. 2D), while almost 90% have one or more children, but almost 25% of them were engaged in the fishery.

Fishing vessels were characterized by small length (48.3% < 4.5 m with a mean length of 4.6 ± 0.8 m SD) and low engine horsepower (48.3% < 7.35 kW with a mean of 7.0 ± 2.4 kW). The preparation time of fishing trial fluctuated around 4.5 h, irrespectively of the season (ANOVA; $F = 0.69$, $P > 0.05$) (Fig. 2E), whereas, the duration of fishing was significantly (ANOVA; $F = 39.27$, $P < 0.05$) higher in winter and autumn, exceeding 48 and 24 h, respectively (Fig. 2F). Significantly (post-hoc Tukey test: $P < 0.05$) higher fishing activity and catches were attained during winter (Table 1) with half of the catches being represented by *Carassius gibelio* (Bloch, 1782) and to a lesser extent by *Perca fluviatilis* Linnaeus, 1758, *Cyprinus carpio* Linnaeus, 1758, and *Abramis brama* (Linnaeus, 1758) (Table 2). Discards contributed less than 1% in the catches (Table 2).

Vast majority of the fishers (91.4%; Table 3) are using benthic gillnets all year round, whereas other fishing gears were also used for specific species-season combinations; pelagic nets for catching *Alosa macedonica* (Vinciguerra,

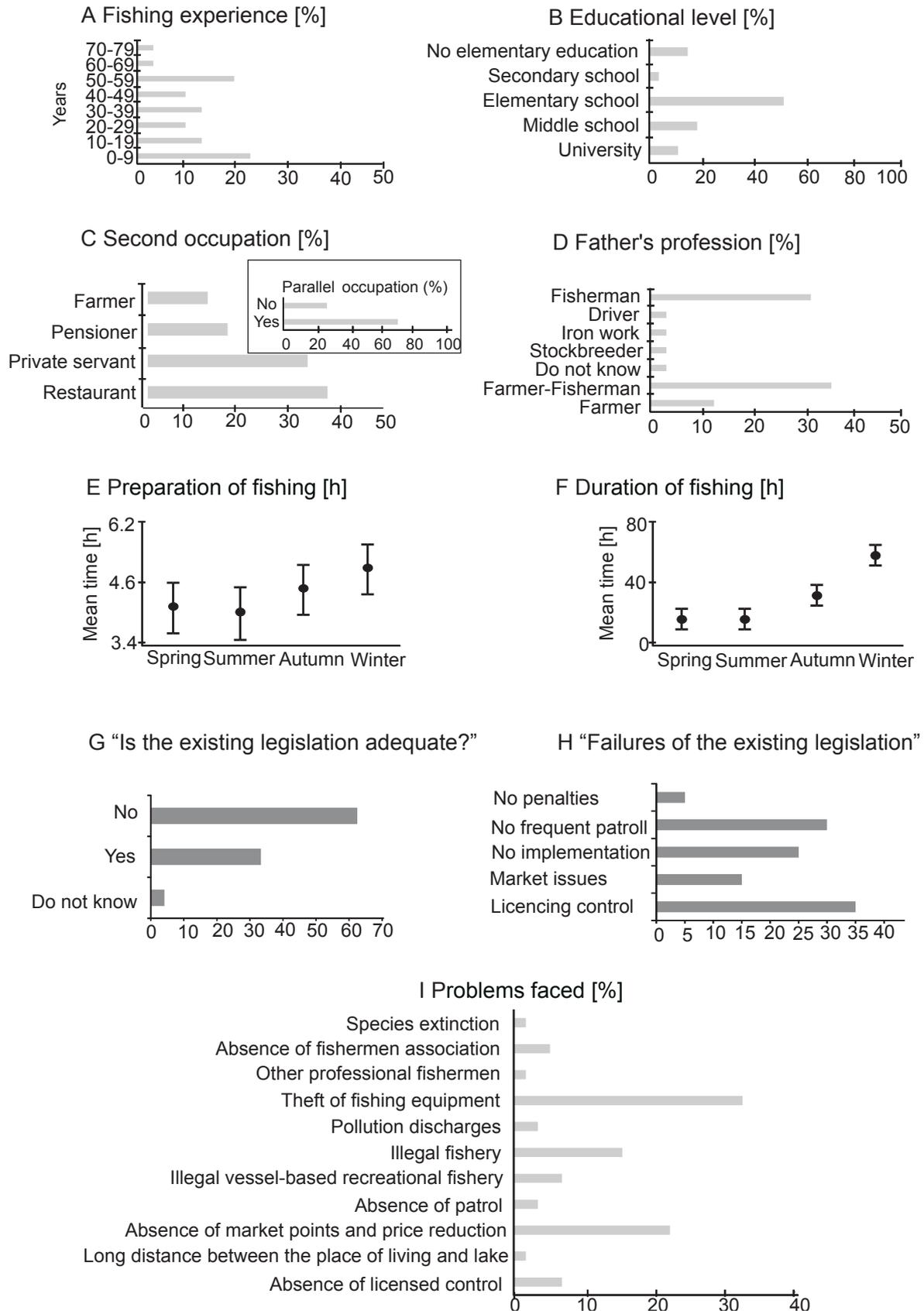


Fig. 2. Analysis of the questionnaire data collected from professional fishers operating at Volvi Lake since 1950; Profile of professional fishers (A–D), time for fishing preparation (E), fishing duration (F), critical reception of the existing legislation (G), detailed breakout of the current legislation failures (H), and problems faced by the fishers (I)

1921) and *C. carpio*, longlines for *C. carpio* from spring to autumn and in few cases trammel nets for *P. fluviatilis*. More than half of the interviewed fishers (56.7%) sold their fish in the retail market except for *C. gibelio*, of which the vast majority of the catches is directed to wholesales.

Catch per fishing days (expressed in days kg · day⁻¹) differed significantly both by season and fisher's category, with the effect of fisher's category being more intense than a season (two-way ANOVA; $F_{\text{category}} = 35.8$ vs. $F_{\text{season}} = 10.8$). Fishers were categorized into two groups; regularly operating (34%) and irregularly operating (Table 1). In fact, the regularly operating professionals caught slightly more than 80% of the lake's annual fisheries

catches and were operating on average 195.6 days per year, fishing approximately every second day, regardless of the season and in some cases, especially in autumn and winter, they fished daily. On the contrary, irregularly operating fishers exhibited the lowest fishing activity in the spring and summer (fewer than 3–6 days per month), and the highest during autumn and winter (Table 1). Regularly operating fishers used a wider range of mesh sizes of benthic gillnets; apart from the generalized use of benthic gillnets with mesh sizes from 26 mm to 100 mm, they also used longlines (hook of No. 7), pelagic and trammel nets. On the other hand, irregularly operating fishers used only benthic gillnets with mesh sizes from 38 to 80 mm.

Table 1

The principal catch parameters of the fishery in Volvi Lake based on interviews conducted with the professional fishermen within 2014–2015

Parameter	Spring		Summer		Autumn		Winter		Annual	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
All fishers										
Total catch [kg]	16165.0 ^b		8981.0 ^a		16660.0 ^b		40816.5 ^c		82623.5	
Catch per fisher [kg]	557.4 ^a	848.3	309.7 ^a	391.8	574.5 ^a	977.8	1407.5 ^b	2847.0	2849.1	4416.7
Number of fishing days	13.7 ^a	9.4	33.2 ^b	28.3	40.7 ^b	27.0	44.4 ^b	25.8	122.2	82.0
Regularly operating fishers										
Total catch [kg]	13801.0		6781.0		12720.0		36500.0		69802.0 ¹	
Catch per fisher [kg]	1380.1	1037.6	6781.1	477.7	1272.0	1454.0	3650.0	4079.0	6980.2 ¹	5616.5
Number of fishing days	22.5	8.6	57.7	29.7	61.3	31.0	66.0	23.7	195.6 ¹	93.5
Irregularly operating fishers										
Total catch [kg]	2364.0		2200.0		3940.0		4316.5		12820.5 ²	
Catch per fisher [kg]	124.4	84.0	115.8	97.7	207.4	132.7	227.2	156.7	674.8 ²	318.1
Number of fishing days	8.1	4.5	17.4	11.6	30.9	18.8	33.0	19.0	83.6 ²	39.1

SD = standard deviation; Superscript letters and numbers indicate significantly (Tukey post-hoc test $P < 0.05$) different groups; a < b and 1 < 2.

Table 2

Seasonal percentage (%) contribution of commercial and discarded catches per season and species for all species combined caught in Volvi Lake

Species name	Spring	Summer	Autumn	Winter
Commercial species				
<i>Cyprinus carpio</i>	12.3	32.4	14.3	5.2
<i>Abramis brama</i>	21.2	10.4	8.4	6.9
<i>Alosa macedonica</i>	4.8	6.5		0.4
<i>Perca fluviatilis</i>	16.2	43.6	24.8	8.1
<i>Carassius gibelio</i>	37.3	5.3	43.7	70.0
<i>Rutilus rutilus</i>	7.2	1.2	8.0	8.6
<i>Esox lucius</i>	0.5	0.6	0.5	0.8
<i>Anguilla anguilla</i>	0.6		0.3	
Discarded species				
<i>Lepomis gibbosus</i>	36.8	66.0	100.0	100.0
<i>Abramis brama</i>	52.6			
<i>Alosa macedonica</i>	10.5			
<i>Carassius gibelio</i>		34.0		
Contribution, all species combined				
Landings	98.7	98.1	99.5	99.9
Discards	1.3	1.9	0.5	0.1
Catches	19.2	10.1	20.3	50.4

Bold type indicates the highest values.

Almost two thirds of the respondents (62.5%) considered that the existing legislation in inland systems was not adequate (Fig. 2G) with the main reason for that the “Absence of control in licensing system” (35%) and the “Inefficient patrolling from the port authorities” (30%) (Fig. 2H). Apart from the legislative issues, the most common problems encountered by the interviewed fishers were “The theft of their equipment” (32.2%), the “Absence of market points and price reduction” (22.0%) and “Illegal fishing” (15.3%) (Fig. 2I). Almost 75% of the interviewed fishers considered that there was a problem with the invasive species, specifically the introduction and population increase of *Lepomis gibbosus* (Linnaeus, 1758) (72.7%) and to a lesser extent of *C. gibelio* (27.3%). Approximately 2/3 of the fishers disagreed with the existing legislation (66.7%), with a vast majority of them (90%) stated that increasing the fishing patrol is necessary.

Lake’s ecological state. The water column in the lake is thermally structured during summer and appears quite uniform from the surface to the bottom throughout the rest of the year (Fig. 3). Chlorophyll *a* fluctuated between 2.6 and 20.2 mg · L⁻¹ (with the mean seasonal values ranging from 8.6 mg · L⁻¹, in January, to 13.7 mg · L⁻¹, in May). These values were in close agreement with the corresponding ones estimated by Moustaka-Gouni (1988) in August 1986 (6–28 mg · L⁻¹) (Fig. 3). A significant part of the lake volume area was strongly influenced by the presence of hypoxic/anoxic conditions (Table 4). Dissolved O₂ exhibited a high concentration in epilimnion throughout the year, whereas below the thermocline, hypoxic (<2 mg · L⁻¹) and anoxic (<0.5 mg · L⁻¹) conditions occurred especially between July and August (Table 4). Low O₂ concentrations were observed near the bottom during spring and autumn, whereas in the winter the water column was sufficiently oxygenated.

Historical evolution of fisheries catches and human impacts. The annual catch in Volvi Lake during 1928–1939 fluctuated around a mean value of 559 t with a minimum of 403 t (in 1935) and a maximum of 741 t (in

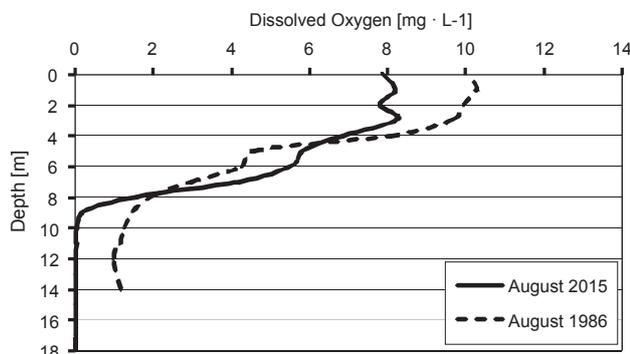


Fig. 3. Comparison of O₂ concentration values in the water column of Volvi Lake between August 1986 (Moustaka-Gouni 1988) and August 2015 (presently reported study)

1932) (Fig. 4A). The species that cumulatively contributed more than 70% in the total catches were *C. carpio* (34.9%) and *Rutilus rutilus* (Linnaeus, 1758) (25.6%), followed to a lesser extent by *A. macedonica* (10.4%). During the Second World War (1940–1945) organised inland fisheries had been limited and only after 1948 the catches approached their pre-war stage (513 t) (Fig. 4A) with *C. carpio* (41.0%) and *R. rutilus* (40.0%) being the most abundant species (Fig. 4B). Catches were maintained around 500 t during 1961–1971, whereas afterward they exhibited a downward spiral to a minimum of 10 t in 2007 and since then, catches slightly increased up to 33.9 t. Table 5 integrated human impacts on the lake’s ecosystem, its fisheries, and surrounding systems from the first report of actions in the lake (1926) till 2019. These issues are discussed in the next section and are complemented with potential explanations for the observed status of the ecosystem and its fish resources.

DISCUSSION

The integration of the information derived from fishers’ ecological knowledge, historical archives, and ecological data sheds light on the role of a local freshwater fishery in a data-deficient system and leads to better evaluation of the management policies.

Table 3

Seasonal percentage (%) usage of fishing gears in relation to season and sizes used in Volvi Lake

Gear	Mesh size or hook No.	Percentage usage of fishing gears			
		Spring	Summer	Autumn	Winter
Benthic gillnets	22–28	9.4	3.6	10.3	11.1
Benthic gillnets	28–45	28.1	25.0	17.2	14.8
Benthic gillnets	50–100	56.3	50.0	65.5	74.1
Pelagic nets	65–100	0.0	7.1	0.0	0.0
Trammel nets	60	0.0	3.6	0.0	0.0
Longlines	7	6.3	10.7	6.9	0.0

Mesh size in knot to knot bar length, [mm]

Table 4

Percentages of bottom surface and water volume of the lake affected by hypoxic conditions (oxygen levels below 2 mg · L⁻¹) during the study period and percentages of fishing activity allocation (% of total fishing days) in the deep parts of the lake

Parameter	October 2014	January 2015	May 2015	August 2015
Bottom surface	32%	0%	51%	76%
Water volume	5%	0%	12%	54%
Fishing activity	31%	34%	10%	25%

* Kleantidis P.K. 2002. Biologia tis anaparagosis, trophikes sinithies kai dinamiki plithismou tou endimikou psariou *Alosa macedonica* (Vinciguerra, 1921) tis limnis Bolvis. [Biology of the reproduction, feeding habits and population dynamics of the endemic fish species *Alosa macedonica* (Vinciguerra, 1921) of the Volvi Lake.] PhD Thesis, Aristotle University of Thessaloniki, Greece. [In Greek.]

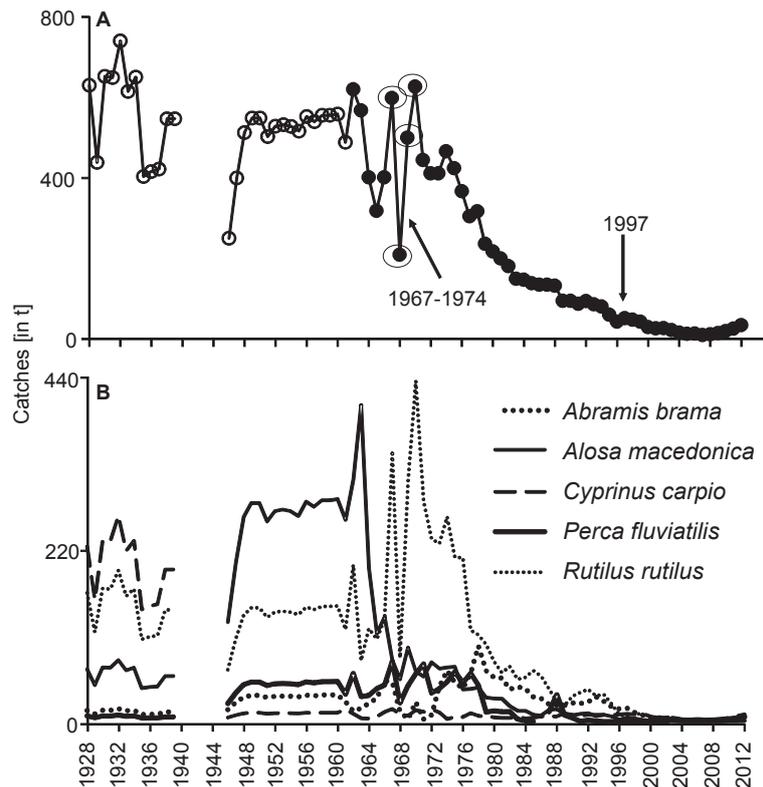


Fig. 4. (A) Annual catches in Volvi Lake within 1928–2012; open circles indicated reconstructed fisheries data (see Materials and methods) and solid circles indicated data reported by the local fishery office, (B) species catches for the most abundant species caught in the Volvi Lake, 1929–2012; arrows and circles indicate periods when severe socio-economic and ecological issues occurred

Linking lake's ecology with fisheries knowledge. Volvi Lake is a mesotrophic to eutrophic lake and nowadays its trophic level appeared quite stable, similarly with the physicochemical trends (i.e., temperature and oxygen) depicted during the last 30 years (Moustaka-Gouni 1988, Zarfadjian et al. 1990). An important feature of the lake is that a significant part of the lake was strongly influenced by the presence of hypoxic/anoxic conditions (Fig. 3B), particularly below 14 m, during May–August. In contrast, during October–April, the hypoxia at the bottom is gradually decreasing and almost all the bottom surface and water volume of the lake were adequately oxygenated because of the mixing of the lake. Even though the period of the appearance of hypoxic/anoxic condition was stable during the last 30 years, based on dissolved O_2 estimations (Fig. 3), hypoxic and/or anoxic spatial/temporal conditions at the bottom are associated with the lake's nutritional status and is an indicator of ecological degradation of the lake (Wetzel 2001). Habitat reduction and the loss of fauna, both caused by hypoxia (Vanderploeg et al. 2009) had a major impact on the benthic fauna that supports the main diet of lake species. For instance, Chironomidae species, which represent the main diet of *C. carpio* and *A. brama* (see Bobori et al. 2013), were six-fold reduced during summer (Zarfadjian et al. 1990), when the above-mentioned fish species were mostly spawning. In contrast, *R. rutilus*, whose catches are maintained at higher levels than those of *C. carpio* and *A. brama*, outcompete *A. brama* for bivalves and appears to be more effective

feeder than the latter (Bobori et al. 2013) and thus more resistant to anoxic conditions. Other species such as *Alburnus alburnus* (Linnaeus, 1758) and *A. macedonica* adapts a more flexible strategy to overcome the seasonal anoxic expansion either by presenting multiple spawning strategies (Attou and Arab 2019) or by migrating to the periphery of the lake and to the upper 8-m deep water layer during summer (Kleanthidis unpublished*), respectively.

A notable point is also the strong matching between fishers' spatial expansion and the extent of non-hypoxic areas during summer. Low dissolved O_2 incidents strongly affected fish spatial distribution and reduced the operational capacity of the fishers by limiting their effective area (see Table 4). In fact, during autumn–winter period fishing operations were spread in the lake area and down to the depth of 20 m, whereas in contrast, during spring–summer period fishing operations were distributed in the perimeter of the lake and not below 6–7 m (see Table 4). This phenomenon was also confirmed by fishers that stated a reduction in their fishing intensity in summer compared to that during winter (see Table 4). The seasonal fishing ban during April and May, imposed for protecting fish species' reproduction, also reduces fishing trials during spring when compared with summer, but depicted higher catches than summer, possibly due to an increased effort before the ban to counterbalance economic losses.

Causes of fishery degradation. Fisheries catches during the last 90 years represented a continuously declining trend that might be associated with the combined effect

Table 5

Main socio-economic and political events that took place in Volvi Lake, Greece, from the early 20th century

Period	Issue	Main event	Source
1926	Ecological degradation	Construction of communication channel between Koronia and Volvi lakes	Mourkidis 1986b
1932	Ecological degradation	Water level reduction by 1 m	
1945–1955	Fishing effort	Modernisation of almost 20% of freshwater fishing vessels in Greece	Moutopoulos and Stergiou 2011
1952	Marketing issues	Price reduction of freshwater fishes	Ananiadis 1968
1953–1970	Ecological degradation	10–% reduction of water surface (from 75 km ² to 68 km ²)	Mourkidis 1986a
1955	Fishing effort	Beach seine net ban	Mourkidis 1986b
1950–1962		Engines gradually installed in almost all fishing vessels	
1963–1965		Replacement of cotton nets with nylon ones; increase of net setting time from 12 h to 2–3 days	Vogiatzis et al. 1983
1962	Species introduction	Migration of <i>Carassius gibelio</i> from adjacent Koronia Lake	Vogiatzis et al. 1983
1963	Ecological degradation	Algal bloom	Simis unpublished1 *
1965	Ecological degradation	Algal bloom	Simis unpublished*
1966	Ecological degradation	Eutrophication revealed by first study performed	Mourkidis 1986b
1966	Ecological degradation	Small dam construction on communication channel with sea	
1976	Marketing issues	Export of <i>Alburnus alburnus</i> and <i>Rutilus rutilus</i> to Yugoslavia	
1977	Ecological degradation	Algal bloom	Fishing 1974
1977	Ecological degradation	Anoxic layers below 14 m	Simis unpublished*
1980	Fishing effort	Increase of minimum net mesh size from 10 mm to 15 mm	Mourkidis et al. 1978
1986	Species introduction	Introduction of <i>Silurus asotus</i>	Vogiatzis et al. 1983
1985	Official stocking	Stocking with <i>Perca fluviatilis</i>	Simis unpublished*
1985		Stocking with <i>Esox lucius</i>	Economidis et al. 2000
1986		Stocking with <i>Mugil cephalus</i>	Vogiatzis et al. 1983
1992		Stocking with <i>Cyprinus carpio</i>	Economidis et al. 2000
1994		Stocking with <i>Cyprinus carpio</i>	
1995		Stocking with <i>Cyprinus carpio</i>	
2000		Stocking with <i>Perca fluviatilis</i>	
2007		Stocking with <i>Cyprinus carpio</i>	
2000	Marketing issues	Export of <i>Perca fluviatilis</i> to France	Presently reported study
2010–2016		Export of <i>Carassius gibelio</i> to other Balkan countries	Presently reported study

* Kleantidis P.K. 2002. Biologia tis anaparagogis, trophikes simithies kai dinamiki plithismou tou endimikou psariou *Alosa macedonica* (Vinciguerra, 1921) tis limnis Bolvis. [Biology of the reproduction, feeding habits and population dynamics of the endemic fish species *Alosa macedonica* (Vinciguerra, 1921) of the Volvi Lake.] PhD Thesis, Aristotle University of Thessaloniki, Greece. [In Greek.]

of: (a) overfishing, (b) habitat and water degradation, (c) species invasion from accidental introductions, and (d) inter-specific competition.

Intensive fishing of the lake has been observed since the early years of the 20th century (the mid-1920s and 1930s). Professional fishers used low selective gears, such as beach seines and gillnets with small mesh sizes (from 22 mm to 28 mm) that resulted in high discards (Tsakakis 1950). After the Second World War, the lake has been intensively fished by a larger number of fishers than afterward (150 in 1960: Ananiadis 1968 vs. 74 nowadays). Although the technical characteristics of the vessel length did not considerably change (up to 7 m) during the last 50 years, the fishing effort was increased due to changes in the fishing gears. Since early 1960s fishers replaced the cotton-made nets with nylon ones (Vogiatzis et al. 1983), which exhibit lower visibility in the water and are more resilient to decay allowing, thus, the fishers to leave their nets for a longer time in the water (up to three days during winter). An increase of fishing pressure on lake's fish resources was also observed at the late 1990s after the collapse of the fisheries of the adjacent Koronia Lake and the translocation of the entire professional fishing fleet to Volvi lake after 1997 (Fig. 1).

Habitat and water degradation also negatively impacted the species reproductive success due to the reduction of their reproductive hot-spots. The exponential increase of the standard of living in Greece, the subsequent increase of population, and the organization of the agricultural section after the Second World War (Chouliariakis 1988) considerably increased the pressure on lake ecosystems. In fact, the escalation of the agricultural runoff (42%–48% of the total discharges: Mourkidis 1986a), animal husbandry effluents, and untreated communal wastewater containing detergents have worsened the water quality of the lake and its surrounding streams during the last 60 years (Kaiserili et al. 2002). These incidents might be responsible for the occurrence of algal bloom phenomena, firstly observed during the mid-1960s (Table 5) that severely affected fish survival, especially immature ones (Gordon et al. 2005). The excessive drilling for water due to irrigation at the peak of species reproductive period (spring-summer) also impacted on the stocks by reducing their critical habitats, especially for species that lay their eggs over aquatic plants and shallow submerged vegetation (i.e., *C. carpio*, *Esox lucius* Linnaeus, 1758, *P. fluviatilis*) (see Froese and Pauly 2019). Construction of dams also restricted the upward migration of diadromous fish species, such as *Anguilla anguilla* (Linnaeus, 1758) and *Mugil cephalus* Linnaeus, 1758.

Climatic alteration affects fish survival either directly (by extreme temperature) or indirectly (by extreme precipitation). In two out of three driest years observed (1977 and 2000) since 1930 (Pakalidou and Karacosta 2018), catches exhibited a considerable decrease by 21 percentage points and 46 percentage points, respectively. With respect to precipitation, there was a turning point of the driest seasons within 1981–2000 (Pakalidou and Karacosta 2018) with a downward trend of annual rainfall (Feidas et al. 2007) that match with the five times decrease of fisheries catches during that period (Fig. 4A).

Contrarily to the above, restocking trials with species inhabiting the system (Table 5) resulted in increasing catches for that species. Restocking with *P. fluviatilis* in 1985 resulted in increasing catches two and three years afterwards (Fig. 4B), but with a subsequent decline of their preys, *A. macedonica* and *R. rutilus* (see Kleanthidis 2002). In contrast, the introduction of species originating in other freshwater systems had negative effects to the local species. This is the case for the dominance of *Silurus glanis* Linnaeus, 1758 on *Silurus aristotelis* Garman, 1890 after the accidental introduction of the former in mid-1980s (Bobori et al. 2001). Nowadays, large quantities of *L. gibbosus* has also appeared (Bobori et al. 2019), possibly resulting from accidental release from aquaria (Perdikaris et al. 2016).

Evaluation of fisheries monitoring in lakes. What is important from the presently reported study is the categorisation of the professional fishers into two categories of fishing activity; the regularly operating and irregularly operating ones. The implementation of management actions that are based on fisher's profile would facilitate the synthesis of the different activities developed by fishers and would define the evaluation of the fleet dynamics. In this context, fishing effort control measurements implemented through the license control systems would have a negligible effect on the ecosystem sustainability, because the reduction of fishing effort regardless of the level of dependence of the fishers can lead to the reduction of nominal fishing effort (abandoning fishing by irregularly operating professionals) (Tzanatos et al. 2006).

The actual impact of fisheries is also hard to be evaluated due to misreporting estimates and serious limitations in the official landing statistics. Practically, landing records in freshwaters were based on a non-mandatory declaration of the professional fishers, every two years, when they had to renew their professional license in the local fisheries office, thus, fishers probably declared lower quantities to pay lower taxes. In contrast, due to the anonymity of the interviews in the presently reported study (protecting them from being traced for tax purposes), fishers might provide more accurate catch estimates. Political instability may also severely impact the quality of fisheries data, as in our case the establishment of a military dictatorship during 1967–1974 probably led to biased lake catches (open circles in Fig. 4A) due to deliberate conceal of catches for taxation reasons and/or insignificant economic gain.

Catches from low commercially important species (i.e., *A. brama*, *Alburnus alburnus*, *A. macedonica*, and *R. rutilus*) are often deliberately or unintentionally misidentified within other fish groups due to their low market demand. Thus, the considerable decline in fisheries catches and the abrupt changes in those species' catches among different periods might not be related to ecological changes, but rather to low economic value. This is the case for *R. rutilus* that exhibited a low contribution to the total catches, even though its top predators, *E. lucius*, *A. anguilla* and *S. glanis* (see Froese and Pauly 2019), have been severely reduced or extirpated (for *S. glanis*) from the lake 30 years ago. Likewise, the

low value of the endemic species *A. macedonica* (less than €1.5 per kg), urges fishers to avoid catching it even though it is considered to be present in large quantities (Zarfdjian et al. 1990, Bobori and Economidis 2006). Thus, the use of the official catch data in freshwaters, to cover meta-analytic issues in an ecosystem-based approach (e.g., ecological indices and modelling approaches), should be considered with caution.

Considering the complete lack of knowledge regarding the catch of the recreational and illegal fisheries conducted in the lake especially in shallow waters when fish spawn, it can be assumed that the actual catches are much higher and thus the officially reported data could be very misleading. In order to counterbalance this issue, the supplementary use of historical information complemented with data collected from local knowledge can be used to provide more representative and factual information (Giovos et al. 2019).

Issues impending lake fisheries future. Many problems faced by the fishers of Volvi Lake remained the same for almost 70 years (i.e., lack of investment, accidental introduction of alien species, absence of modernised vessels, low economic productivity and illegal fishing) (Ananiadis 1948, 1968) and restricted freshwater fishery to an early-stage of development. Apart from economic issues, the second most important problem is the illegal fishing and equipment theft. Recreational fishery in Greek lakes is prohibited by vessels all year round, whereas the shore-based ones are allowed (except in the month of May). Halting the illegal fishing could be accomplished if fisheries legislation is modified, taking into account the number of the most active fishers and enforcing fisheries control based upon social participation (Arlinghaus et al. 2015, Giovos et al. 2019). This would trigger professional fishers to establish self control (Zaucha et al. 2016) by contributing with their professional knowledge and experience to effective management measures acting as guardians of traditional fisheries.

An aggravating factor of the local fishery is the gradual aging of the fishers' population that has been also observed in other Greek freshwaters (i.e., in Lake Trichonis, the largest natural lake in Greece) (Roussi-Dimitriou et al. 1997) and coastal marine fisheries (Tzanatos et al. 2006). The exploitation of lakes has not been linked to the recruitment of young fishers, because the young are not willing to be engaged in the fishers' profession. The tendency to abandon the fishers' profession by the next generations reflects the lack of a long-term strategy in the fisheries sector that subsequently poses risks to the future of the inland fishery (Bobori and Economidis 2006). An uncertain future of the fisheries is also aggravated by the small number of fishers being fully dependent on fisheries, especially during periods when other professions (e.g., agriculture) are more profitable. In fact, according to a study on fishers' financial situation in Volvi Lake (Valoukas et al. 2000), the number of regularly operating fishers (those being members of the fishers' association) during the 1990s was 25, almost three times higher than today as indicated by our results (nine regularly operating fishers). This problem is enhancing the lack of stakeholder

participation in the decision-making policies and the reluctance of fishers to participate in subsidy programs.

Following certain best-practises adopted in freshwater systems almost 60 years ago, (i.e., the establishment of a prohibited fishing period for all fishing gears, the increase of minimum mesh of the net) (Table 5), a promising issue of the current fishing exploitation is the ecologically sound lake's fishing tactics, because of the use of highly selective gears (nets with a mesh size greater than 50 mm) and the subsequent limited amount of discards (almost 1% to the total catches). These initiatives safeguard the commercial stocks from growth overfishing by allowing enough juveniles to survive and spawn and reduced the impact on the small-sized endangered species (*Vimba* spp.).

CONCLUSIONS

The methodology and results presented here should optimize the status of the fisheries exploitation in the lake and could be incorporated in the decision-making process towards the improvement of the implementation of the EU Water Framework Directive 2000/60 (Anonymous 2000, Voulvoulis et al. 2017). Taking also into account that the official statistics did not present the real fishery status and/or fishing effort, the cooperation among scientists, stakeholders, authorities, and local communities must be encouraged. This would provide new insights for enhancing fisheries' monitoring and patrolling and define a typology in freshwaters based on the integration of fisheries, economic and social-cultural aspects.

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