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## The fish fauna in lentic ecosystems of Greece

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### Abstract

This study provides an annotated checklist of the freshwater fish species recorded in the lentic ecosystems of Greece. Species distributional data were derived from an extensive review of published and unpublished sources and were evaluated for their consistency, adequacy and reliability. Overall, 650 freshwater lentic ecosystems (149 natural and 501 artificial) were investigated from which, 480 were fishless or fish data were unavailable. In the remaining 170 ecosystems, 122 taxa were recorded (belonging to 22 families and 57 genera). Some of the records concerned species with extirpated populations, species of doubtful occurrences and taxa of uncertain taxonomic status. The highest species richness (52 species) was recorded in the Ionian ecoregion while endemism was highest in the Macedonia-Thessaly ecoregion (43.75%). The Eastern Aegean ecoregion presented the highest level of introduced species (75%). Only eight ecosystems hosted 20 or more species, while 92 ecosystems had over 50% of introduced species. The most widespread native species (*Anguilla anguilla* and *Luciobarbus albanicus*) are two highly migratory species, highlighting the importance of connectivity of aquatic ecosystems. The most widespread translocated species was *Cyprinus carpio* due to its high commercial and recreational value, whereas *Gambusia holbrooki* confirmed its high dispersal ability being the most widespread alien species. More than one-third of the species recorded (37.23 %) are threatened based on the IUCN Red List. The ultimate contribution of this study is to support the coordination and dissemination of baseline information on the freshwater fishes of Greek lentic ecosystems, required by a range of users. This knowledge will enable further understanding of the regional assemblage structure and other biogeographical patterns of the ichthyofauna of Greece and will contribute to species conservation by prioritising areas hosting species in need of protection. Finally, this study reveals the high knowledge gap regarding species composition in many Greek lentic ecosystems and highlights the need for relevant primary research including more systematic and standardised samplings.

**Keywords:** Lakes; fish; fishless; ecoregions; native; introduced; richness; translocated.

### Introduction

Species checklists and database inventories are vital sources of information for researchers, policy makers and water use managers. Such information-gathering tools have long been used for various biodiversity-related research, e.g., monitoring species distributions, extinctions and invasions, supporting biogeographical and macroecological research, and informing biodiversity management policies (Weigelt *et al.*, 2019; Freyhof *et al.*, 2020; IUCN, 2021; Miqueleiz *et al.*, 2022). Most studies targeting to deliver species checklists and inventories however are usually confined to collecting data without evaluating,

qualifying or prioritizing their data sources (Ball-Damerow *et al.*, 2019; Gadelha *et al.*, 2021). Data are typically assembled from heterogeneous sources, such as scientific journals, books, grey literature and unpublished material that resides in individual researchers' computers and institute servers, combined into a single dataset (Opermanis *et al.*, 2014; Schmidt-Kloiber & De Wever, 2018; König *et al.*, 2019). If the potential data sources are not systematically searched, and if rigorous quality control criteria for identifying errors and inconsistencies in the primary data are not established, then the derived species lists will contain omissions and inaccuracies that may damage the performance of the intended applications. Hence, in

many cases, the usefulness of these lists is limited, as the degree of adequacy and reliability of the data is unknown. Despite some major efforts from numerous organizations to assemble, evaluate and integrate biodiversity data and develop large species inventories that satisfy the needs of potential users (Roskov *et al.*, 2019; Reyserhove *et al.*, 2020; Arlé *et al.*, 2021), region-wide biodiversity data of sufficient quality and resolution are not often easily accessible. Accurate country-wide inventories due to their essential importance for species conservation should be dynamic in their initial design, including the most up-to-date status of species site occurrence(s), through a careful review by experts, to ensure quality assurance.

Despite the increasing research effort during the last decades, available inventories and reviews targeting various biotic and abiotic characteristics of Greek lentic ecosystems are far from complete. For instance, the total number of freshwater lentic ecosystems in Greece remains unknown and probably keeps growing, as new water-storage systems are constantly being constructed for power generation and irrigation. A major area where knowledge is limited concerns freshwater fishes in lentic habitats. In former inventory studies, the information provided was sporadic, confined often only on some common fish species (Zalidis & Mantzavelas, 1994; Dafis *et al.*, 1997). Recent inventory efforts were faunistically more complete, but were mostly concerned with certain subsets of lentic systems, e.g., were confined to the Aegean wetlands (Catsadorakis & Paragamian, 2007; WWF, 2020), covered only some parts of the Greek territory (Economou *et al.*, 1999; Ministry of Agriculture, 2001) or dealt only with natural lakes (Koussouris, 2014). The most recent and updated inventory of wetlands in continental Greece focused on boundary mapping with remote sensing techniques (Fitoka *et al.*, 2020); however, so far it has integrated existing biodiversity data, including fish fauna, only for few sites. Current and under development databases and inventories by the Greek Ministry of the Environment and Energy, as well as the biological data submitted by Greece and contained in the EU Natura 2000 database, also provide limited and fragmented coverage of fishes in lentic systems. These databases contain data primarily for ‘species of Community interest’, and their spatial coverage is confined to sites protected under the EU legislation. National biodiversity laws such as the Presidential Decree 67/1981 and the Law 1335/1983 are valuable as bases for the protection of species; however, they are outdated and not applied in practice. On the other side, the Greek Red Book which was recently updated (Legakis & Maragou, 2009) lacks legal force.

Three reasons may account for the limited coverage of lentic fish species by the existing inventory databases. Firstly, inventory studies have traditionally focused on large natural lentic ecosystems of economic or ecological importance (e.g., CORINE biotopes and RAMSAR or Natura 2000 sites). Smaller water bodies and man-made lakes or impoundments in Greece have received less scientific and policy attention under the erroneous assumption that they are of limited socio-economic and ecological importance (Konstantinidis *et al.*, 2018). Sec-

ondly, inventory data on fish were often assembled by non-experts in ichthyology, who were not familiar with the relevant literature and its technicalities, and thus were not able to exploit all potential data sources. Finally, spatial occurrence data for lentic fishes are limited and have some degree of vagueness, e.g., concerning the degree of utilisation of lentic or lotic habitats. For example, Economou *et al.* (2007) produced an inventory checklist of the freshwater fishes in Greek freshwaters, in which the data were organised at the “hydrographic basin area” scale (meant to encompass all types of waters located within the entire watershed area, e.g., rivers, lakes, reservoirs, wetlands, etc). This grouping approach was justified at the time, because habitat-specific data within the geographic range of species were not sufficiently available. However, this approach yields a confusing picture of the distribution and diversity of lentic fishes, because it does not allow to identify which species are dominant in lentic ecosystems and in which lakes within each hydrographic basin they occur.

Academic research over the past decades has led to significant advances in the knowledge of the freshwater fish fauna of Greece, and much information about the distribution and ecology of many species is now available (for synthetic reviews and checklists see the early 1930s publications of Stephanidis, 1939a, b; followed several decades later by Economidis, 1973, 1991; Economidis *et al.*, 2000; Bobori *et al.*, 2001; Bobori & Economidis 2006; Economou *et al.*, 2006, 2007; Koutsikos *et al.*, 2012; Barbieri *et al.*, 2015). Until now, this information has not been substantially exploited as a source in inventory studies and biodiversity databases. A plausible reason for this is that the scattered and technical nature of these publications makes it difficult for non-specialists to find, evaluate and make use of the relevant publications. It is well established that research often fails to provide usable information that is needed for policy and management, not because research data are not available, but because the research outputs are not organised and presented in a way accessible to managers and policy makers (Hering, 2016). Thus, it is required to develop processes and tools for collating, interpreting and “translating” the research findings into usable information for policy development and management practice. Informed inventories and checklists can bridge academic knowledge with scientific or practical applications, thereby supporting environmental policies and management planning. They can also provide baseline data for research in fields that rely on large spatial datasets of species distributions, such as biogeography, landscape ecology, macroecology, alien species invasion dynamics, biodiversity assessments, biomonitoring planning and conservation prioritisation. Finally, they can guide future research needs and priorities, by indicating under-studied species and under-researched areas, and also by revealing hidden knowledge in large datasets or past literature, thus reducing the possibility of research duplication.

The effectiveness of checklists and their usefulness depends on their completeness and reliability. In applied science and biodiversity management, incomplete or in-

accurate checklists can disorient biodiversity management and conservation efforts. The aim of this study is to provide an up-to-date inventory of freshwater fish species of natural and artificial lentic ecosystems of Greece. Based on specific methodological criteria for the selection and evaluation of information and by containing data quality annotations to indicate the degree of uncertainty associated with the data, this study aims to contribute to research design and policy development by highlighting knowledge gaps of lentic fish species distributions and community assembly patterns. In addition, it can contribute to a better understanding of the regional diversity, taxonomic diversity and biogeographic structure of the Greek lentic ichthyofauna and thereby assisting in proper conservation decision-making.

## Materials and Methods

### The studied ecosystems

We compiled a dataset of 650 freshwater lentic ecosystems in Greece including also transboundary systems (i.e., shared with neighboring Balkan countries Albania, North Macedonia and Bulgaria). While our primary goal focused on lentic ecosystems with fish presence, we also included fishless ecosystems, as well as unexploited ecosystems with unreported or ambiguous fish data (Supplementary material, Fig. S1 and Table S1), because the reasons for the absence of fish do constitute valuable information. We included both, natural lentic ecosystems (i.e., alluvial, karstic, tectonic, glacial/alpine, and alleged to have been created by extraterrestrial impact e.g., lakes Komiti and Zirelia), and artificial ecosystems (i.e., reservoirs, ponds, mining pools) formed as a result of intentional river damming or outside of riverine corridors within forest, agricultural, or urban land. Coastal brackish lagoons and other transitional waters such as coastal wetlands were not included in this inventory, with few however exceptions. Specifically, we included a small number of brackish lentic ecosystems either because of their ichthyofaunal interest (e.g., Lake Vouliagmeni in

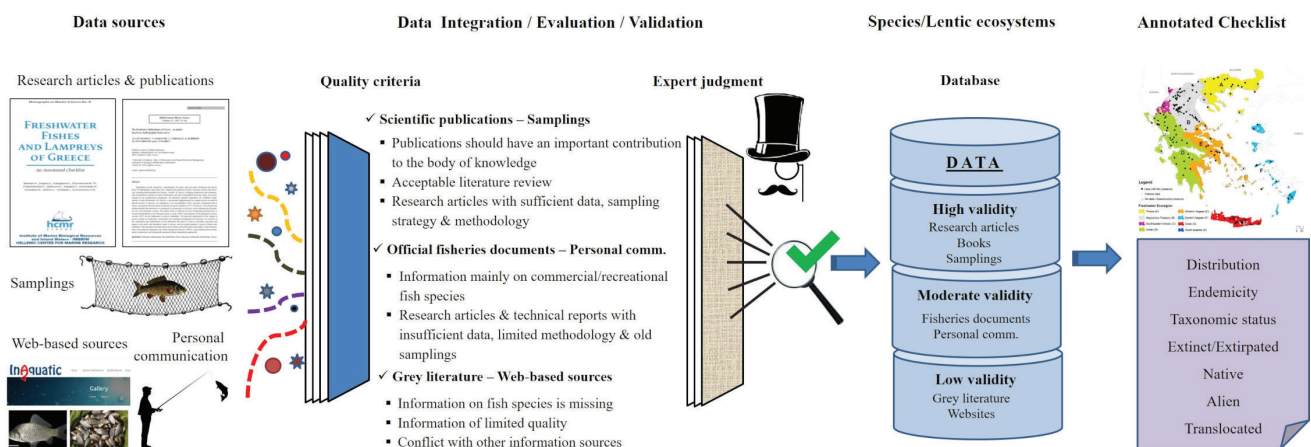
Attica) or the noteworthy absence of fish species (e.g., Pikrolimni, a natural inland hypersaline lake). In addition, we included several small lentic ecosystems that undergo seasonal desiccation to record the absence of fish species and emphasize their fragile character. On the contrary, lakes that have been permanently drained for several decades were omitted (e.g., Kopaida, Xyniada). A large part of the small lentic ecosystems was derived from the most recent inventory of wetlands in continental Greece, by Fitoka *et al.* (2020).

No surface area limits were considered for the inclusion of a lentic ecosystem in our inventory. Mean surface area and altitude of each system were retrieved largely from published literature however, for several lentic ecosystems, surface area was re-calculated by using Google Earth® tools and altitude was extracted by ArcGIS (ESRI - ArcGIS v. 10.4). In few cases, where several small lakes were adjacent to each other forming a lake complex (e.g., Paleros ponds, Chrysopouli lakes), coordinates and other information are referred to the largest lake. Each lake was categorised into one out of eight fish ecoregions (hereafter ecoregion), based on Zogaris & Economou (2017): i.e., 1) Thrace, 2) Macedonia-Thessaly, 3) Southeastern Adriatic, 4) Ionian 5) Eastern Aegean, 6) Western Aegean and 7) Crete. No lentic bodies were located in the Southern Anatolia ecoregion, which solely includes Greece's most eastern island cluster of Greece, Kastellorizo.

### Fish species occurrence records

The data used in the present study were obtained from an extensive review of published and unpublished sources that were evaluated for their adequacy, quality and reliability prior to the development of the annotated checklist. An overview of the methodological procedure followed during this study is provided in Figure 1, and is detailed below.

Species distributional data were gleaned from various sources and inevitably were highly heterogeneous (main sources for each lake are provided in the Supplementary material, Table S1). We drew much information



**Fig. 1:** The methodological procedure applied in this study: data sources, evaluation and validation control, accuracy categorization, development of the annotated checklist.

from relevant publications (research articles, technical reports, dissertation theses, conference proceedings, books and grey literature) and web-based sources. Specifically, a large web-based survey was conducted during the years 2017-2020, using several keyword combinations in English and Greek, to exploit all available information. We typically included the name of the lake under investigation, followed by various combinations of words such as “fish”, “fish fauna”, “ichthyofauna”, “fisheries”, “ιχθυοπανίδα”, “ψάρια”, “αλιεία”, “ψάρεμα” and/or other limnological features. In few occasions, data were acquired through audiovisual material from YouTube™ and social media (e.g., Facebook™) and verified by personal communication. Furthermore, personal communications were conducted with official authorities (Fisheries Departments of Regional Units), local fishermen and recreational anglers. Finally, we used unpublished data from field surveys that were conducted with the participation of the authors.

Special attention was given to document and ascertain the quality of each particular record. In order to include a species in a lake’s/reservoir’s assemblage list, it had to be provided by either: a) one reliable source (scientific publication, technical report, conference proceedings), b) the authors during field surveys, c) personal communication with ichthyologists from Fisheries Departments of Regional Units, and/or d) personal communication with local fishermen, recreational anglers and experienced naturalists. In cases of a doubtful record deriving from personal communication, additional evidence was required (e.g., photographic material) to include the record in the database. Other sources of grey literature were also used, however, efforts were made to crosscheck the record with an additional source (sampling, publication, report or personal communication). If no additional information was available, then this record was either discarded or held as questionable and labeled with a question mark.

### ***The checklist development procedure***

The species checklist was developed with an inventory perspective and is appended by methodological and descriptive annotations that assist users in identifying main data sources and the location of records. It also provides the kind and detail of information required by specialised users, such as the taxonomic, biogeographic and provenance statuses of species in each inventoried lentic system.

The following criteria, approaches, principles and terms were applied for the compilation of this checklist:

- a. All fish species, native, alien or translocated (for definitions see Koutsikos *et al.*, 2019a), that spend all or a significant period of their life-cycle in freshwaters were considered for inclusion. Species endemism was based on Economou *et al.* (2007) and Barbieri *et al.* (2015). Species were regarded as occurring in a given lentic system whether found within the lake itself or in the surrounding wetlands and the very lower reaches of tributaries flowing into that ecosystem.

Data from samples obtained from fluvial waters upstream of reservoirs were accepted for inclusion in the inventory dataset if certain conditions were satisfied. Specifically, we took into account proximity to the lacustrine environment (e.g., near the mouth of the river feeding into the reservoir), the species’ ecological niche (e.g., known degree of limnophily), and other relevant information sources (e.g., sampling data). Data from samples taken downstream of a barrier (dam) were not included unless the species in question was also found upstream of the reservoir.

- b. Diadromous species, for which occurrence in the lentic systems inventoried has been reported, such as eels, sturgeons and shads, as well as some euryhaline species that typically inhabit river estuaries (e.g., sand-smelt and some gobies), were included. Species having a definite marine life-history occasionally found in (sometimes stocked into) lacustrine environments of Greece (e.g., mugilids, sea bream, sea bass) were excluded.

Valid species names used were in accordance with Barbieri *et al.* (2015), for consistency with recent inventory and monitoring studies. In some instances, we retained the original genus of taxa for which taxonomic revisions have been recently proposed, pending further acceptance (e.g., we retained the genus *Rutilus* that was resurrected to the genus *Leucos* by Bianco & Ketmaier, 2014). Throughout the text, we use the terms taxa or species interchangeably, depending on the targeted analysis. This was unavoidable since some species that are recorded only to genus level and present identification issues, were given operational taxa names (e.g., *Salmo* sp., *Squalius* sp.). Common names nomenclature strictly follows Barbieri *et al.* (2015) with few new taxa names supplemented by Fishbase (Froese & Pauly, 2021). The use of “cf” before a species name indicates that the specimens look similar to that species, but may represent an undescribed species or the identification of the species retains a level of uncertainty.

Species of doubtful provenance or taxonomic status were included with notations: (a) doubtful taxonomic status, (b) uncertainty about the native or introduced status of a population, (c) the population is presumed extirpated or possibly extirpated or extremely low in numbers based on published information and compelling evidence from other sources (applies mainly for sturgeons, grass carp, silver carp, bighead carp, wels, pikes and tench), (d) introduced species in a lentic system due to repeated stocking but with doubtful establishment success, (applies mainly for the rainbow trout *Oncorhynchus mykiss*; see Koutsikos *et al.*, 2019b), and (e) species reported as present in lentic systems in some publications but which, according to sample data and other sources, are restricted to river outflows entering into lakes and rarely occur within lakes (e.g., barbels, gudgeons and nases). For the compilation of lists of the most widespread lentic fishes, only confirmed records of extant taxa were used (i.e., excluding questionable or extirpated populations).

Species conservation status of the recorded fish taxa was evaluated based on the inventory of the IUCN red list

of threatened species (IUCN, 2021), the Red Data Book of Threatened Animals of Greece (Legakis & Maragou, 2009) and Annexes II and IV of EU Habitats Directive (92/43/EC). The conservation status of the introduced species was not taken into consideration in our analyses, neither that of unidentified species known only to genus level (e.g., *Squalius* sp.).

Quality criteria were applied to evaluate the validity of the information available for each lentic ecosystem (see Fig. 1 and Supplementary material, Table S1). As a generality, the data derived from field samplings or obtained from credible scientific sources (journal publications, books, conference proceedings and technical reports) were categorised as of high validity. Those gathered from official fisheries documents, contacts with the staff of Fisheries Departments, personal communications with fishermen and anglers or social media were categorised as of moderate validity since they are mostly referred to fish stockings and species of commercial interest, often using invalid taxonomy and dubious common names. In addition, research articles and technical reports with insufficient samplings and data were also evaluated as of moderate validity. Finally, data were scored as of low validity when they were derived from low quality grey literature, or the information provided was judged to be of limited relevance and quality, or it was evidently in conflict with other information sources.

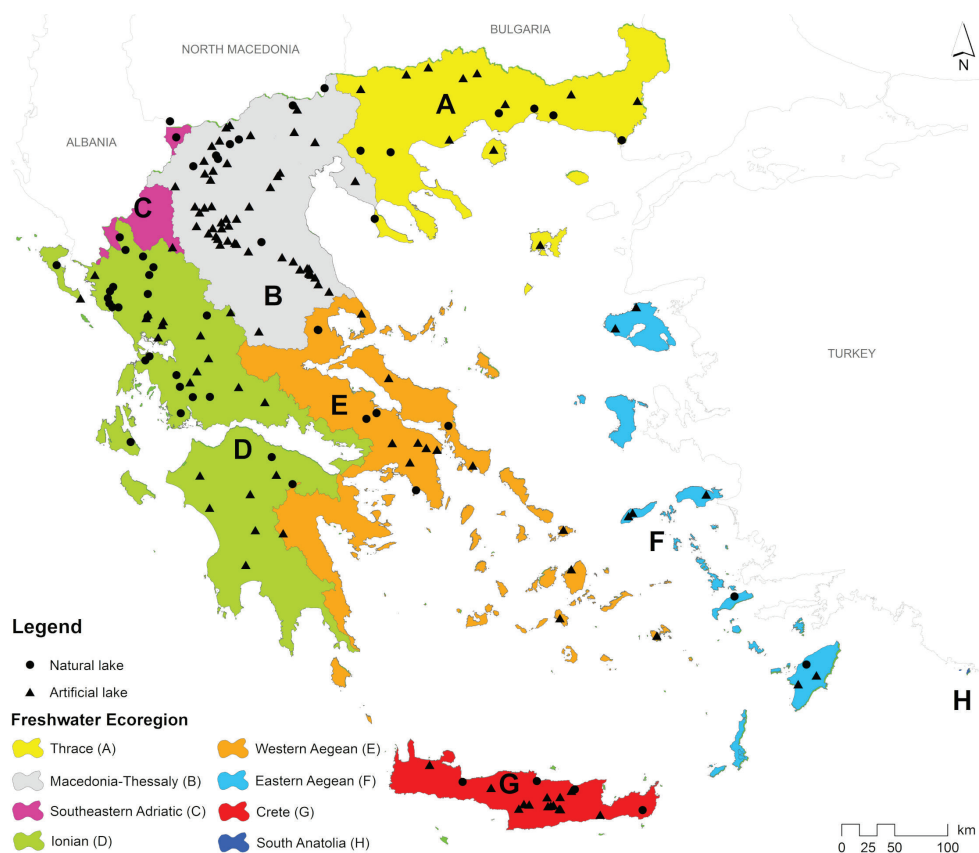
## Results

### *Spatial extent and distribution of Greek lentic ecosystems*

Overall, 650 lentic ecosystems were examined in this study (149 natural ecosystems and 501 artificial) from which, 480 were fishless or unexploited since fish presence data were doubtful or unavailable (Supplementary material, Fig. S1 and Table S1). In the remaining 170 ecosystems (Fig. 2; see also Supplementary material, Figs S2-S11), at least one fish species was recorded.

The majority of the lentic ecosystems with fish presence were artificial (116; 68.23%; i.e., dams, reservoirs, ponds, impoundments) and the rest (54; 31.77%) were of natural origin. Most of these recorded ecosystems are located in north-central and western Greece. Specifically, 58 lentic ecosystems (34.11%) out of the total investigated with fish presence are located in the Macedonia-Thessaly ecoregion, followed by the Ionian ecoregion with 45 lentic ecosystems (26.47%) (Table 1).

The total explored area was 1,357.88 km<sup>2</sup>. The Ionian ecoregion presented the largest overall lentic surface area, while the smallest total lentic area was observed in the Eastern Aegean ecoregion. The lowest mean surface area was recorded in the Crete ecoregion (Table 1). The mean surface area of artificial lentic ecosystems was 4.5 km<sup>2</sup> (min = 0.004 km<sup>2</sup>, max = 85.7 km<sup>2</sup>, n = 116), while of the natural systems it was 15.4 km<sup>2</sup> (min = 0.0003 km<sup>2</sup>, max = 260 km<sup>2</sup>, n = 54). The mean altitude for lentic



**Fig. 2:** Distribution map of lentic ecosystems with fish presence included in the dataset for each freshwater ecoregion of Greece (see also Figs S2-S11 for the precise location of each lentic ecosystem per ecoregion).

**Table 1.** Summary data of the studied lentic ecosystems with fish presence per ecoregion in Greece.

	Ecoregions							Total Greece
	Thrace	Macedonia Thessaly	Ionian	Western Aegean	Eastern Aegean	Southeastern Adriatic	Crete	
<b>Number of lakes</b>	18	58	45	19	9	3	18	170
<b>Number of natural lakes</b>	7	8	25	6	2	2	4	54
<b>Number of artificial lakes</b>	11	50	20	13	7	1	14	116
<b>Total lake area (km<sup>2</sup>)</b>	233.71	318.60	427.67	48.64	6.11	316.60	6.76	1,357.88
<b>Mean area (min-max) (km<sup>2</sup>)<sup>1</sup></b>	12.98 (0.011-68)	5.4 (0.0003-74)	9.5 (0.002-96.5)	2.56 (0.008-25)	0.68 (0.002-4.86)	105.53 (8.6-260)	0.38 (0.002-1.7)	7.99 (0.0003-260)
<b>Mean altitude (min-max) (m)</b>	175.1 (0-840)	449.6 (18-1034)	229.1 (0.5-869)	152 (0-657)	220.6 (23-721)	1018 (852-1350)	260.8 (19-567)	306.8 (0-1350)
<b>Number of families</b>	17	15	16	7	5	11	6	22
<b>Number of genera</b>	40	36	33	19	11	26	9	57
<b>Number of taxa<sup>2</sup></b>	47	48	52	24	12	32	10	122
<b>Mean number of taxa/lake (min-max)</b>	9.72 (1-27)	5.97 (1-20)	7.29 (1-23)	3.84 (1-12)	3.11 (1-6)	18.33 (12-25)	2.94 (1-7)	6.22 (1-27)
<b>Endemic taxa to S. Balkans<sup>3</sup></b>	9	15	1	0	0	6*	0	26
<b>Endemic taxa to Greece</b>	5	5	17	6	1	0	0	32
<b>Near endemic taxa</b>	0	1	4	0	0	6	0	11
<b>Total endemic taxa</b>	14	21	22	6	1	12	0	69
<b>% endemics taxa</b>	29.79	43.75	42.30	25	8.33	37.5	0	56.5
<b>Native taxa<sup>4</sup></b>	19	9	6	3	2	1	3	22
<b>% native taxa</b>	40.42	18.75	11.53	12.5	16.67	3.13	30	18.03
<b>Alien taxa<sup>5</sup></b>	10	16	17	10	6	12	6	24
<b>% Alien taxa</b>	21.28	33.33	32.69	41.67	50.00	37.50	60.00	19.67
<b>Translocated taxa<sup>6</sup></b>	4	2	7	5	3	7	1	7
<b>% Translocated taxa</b>	8.51	4.17	13.46	20.83	25.00	21.88	10.00	5.74
<b>Translocated (Native)<sup>7</sup></b>	6	10	10	2	1	0	1	29

<sup>1</sup> calculated by averaging the lakes surface areas from each ecoregion

<sup>2</sup> including taxa with doubtful occurrences, unresolved taxonomic status and species varieties

<sup>3</sup> not including endemic taxa that are introduced in the ecoregion. These taxa are included as translocated

<sup>4</sup> not including native taxa that are introduced in the ecoregion. These taxa are included as translocated

<sup>5</sup> taxa with origin outside of Greece

<sup>6</sup> native taxa translocated outside their natural distributional range, displaying only introduced populations

<sup>7</sup> native taxa that are introduced in some lentic ecosystems but also displaying some native occurrences within ecoregion

\* Including the taxa *Alburnoides prespensis* complex

ecosystems with fish presence was 306.8 m, ranging from 0 to 1,350 m, with the highest altitudes recorded in the Southeastern Adriatic ecoregion, followed by the Macedonia-Thessaly ecoregion (Table 1). It should be noted that in the Southeastern Adriatic ecoregion there are alpine lakes at altitudes up to 2,432 m, but they lack fish. The altitude of the artificial lentic ecosystems with fish presence ranged between 1-1,350 m with a mean value of 338.5 m, while the altitude of natural lentic systems ranged between 0 and 853.5 m with a mean altitude of 238.5 m.

### The ichthyofauna of the Greek lentic ecosystems

All taxa known from the lentic systems of Greece are presented in the checklist of Appendix Table A1. The regional occurrences and species lists for each system are shown in Appendix Tables A2-A11. In total, 122 taxa present in 170 lentic ecosystems were recorded, including species with doubtful occurrence and unresolved taxonomic status (i.e., *Knipowitschia* sp., *Salmo* sp., *Squal-*

*ius* sp., *Tilapia* sp., *Coregonus* sp.) and species varieties (i.e., koi carp *Cyprinus cf. carpio*).

All taxa were arranged in 22 families and 57 genera. The Cyprinidae family was dominant with 68 taxa, comprising 55.73% of the total taxa. Three families (Salmonidae, Cobitidae and Gobiidae) were represented by more than 6 species, 11 families by only 1 while the rest by 2 to 3 species. Overall, 91 native fish species were reported. Of these, five species were recorded only as translocated, as no extant populations were found within their natural distributional range (*Acipenser naccarrii*, *Alburnus alburnus*, *Petroleuciscus smyrnaeus*, *Sander lucioperca* and *Squalius* sp. Aoo). Of all taxa, 58 taxa were designated as endemic, either to Greece or to the Southern Balkans, and 11 additional species were confirmed as near-endemics i.e., occurring also in shared transboundary freshwater lakes and/or river basins (Table 1). A total of 24 species were identified as alien in Greece, while 29 native species were found outside of their native distributional range and were designated as translocated (Table 1).

The most widespread native, alien and translocated species in the lentic ecosystems of Greece are presented

**Table 2.** The most widespread native, alien and translocated fish taxa in Greek lentic ecosystems. Only confirmed records are presented in the table (i.e., excluding questionable or extirpated populations).

Native species	Lentic ecosystems	Frequency of occurrence (%)
<i>Anguilla anguilla</i>	42	24.71
<i>Luciobarbus albanicus</i>	20	11.76
<i>Rutilus rutilus</i>	17	10.00
<i>Squalius peloponnesius</i>	16	9.41
<i>Telestes pleurobipunctatus</i>	14	8.24
<i>Barbus peloponnesius</i>	13	7.65
<i>Barbus balcanicus</i>	12	7.06
Alien Species	Lentic ecosystems	Frequency of occurrence (%)
<i>Gambusia holbrooki</i>	73	42.94
<i>Carassius gibelio</i>	59	34.71
<i>Oncorhynchus mykiss</i>	35	20.59
<i>Lepomis gibbosus</i>	32	18.82
<i>Carassius auratus</i>	24	14.12
<i>Pseudorasbora parva</i>	17	10.00
<i>Coregonus</i> sp.	3	1.76
Translocated	Lentic ecosystems	Frequency of occurrence (%)
<i>Cyprinus carpio</i>	93	54.71
<i>Perca fluviatilis</i>	13	7.65
<i>Tinca tinca</i>	12	7.06
<i>Silurus glanis</i>	10	5.88
<i>Esox lucius</i>	9	5.29
<i>Economidichthys pygmaeus</i>	5	2.94
<i>Rutilus rutilus</i>	5	2.94



in Table 2. *Anguilla anguilla* was reported in 42 systems, followed by *Luciobarbus albanicus*, which was reported in 20 systems. Concerning translocated taxa, *Cyprinus carpio* was by far the most widespread recorded species with confirmed presence in 93 lentic systems of Greece, followed by the alien *Gambusia holbrooki* (in 73 systems, Table 2).

### Ecoregional distribution of the native lentic fishes

The distribution pattern of native taxa suggests a strong biogeographic structure, with ecoregions differing in their faunal composition. Indeed, 69 species occur in only one ecoregion and only 19 (Table 3) are found in more than one ecoregion. The species that are most widespread across ecoregions are diadromous or euryhaline forms with a high degree of salinity tolerance (*A. anguilla*, *Atherina boyeri* and *Salaria fluviatilis*). The Macedonia-Thessaly and Thrace ecoregions display some exceptions to this distribution, showing a higher degree of faunistic similarity (13 common species) relative to the other ecoregions.

In species richness comparisons among ecoregions,

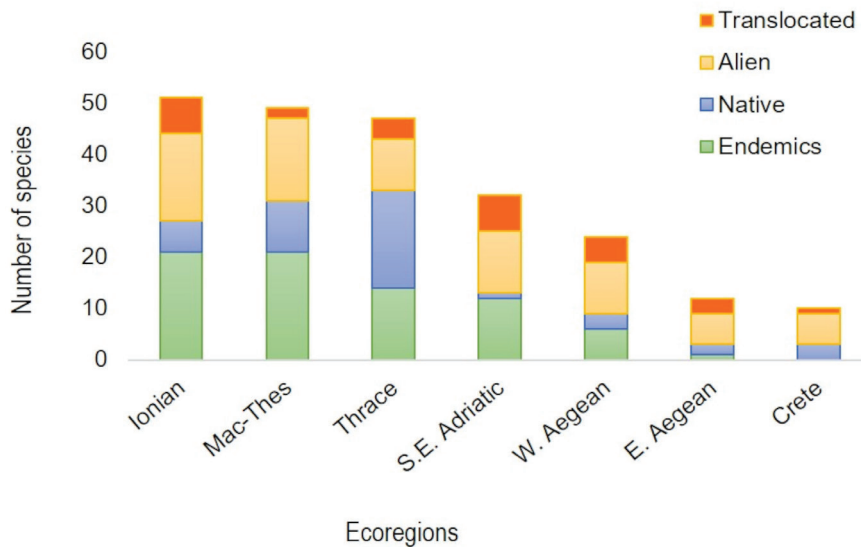
the Ionian indicated the highest species richness (52 species), followed by Macedonia-Thessaly (48 species) and Thrace (47 species). Crete had the lowest species richness (10 species, Fig. 3). The Macedonia-Thessaly and the Ionian ecoregions presented also the highest endemism levels (43.75% and 42.30%, respectively), while Crete the lowest (0%). The Eastern Aegean and Crete ecoregions presented the highest levels of non-indigenous taxa (75% and 70%, respectively), while the Thrace ecoregion the lowest (29.79%).

Considering the ecoregional distribution of native species in natural ecosystems, *A. anguilla* was yet again the most widespread species occurring in four ecoregions, followed by *A. boyeri* and *S. fluviatilis* which were found in three ecoregions (Table 4).

*Cyprinus carpio* was the most widespread translocated species occurring in six ecoregions, followed by *A. anguilla* and *Tinca tinca* that were recorded in three ecoregions. The only species present in all ecoregions was the alien species *G. holbrooki*, followed by *Carassius gibelio* which was recorded in six ecoregions (Table 4). Concerning the artificial lentic ecosystems, similar distribution ranges were observed for all the aforementioned species with the exception of *Perca fluviatilis* and *Silurus glanis*

**Table 3.** Faunistic similarities among ecoregions (native fish taxa with joint presence in more than two ecoregions).

Species	Cretan	E Aegean	Ionian	Mac-Thess	SE Adriatic	Thrace	W Aegean	N Ecoregions
<i>Alosa fallax</i>				+		+		2
<i>Anguilla anguilla</i>	+	+	+	+	+	+	+	7
<i>Atherina boyeri</i>	+		+			+		3
<i>Chondrostoma vardarense</i>				+		+		2
<i>Cyprinus carpio</i>				+		+		2
<i>Esox lucius</i>				+		+		2
<i>Gasterosteus gymmurus</i>			+			+		2
<i>Gobio bulgaricus</i>				+		+		2
<i>Knipowitschia caucasica</i>						+	+	2
<i>Pelagus stymphalicus</i>			+				+	2
<i>Perca fluviatilis</i>				+		+		2
<i>Rutilus rutilus</i>				+		+		2
<i>Salaria fluviatilis</i>	+	+	+			+		4
<i>Salmo farioides</i>			+		+			2
<i>Salmo macedonicus</i>				+		+		2
<i>Scardinius erythrophthalmus</i>				+		+		2
<i>Silurus glanis</i>				+		+		2
<i>Tinca tinca</i>				+		+		2
<i>Vimba melanops</i>				+		+		2



**Fig. 3:** Ecoregional species richness (translocated, alien, native and endemics).

that were the second most widespread translocated species in these ecosystems (Table 5).

#### ***Spatial patterns in fish species richness in Greek lentic ecosystems***

Most lentic ecosystems with high species richness were observed in the northern and western part of the country, while species-poor ecosystems were located in the southern part including also the islands of Ionian and Aegean seas as well as the island of Crete (Fig. 4).

Natural lentic ecosystems had higher mean species richness (mean  $\pm$  SD;  $8.20 \pm 7.50$ ) than artificial lentic ecosystems (mean  $\pm$  SD;  $5.31 \pm 5.01$ ). This pattern is also observed when the total richness between the 10 top natural and 10 top artificial lentic ecosystems is compared (Table 6).

More than half of the examined ecosystems with fish presence (106; 62.35%) hosted from one up to five species, while only eight lentic ecosystems (4.71%) hosted 20 or more species (Fig. 5). When only the native species were considered, 127 (74.71%) ecosystems hosted up to five species (Fig. 5). Surprisingly, only 13 ecosystems (7.65%) were free of alien or translocated species, while 92 (54.12%) had over 50% introduced species. The vast majority of the studied ecosystems (146; 85.88%) hosted up to five alien or translocated species.

#### ***Fish species conservation status***

Overall, 94 species of the taxa included in this checklist have been evaluated for their conservation status on the basis of criteria set by the IUCN Red List, the Greek Red Data Book and the EU Habitats Directive (92/43/EC). Based on the IUCN list, 35 species (37.23%) are under immediate extinction risk and are assigned to the threatened categories of CR ( $n = 10$ ), EN ( $n = 12$ ) and VU

( $n = 13$ ) (Fig. 6). Similarly, 34 species (36.17%) are considered threatened based on the Greek Red Data Book, while 49 species (52.68%) are included in the Annexes of the Habitats Directive (Appendix Table A1).

#### ***Main data sources and evaluation categorization***

The majority of the data evaluated during this study were of moderate or low validity and accuracy (Figure 7). Specifically, 72.35% of the main data sources for lentic ecosystems with fish presence were classified of moderate or low validity and accuracy since almost 50% of the information was derived only from non-scientific sources (administrative documents, personal communication with Fisheries Departments and local fishermen and, in some cases, from grey literature). High validity and accuracy data were derived mainly for large lakes that hosted fish, for some of which the data were derived from field samplings and research publications ( $n = 47$ ; 91.25%). Based exclusively on the high quality research studies, the overall knowledge was generated through five consequent decades, from 1970s until 2010s, with the last two decades contributing at almost 80% of the available knowledge. Most data sources for fishless ecosystems and unexploited ecosystems with doubtful fish occurrences were evaluated of low validity and accuracy (97.70%). For the majority of these ecosystems any information related to fish species was missing.

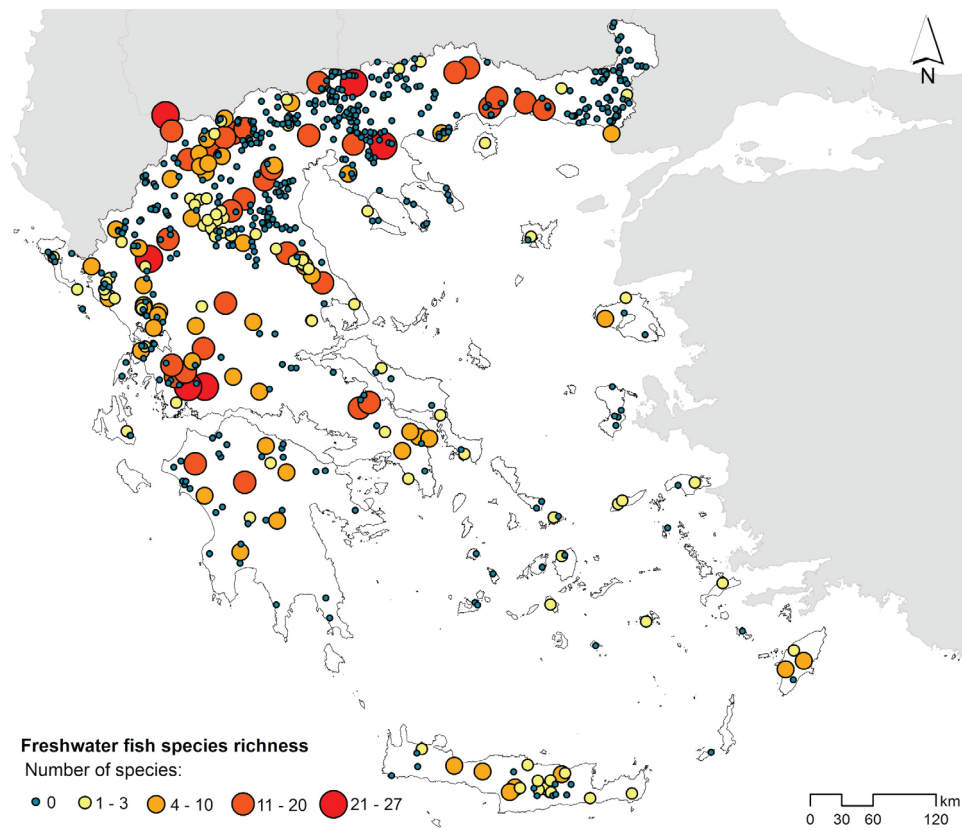
An overall evaluation of the main sources of information for all studied ecosystems ( $n = 650$ ), indicated that fish data were unavailable or non-existent, especially for small-sized lentic ecosystems (61.17%). For many systems, personal communications represented the main part of fish data sources (14.61%) (Fig. 8). Personal observations (35 sources; 5.01%), electrofishing, mainly with backpack devices along the shorelines of lentic ecosystems (29 sources; 4.15%), grey literature (28 sources; 4.01%) and the use of gill nets (25 sources; 3.58%) con-

**Table 4.** The most widespread native, translocated and alien fish taxa in Greek natural lentic ecosystems with fish presence (n = 54) ranked based on an ecoregional approach (from 1-10). Only confirmed records are presented in the table (i.e., excluding questionable or extirpated populations).

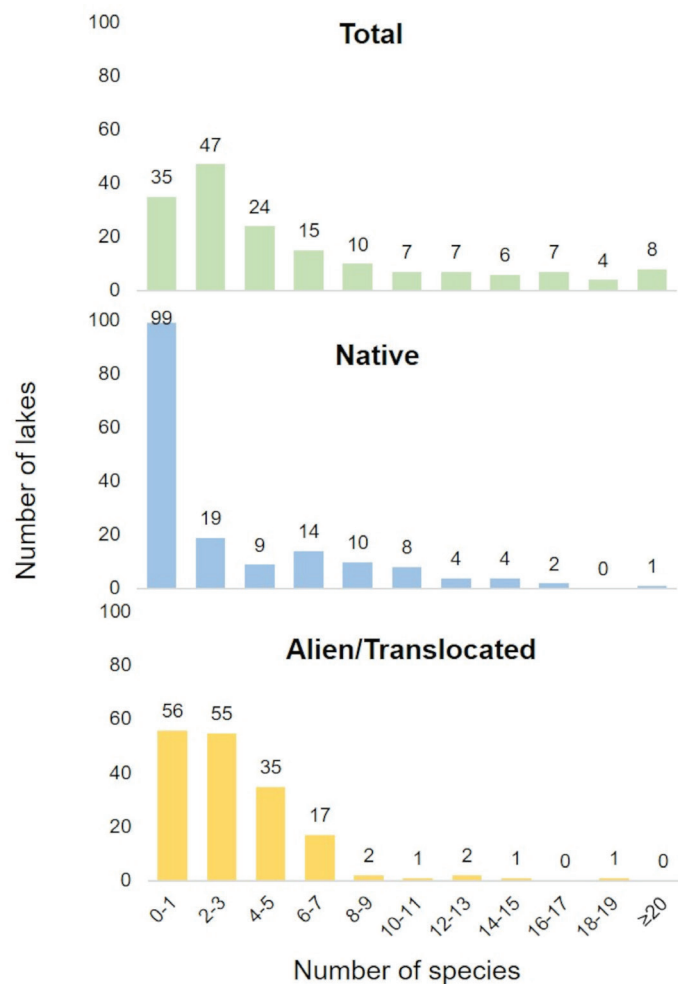
<b>Native species</b>	<b>Ecoregions</b>	<b>%</b>	<b>Lentic ecosystems</b>	<b>%</b>
<i>Anguilla anguilla</i>	4	57.14	17	31.48
<i>Atherina boyeri</i>	3	42.86	8	14.81
<i>Salaria fluviatilis</i>	3	42.86	4	7.41
<i>Cyprinus carpio</i>	2	28.57	7	12.96
<i>Esox lucius</i>	2	28.57	6	11.11
<i>Gobio bulgaricus</i>	2	28.57	4	7.41
<i>Perca fluviatilis</i>	2	28.57	4	7.41
<i>Rutilus rutilus</i>	2	28.57	8	14.81
<i>Scardinius erythrophthalmus</i>	2	28.57	4	7.41
<i>Tinca tinca</i>	2	28.57	5	9.26
<b>Translocated species</b>	<b>Ecoregions</b>	<b>%</b>	<b>Lentic ecosystems</b>	<b>%</b>
<i>Cyprinus carpio</i>	6	85.71	24	44.44
<i>Anguilla anguilla</i>	3	42.86	3	5.56
<i>Tinca tinca</i>	3	42.86	9	16.67
<i>Economidichthys pygmaeus</i>	2	28.57	3	5.56
<i>Silurus aristotelis</i>	2	28.57	4	7.41
<i>Silurus glanis</i>	2	28.57	3	5.56
<i>Cobitis hellenica</i>	1	14.29	1	1.85
<i>Perca fluviatilis</i>	1	14.29	4	7.41
<i>Rhodeus amarus</i>	1	14.29	2	3.70
<i>Rhodeus meridionalis</i>	1	14.29	3	5.56
<b>Alien species</b>	<b>Ecoregions</b>	<b>%</b>	<b>Lentic ecosystems</b>	<b>%</b>
<i>Gambusia holbrooki</i>	7	100.00	35	64.81
<i>Carassius gibelio</i>	6	85.71	23	42.59
<i>Pseudorasbora parva</i>	4	57.14	8	14.81
<i>Carassius auratus</i>	4	57.14	6	11.11
<i>Lepomis gibbosus</i>	3	42.86	9	16.67
<i>Oncorhynchus mykiss</i>	2	28.57	4	7.41
<i>Ameiurus cf. nebulosus</i>	1	14.29	1	1.85
<i>Coregonus sp.</i>	1	14.29	1	1.85
<i>Cyprinus cf. carpio (koi)</i>	1	14.29	1	1.85
<i>Poecilia latipinna</i>	1	14.29	1	1.85

**Table 5.** The most widespread native, translocated and alien fish taxa in Greek artificial lentic ecosystems with fish presence (n = 114) ranked based on an ecoregional approach (from 1-10). Only confirmed records are presented in the table (i.e., excluding questionable or extirpated populations).

<b>Native species</b>	<b>Ecoregions</b>	<b>%</b>	<b>Lentic ecosystems</b>	<b>%</b>
<i>Anguilla anguilla</i>	7	100.00	25	21.93
<i>Salaria fluviatilis</i>	3	42.86	7	6.14
<i>Chondrostoma vardareense</i>	2	28.57	9	7.89
<i>Rutilus rutilus</i>	2	28.57	9	7.89
<i>Pelagus stymphalicus</i>	2	28.57	7	6.14
<i>Salmo farioides</i>	2	28.57	7	6.14
<i>Vimba melanops</i>	2	28.57	7	6.14
<i>Gobio bulgaricus</i>	2	28.57	5	4.39
<i>Perca fluviatilis</i>	2	28.57	5	4.39
<i>Rhodeus amarus</i>	2	28.57	5	4.39
<b>Translocated species</b>	<b>Ecoregions</b>	<b>%</b>	<b>Lentic ecosystems</b>	<b>%</b>
<i>Cyprinus carpio</i>	7	100.00	69	60.53
<i>Perca fluviatilis</i>	3	42.86	9	7.89
<i>Silurus glanis</i>	3	42.86	7	6.14
<i>Squalius vardarensis</i>	2	28.57	2	1.75
<i>Esox lucius</i>	1	14.29	8	7.02
<i>Rutilus rutilus</i>	1	14.29	5	4.39
<i>Tinca tinca</i>	1	14.29	3	2.63
<i>Alburnus alburnus</i>	1	14.29	2	1.75
<i>Barbus balcanicus</i>	1	14.29	2	1.75
<i>Economidichthys pygmaeus</i>	1	14.29	2	1.75
<b>Alien species</b>	<b>Ecoregions</b>	<b>%</b>	<b>Lentic ecosystems</b>	<b>%</b>
<i>Gambusia holbrooki</i>	6	85.71	38	33.33
<i>Carassius gibelio</i>	6	85.71	36	31.58
<i>Carassius auratus</i>	6	85.71	18	15.79
<i>Oncorhynchus mykiss</i>	5	71.43	31	27.19
<i>Lepomis gibbosus</i>	5	71.43	23	20.18
<i>Pseudorasbora parva</i>	3	42.86	9	7.89
<i>Coregonus sp.</i>	2	28.57	2	1.75
<i>Cyprinus carpio (koi)</i>	2	28.57	2	1.75
<i>Ameiurus cf. nebulosus</i>	1	14.29	1	0.88
<i>Gymnocephalus cernua</i>	1	14.29	1	0.88



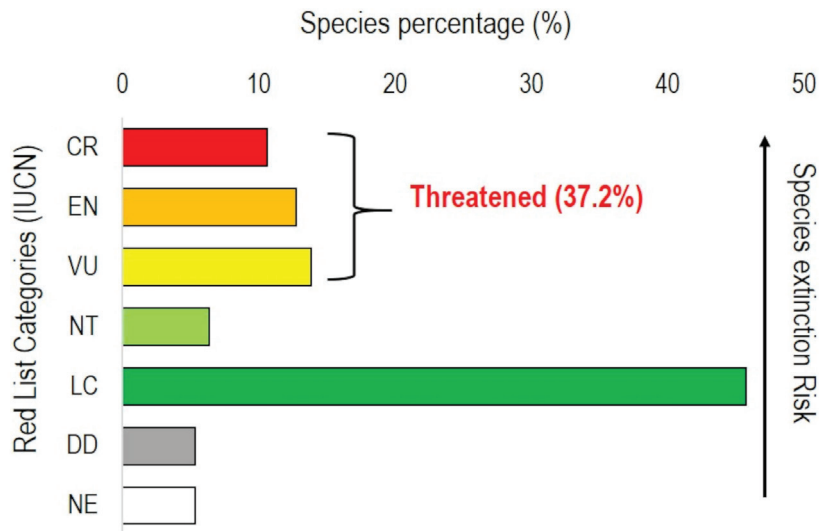
**Fig. 4:** Freshwater fish species richness in lentic ecosystems of Greece.



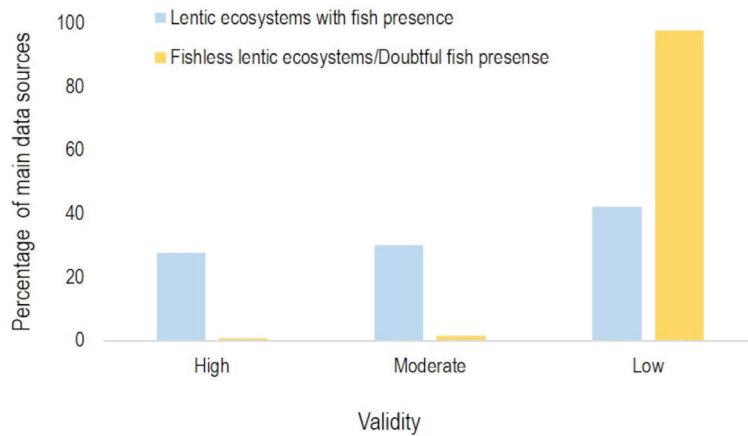
**Fig. 5:** Frequency distribution of species richness in Greek lentic ecosystems (all species, Native and Alien/Translocated species).

**Table 6.** The top-10 natural and artificial Greek lentic ecosystems based on total, native and non-indigenous (translocated and alien) richness of fish taxa. Mean richness and standard deviation in parentheses are also given for the entire dataset of the studied ecosystems with fish presence (natural = 54, artificial = 116). Fish taxa with questionable or extirpated populations are also included.

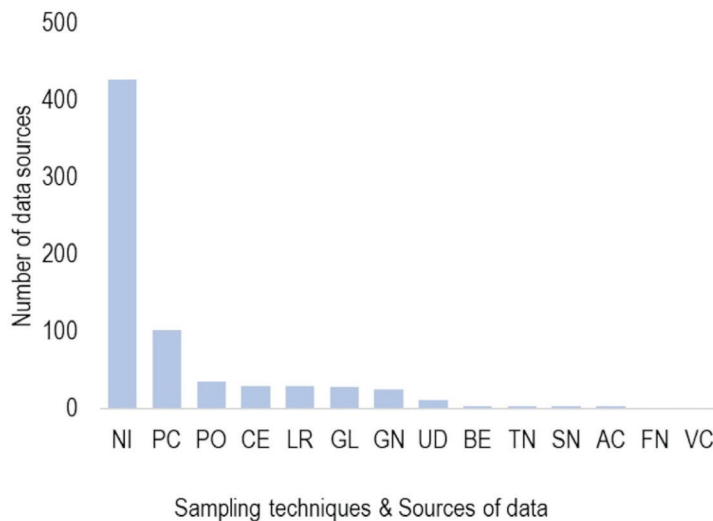
Top 10 Natural lentic ecosystems			Top 10 Artificial lentic ecosystems		
T o t a l r i c h n e s s					
Lake	Ecoregion	N of taxa	Lake	Ecoregion	N of taxa
Volvi	Thrace	27	Kerkini	Thrace	23
Megali Prespa	SE Adriatic	25	Polyfytos	Mac-Thess	19
Trichonis	Ionian	23	Eleousa	Mac-Thess	19
Pamvotis	Ionian	22	Karla	Mac-Thess	18
Lysimachia	Ionian	21	Platanovrysi	Thrace	17
Vegoritisi	Mac-Thess	20	Thisavros	Thrace	17
Doirani	Mac-Thess	20	Tavropos (Plastira)	Ionian	17
Mikri Prespa	SE Adriatic	18	Girtonis	Mac-Thess	16
Alatza Giola	Thrace	16	Sfikia	Mac-Thess	15
Ozeros	Ionian	16	Kremasta	Ionian	15
Mean richness of top-10 (taxa/system)		20.8 (3.61)			17.6 (2.36)
Mean richness (in 170 systems)		8.2 (7.50)			5.31 (5.01)
N a t i v e r i c h n e s s					
Lake	Ecoregion	N of taxa	Lake	Ecoregion	N of taxa
Volvi	Thrace	20	Kerkini	Thrace	15
Trichonis	Ionian	16	Karla	Mac-Thess	14
Doirani	Mac-Thess	16	Eleousa	Mac-Thess	14
Lysimachia	Ionian	14	Polyfytos	Mac-Thess	12
Alatza Giola	Thrace	12	Girtoni	Mac-Thess	12
Vistonis	Thrace	12	Agras	Mac-Thess	11
Ozeros	Ionian	11	Platanovrysi	Thrace	10
Ismarida	Thrace	11	Thisavros	Thrace	10
Megali Prespa	SE Adriatic	10	Toxotes	Thrace	10
Vegoritisi	Mac-Thess	10	Ilarionas	Mac-Thess	9
Mean richness (taxa/system)		13.2 (3.25)			11.7 (2.05)
Mean richness (in 170 systems)		4.59 (4.97)			2.48 (3.85)
N o n - i n d i g e n o u s r i c h n e s s					
Lake	Ecoregion	N of taxa	Lake	Ecoregion	N of taxa
Pamvotis	Ionian	18	Tavropos (Plastira)	Ionian	12
Megali Prespa	SE Adriatic	15	Kerkini	Thrace	8
Kastoria	Mac-Thess	12	Platanovrysi	Thrace	7
Vegoritisi	Mac-Thess	10	Polyfytos	Mac-Thess	7
Mikri Prespa	SE Adriatic	9	Thisavros	Thrace	7
Trichonis	Ionian	7	Perdika	Mac-Thess	7
Volvi	Thrace	7	Kremasta	Ionian	7
Lysimachia	Ionian	7	Aoos springs	SE Adriatic	7
Chimaditis	Mac-Thess	7	Marathona	W Aegean	7
Yliki	W Aegean	6	Sfikia	Mac-Thess	6
Mean richness (taxa/system)		9.8 (4.02)			7.5 (1.64)
Mean richness (in 170 systems)		3.61 (3.69)			2.83 (2.13)



**Fig. 6:** Fish species in lentic ecosystems of Greece assigned to a threatened category status according to the Red List of IUCN (2021). CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Low Concern, DD: Data Deficient, NE: Non-Evaluated.



**Fig. 7:** The validity of all available information used in the current study, for lentic ecosystems with fish presence and ecosystems that are fishless or with doubtful fish occurrence.



**Fig. 8:** Sampling techniques and main sources of retrieved data concerning the current study (NI: No Information, PC: Personal Communication, PO: Personal Observations, CE: Coastal Electrofishing, LR: Literature Review, GL: Grey Literature, GN: Gill Nets, UD: Unpublished Data, BE: Boat Electrofishing, TN: Trammel Nets, SN: Scoop Nets, AC: Anglers Catch, FN: Fyke Nets, VC: Visual Censuses).

tributed at similar shares to the knowledge basis (Fig. 8). Finally, data originating using trammel nets, boat electro-fishing, scoop nets and anglers' catches contributed at a limited scale (3 sources; 0.42%, Fig. 8).

## Discussion

This study provides the first extensive inventory of freshwater fishes in lentic ecosystems in Greece. It covered not only large lakes, the fish fauna of which is currently well known, but also many smaller lentic ecosystems, which have seldom been examined for fish in previous research studies (e.g., Zalidis & Mantzavelas, 1994; Economou *et al.*, 2007; Koutsikos *et al.*, 2012; Economou *et al.*, 2016). Indeed, the amount and quality of information were unevenly distributed across lentic systems differing in type and size. Complete or nearly complete species lists have been compiled only for some of the largest lakes, especially those in which research projects have been implemented (e.g., lakes Trichonis, Volvi and Prespa). This perception, however, is now changing. Ongoing research and review studies increasingly highlight the social and ecological value of small lentic ecosystems and point to the need for conservation and management actions (Downing, 2010; Boix *et al.*, 2012; Bolpagni *et al.*, 2019; Fitoka *et al.*, 2020).

Since the 1950s, the number of large reservoirs has been constantly increasing in Greece, displaying the highest peak in the 2000s (Greek Committee on Large Dams, 2013). In addition, numerous artificial ponds were recently mapped throughout the country (Fitoka *et al.*, 2020), highly exceeding the numbers of previous catalogs (Gerakis & Tsiouris, 2010). Of the 650 water bodies included in the present study, 501 (77%) are artificial, signifying the extent of the drastic interventions that have been incurred to natural ecosystems to meet human needs (i.e., irrigation, urban water supply, hydroelectricity production, etc.). As indicated, many of these artificial systems are "invasion hotspots", from which alien species may subsequently spread to natural systems. In addition, some of these systems include threatened fish species of high conservation value. More research is needed to increase the level of knowledge on artificial lentic systems, especially those which are small in size. In this context, it should be noted that artificial habitats are not explicitly considered for conservation and management by the EU Habitats Directive (1992), which is primarily concerned with natural and semi-natural habitats (European Commission, 2013, 2018). However, liberal interpretations of the Directive's rules and requirements, suggest that artificial habitats need not be excluded from the site designation and management processes if, on a case-by-case basis, it can be demonstrated that they are of outstanding conservation interest (e.g., they host species of special community concern, see McLeod *et al.*, 2009; Bastmeijer 2016). Moreover, large reservoirs have been designated as water bodies according to the Water Framework Directive (EU, 2000). In this context, management measures should be in place to ensure at least their good ecological

potential. Hence, the ecological importance of these artificial waters should not be underestimated, as they often sustain high levels of biological diversity, providing habitat to many species which also occur in natural lakes. Thus, they should be appropriately managed to prevent ecological deterioration, maintain or enhance habitat quality and support human needs (Irz *et al.*, 2006; Fischer & Quist, 2019; Guo *et al.*, 2021).

This study provides an up-to-date national checklist for freshwater fish species of natural as well as artificial lentic ecosystems in Greece, by incorporating and scrutinizing all the related available information. The ultimate objective of this checklist is to coordinate and disseminate basic taxonomic and spatial information of the freshwater fish occurring in Greek lentic ecosystems that are commonly required by a range of users (e.g., policy makers, stakeholders, researchers). Many studies have reported that biological information is not always systematically explored or utilized properly in decision making (Hering, 2016; Schmidt-Kloiber & De Wever, 2018; Sutherland *et al.*, 2019; 2020; Grainger *et al.*, 2020). Insufficient information (quantitative and qualitative), or the inaccessibility of existing information, can affect research strategies, policy decisions on management priorities, research funding and conservation actions. It has been acknowledged that organizing and accurately evaluating the existing biological information (Sutherland *et al.*, 2019), as well as disseminating research results (Hering, 2016) may be more useful for tackling crucial ecological questions and protecting biodiversity compared to funding more new research projects, which are not scientifically substantiated. In the past, incomplete and/or inaccessible information on fish species' distributions of Greece hindered the timely evaluation of areas of high conservation value and their inclusion in the Natura 2000 protected area framework. Greece lacks specific distribution delineations from many aquatic species, even species of high conservation interest (Vavalidis *et al.*, 2021; but see also Pafilis, 2020). Moreover, the current checklist is expected to contribute to species conservation by supporting baseline knowledge to assist in prioritizing areas hosting species in need of protection according to the national legislation. However, the Greek legislation for biodiversity conservation is not functional in practice and has been criticised for weak enforceability and transparency issues (Apostolopoulou & Pantis 2009; Apostolopoulou *et al.*, 2014; Vokou *et al.*, 2014; YPEKA, 2014; Frederiksen *et al.*, 2017; Paliogiannis & Koedam, 2019). Provisions for species conservation were first introduced by legislation dating back to 1981 (Presidential Decree 67/1981) which still constitutes the main legal framework for the protection of the native fauna and flora of Greece. However, the decree has not been revised in the 40 years since its enactment and is now outdated. The long-awaited revised catalog of species to be protected has not yet been compiled, and this seriously hampers the design of species conservation plans (YPEKA, 2014). Eventually, the protection offered to species under the national legislation is only nominal. As the rules now stand, strategy and actions for species conservation have to rely more on EU than on



national legal and policy instruments.

### ***The ichthyological profile of Greek lentic ecosystems***

Greece holds a unique fish fauna diversity within Europe and displays one of the highest levels of freshwater fish endemism in the peri-Mediterranean region (Darwall *et al.*, 2014; Barbieri *et al.*, 2015). The latter is mainly attributed to the complex geological processes of the wider area of the Balkan Peninsula which has allowed repeated fish species colonizations since the Miocene, long-term survival of ancient taxa in aquatic refugia and isolated ecosystems, and enhanced speciation due to persisting biogeographical barriers (Economidis & Banarescu, 1991; Zogaris & Economou, 2017). According to the most recent checklist referring both to lentic and lotic inland ecosystems (Barbieri *et al.*, 2015), 160 fish species have been recorded in the freshwater ecosystems of Greece, 137 of which are native. Based on Barbieri *et al.* (2015), the country presents a substantial proportion of country-specific endemics, 47 in total (34.3% of the native fish fauna). A further 11.67% (16 species) of the recorded freshwater fishes are characterised as “near-endemic”; By excluding aliens (23 species), the percentage of endemic and near-endemic species rises to 55.26%. Finally, 51 fish species (31.87%) that have been recorded from Greece are classified as threatened at a global scale by the IUCN (2021).

In this study, 122 fish taxa were recorded including species with doubtful/unconfirmed occurrences or even with possibly extirpated populations. Considering however the limited available field data and the observed uncertainty regarding species taxonomy, it is highly expected that further field research will reveal higher diversity (*sensu* Essl *et al.*, 2018). Moreover, the fact that in more than 2/3 of the examined ecosystems ( $n = 342$ ; 71.25%) fish presence was either questionable or the knowledge regarding the taxonomy of the species was limited, reveals the high knowledge gap regarding species richness in Greek lentic ecosystems.

Cyprinids being the most widespread native species was not surprising, considering the family's total species number. Similarly, the wide distribution of the native species *A. anguilla* and *L. albanicus* in Greek lentic ecosystems was expected, due to their migratory life history strategies that enable them to spread between lotic and lentic environments. However, these species are highly threatened due to man-made barriers which disrupt their dispersal. Therefore, relating the connectivity between lotic and lentic environments is critically important and should be a conservation priority, since many species depend to these interconnections to fulfill their life cycles. The most widespread translocated species was by far *C. carpio* being widely recorded outside of its native distributional range (i.e., according to Economidis (1991) common carp is assumed to be native in Macedonia-Thessaly and Thrace). The spread of carp is a result of recurring stocking from local fisheries authorities, professional fishermen and anglers triggered by their

economic value and recreational importance. In several cases, stocking with carps is undocumented, includes different cultured-domesticated varieties of foreign origin and, more crucially, occurs without any scientific supervision or any justification that it is needed to enhance carp populations. As a result, many unintentional introductions of alien species occur due to unsupervised carp fry stocking; these include *C. gibelio*, *Carassius auratus*, *Pseudorasbora parva* and *Lepomis gibbosus* which can negatively affect native biota and ecosystem functioning (Perdikaris *et al.*, 2012; Copp *et al.*, 2017; Villizi *et al.*, 2019). According to our data, *C. carpio* and *C. gibelio* co-occur in almost 88% of the lentic ecosystems where the latter is recorded. The wide distributional expansion of the highly invasive alien *C. gibelio* was also revealed in this study, since it was recorded in 57 lentic ecosystems, in distinction with a former study reporting that this species is naturalized in 26 ecosystems including also rivers (Perdikaris *et al.*, 2012). In our study, the high spreading tendency of the eastern mosquitofish *G. holbrooki* (extensively stocked for malaria control since the 1920s, Livadas & Sfagos, 1940) was confirmed, being the most widespread alien species in Greek lotic (Koutsikos *et al.*, 2019a) and lentic ecosystems. The majority of the most widespread alien species recorded during this study have been the commonest invasive fish species in Europe as well as worldwide (Savini *et al.*, 2010; Nunes *et al.*, 2015; Toussaint *et al.*, 2016), such as *L. gibbosus* and *P. parva*, that are regarded as highly invasive and therefore have been included in the 2019 updated Union List of the EU IAS Regulation (European Commission, 2019). Alien fish species richness within the Greek lentic ecosystems can be considered relatively high, compared to the number of alien species introduced in the lotic ecosystems of the country (Koutsikos *et al.*, 2019a). However, nearly half of the 24 recorded alien species have not been reported in recent years, specifically those that depend on deliberate (stocking) or accidental releases (aquaculture escapes). With the exception of *O. mykiss*, which is repeatedly stocked for recreational purposes while in addition its natural reproduction can not be excluded (Stoumboudi *et al.*, 2017; Koutsikos *et al.*, 2019b), the majority of the following species have been possibly extinct or exist in very low numbers into the wild being unable to establish reproductive populations in Greece: *Acipenser baerii*, *Acipenser gueldenstaedtii*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Hypophthalmichthys nobilis*, *Oncorhynchus kisutch*, *Parabramis pekinensis*, *Polyodon spathula*, *Pygocentrus nattereri*, *Salmo* cf. *trutta*, *Salmo letnica* and *Salvelinus fontinalis*. The high recorded number of alien species proves the wide extend of species introductions and stockings that took place throughout the last decades in Greek lentic ecosystems without any governmental or scientific coordination (Crivelli *et al.*, 1997; Economidis *et al.*, 2000; Economou *et al.*, 2001; Koutsikos *et al.*, 2021). Moreover, it highlights the necessity to undertake actions to prevent further uncontrolled introductions and minimize the expansion of invasive species. In this framework, public awareness initiatives (including environmental education) and lim-

nological-ichthyological-conservation research should be set as priorities.

Species richness and endemism levels differed among Greece's ecoregions as well as between natural and artificial ecosystems. Habitat diversity, environmental stability as well as basin surface area and mean altitude have been shown to affect species richness at local and regional scales (Economou *et al.*, 2007). Differences of species richness between natural and artificial ecosystems are also attributed to a combination of historical, geomorphological and ecological factors, an issue that will be thoroughly discussed in follow-up work. Between ecoregions, the highest species richness was observed in the Ionian, Macedonia-Thessaly and Thrace ecoregions which collectively include the most extensive freshwater aquatic networks and the most diverse fish fauna. On the other hand, insular species richness is significantly lower due to isolation, drought and water abstraction, suggesting that the probability of extinction is more likely in small ecosystems. Conversely, given that many small-sized lentic artificial systems are relatively newly-constructed, there is an opportunity to exploit their empty niches as refugia for the insular limnophilic ichthyofauna. A similar trend to richness (i.e., northward/westward increase) was also evident in endemism patterns. Endemism level was highest in Macedonia-Thessaly followed by the Ionian and SE Adriatic ecoregion. Interestingly, the latter comprised only by three lakes (Prespa Lakes and Aaos springs reservoir) indicating the high levels of endemism and confirming that: a) the isolated ancient Balkan lakes have strongly contributed to regional speciation and endemism (Albrecht & Wilke, 2008; Zogaris & Economou, 2017) and b) generally large-size lake ecosystems are historically less prone to extirpations (Bolpagni *et al.*, 2019). Nevertheless, endemics of conservation priority (i.e., locally restricted, endangered species) were present in most ecoregions (with the exception of the island of Crete), thus in need of the particular attention of the scientific community, policy makers and the local communities.

Based on the IUCN Red List, Greece hosts the highest number of freshwater fish species under a threatened status and the most critically endangered species of the Mediterranean countries (IUCN, 2021). The large number of threatened species (35 taxa) recorded in Greek lentic ecosystems indicates the need to protect their populations and habitats. Many of these species are often restricted to a small number of ecosystems or even to a single lake (*Alburnus macedonicus*, *Alburnus vistonicus*, *Alburnus volviticus*, *Cobitis arachthosensis*, *Cobitis hellenica* and *Pelagus epiroticus*) often co-occurring with high numbers of non-indigenous fish species (Koutsikos *et al.*, 2021). Despite the high number of threatened species in Greece, limited science-based concrete conservation actions have been applied, mainly confined to conducting conservation translocations (Paschos *et al.*, 2003; Zogaris *et al.*, 2017; Kalogianni *et al.*, 2019). Several European fish species face the threat of extinction as their populations are severely decreasing (IUCN, 2021). One of the most prominent examples concerns the species *A.*

*anguilla*, which is heavily impacted by overharvesting, pollution and connectivity losses, leading to its listing as CR species by IUCN (Freyhof & Kottelat, 2010). At the regional/local scale, the native *Alosa vistonica* is now confirmed as extinct in Lake Vistonis, as it has not been recorded since the early 1990s, due to hydrological degradation, salinity changes and pollution (Barbieri *et al.*, 2015). The chub *Squalius moreoticus* in Lake Stymphalia is also likely to be extirpated, since the lake completely dried during an extreme drought event that occurred in the early 1990s (Economou *et al.*, 2007; Barbieri *et al.*, 2015). In addition, introductions with chub species from other basins that were conducted after the drought event in Lake Stymphalia, minimizes the possibility elucidating the taxonomic status of this species. Similarly, the endemic *Pelagus epiroticus* once forming large populations in Lake Pamvotis, displayed a declining tendency in the 1980s that led to its population collapse in the mid-2000s (Leonardos *et al.*, 2005; Perdikaris *et al.*, 2005). Until recently, this species was considered as extirpated from the lake. However, according to unpublished data it was re-captured during 2020 by local fishermen under the framework of a research project targeting to assess its current population status (Leonardos *et al.*, 2020), thus we have included it in our checklist. Despite this positive update, genetic analysis is needed to verify the continued presence of this species, since the lake is inhabited by another minnow that was translocated there in the late 1990s (Leonardos *et al.*, 2007). Finally, the annual catches of large-sized commercial species, such as wels, pikes and tench have declined since the mid-1980s due to habitat degradation and overexploitation (Leonardos, 2016), leading in some cases to local extirpations.

#### **Sources of bias, data availability, knowledge gaps and unmet needs**

Undeniably, quantitative data from a sufficient number of representative samplings are of highest value when compiling species checklists. However, this type of data is usually scarce and, in most cases, non-existent, especially for small-sized lakes. In this study, we inevitably used all the available data, despite their high heterogeneity in terms of completeness, accuracy and the provided quantitative information. For the majority of the studied ecosystems, we were obliged to rely on references from previous studies which in turn may have referred to former ones; thus, it was not always easy to objectively evaluate in terms of data quality or record confirmation. For instance, we rejected historical information given by Leake (1835) for lakes Pamvotis and Kastoria since the information provided was impossible to be cross-checked and confirmed by another source. This indiscriminate use of historical information may create ambiguities in several cases. One such example is the case of species that demonstrate rheophilic ecological requirements which had been historically reported as present in many lentic ecosystems (e.g., barbels, nases and gudgeons). These species may have a wide distribution and high abundanc-

es in streams within their distribution range, and obviously also occur in river mouths around lakes. However, they rarely occur within lakes where they have a sporadic presence and are mainly restricted to river's outflows entering a lake, with the possible exception of very small lentic ecosystems. These species appear in our dataset in a heterogeneous way (i.e., in some natural lakes they appear as present, in some with a special notation (e) and in others without notation), based on whether their presence was confirmed by recent sampling data or not (e.g., *Barbus prespensis* in Lake Mikri Prespa; Petriki, 2015).

It is well established that bibliographic data usually overestimates the total species richness of an ecosystem since species that were once reported could afterwards have become extinct (Koutsikos *et al.*, 2021). This was confirmed in the present study as the majority of the alien fish species recorded (i.e., *A. baerii*, *A. gueldenstaedtii*, *C. idella*, *H. nobilis*, *O. kisutch*, *O. mykiss*) are currently presumed as extirpated from the studied ecosystems. However, proving that a taxon is indeed extinct from the wild, requires exhaustive surveys in expected habitats, at appropriate periods which in the case of lentic ecosystems of Greece these surveys are missing. The absence or extirpation of species is difficult to be ascertained, especially when the data are derived from limited field samplings in specific habitats, by using one or few gears. In our study, when the data on absences could not be verified by an independent source, we decided to keep the account of absence as reported by the original source. We acknowledge the limitations of our dataset, which stem primarily from the paucity of complete and reliable information. For instance, for some lentic systems, even large ones (e.g., the artificial reservoirs of Evinos, Smokovo, Sfikia, Assomata) information was extremely limited or almost entirely lacking. Therefore, such data should be used with caution in future bibliographic research and relevant analyses and only after extensive cross-checking to avoid misleading results. We contend, that some errors and omissions could have crept in our inventory, which we consider as a baseline study that will be completed and improved when additional data will be available.

Despite the nationwide geographical coverage of this study, several small-sized lentic ecosystems in the continental part of the country (i.e., temporary ponds and small artificial reservoirs, see Fitoka *et al.*, 2020) as well as in the islands (e.g., in Kerkyra, Crete, Euboea), were not included in our dataset. A specific area of lake ecosystem ecology where research has so far been limited is on artificial lentic systems. Scientific information for these systems was extremely scanty and almost exclusively confined to the largest man-made lakes (e.g., lakes Kerkini and Tavropos). Small artificial water bodies have rarely been the focus of scientific attention. When such information was available, it was usually partial (i.e., referred only to species of commercial importance, e.g., carps), sometimes inconsistent among sources, and often was the by-product of research undertaken with anthropogenic perspectives (e.g., fisheries, aquaculture). To fill this knowledge gap, this study sought to explore alternative sources of information to get at least an approxi-

mate picture of the species composition in such systems. Effectively, most information on small reservoirs and ponds provided in this study was obtained through laborious web searching and personal communications, thus inevitably there is a great deal of uncertainty associated with it. All these primarily small systems, either natural or artificial, should be particularly considered in future field studies for cryptic or human-mediated fish diversity. This is becoming more apparent considering the increasing appreciation of such systems as valuable by anglers, which is expected to further increase the unregulated stockings (Konstantinidis *et al.*, 2018).

Taxonomy represents a perpetual research endeavor or given the great opportunities provided by the recent advances in molecular methods and new taxonomic approaches. Several species have changed scientific names in the last two decades in Greece (Vavalidis *et al.*, 2019) and some are still difficult to be identified in the field. The *Carassius* species complex (i.e., *C. auratus*, *C. gibelio*, *Carassius carassius*, *Carassius langsdorfii*) is a notable example of taxonomic difficulty resulting in identification confusions in the field and also systematic and genetic debate (Kalous *et al.*, 2012; Rylková *et al.*, 2013). Therefore, it cannot be ruled out that some populations e.g., of Prussian carps could be wild-forms of goldfish and *vice versa* (e.g., in the island of Crete). Similarly, small gobiids such as *Knipowitschia* spp. require taxonomic skills and molecular assessment in the laboratory, thus their taxonomy in several lentic ecosystems is still far from complete in several lakes (see Vukić *et al.*, 2016, 2017). The provenance and taxonomy of isolated populations of *Knipowitschia* on certain wetlands are still pending (Vanhove *et al.*, 2011, 2016; Koutsikos *et al.*, 2019a) as well as for some isolated lake populations (e.g., lakes Ozeros and Voulkaria (Barbieri *et al.*, 2015). Another example of taxonomic uncertainty presented in Barbieri *et al.* (2015) is the Greek bitterling which was recently split into two species, *Rhodeus meridionalis* in Macedonia-Thessaly ecoregion and *Rhodeus amarus* in Thrace ecoregion (Bohlen *et al.*, 2006). According to Bryja *et al.* (2010) the bitterling population in Lake Volvi is genetically different from both *Rhodeus* species present in Greece; however, Geiger *et al.* (2014) could not demonstrate strong genetic distinction among populations inhabiting water bodies of northern Greece and called all populations *R. meridionalis*. The provenance of *Rhodeus* population in Prespa lakes remains unclarified. Crivelli *et al.* (1997) and Talevski *et al.* (2009) refer to the Prespa Lakes populations as *R. amarus*, while Krstić (2012) refers to this population as introduced. Furthermore, the endemic small bleak *Alburnus* sp. Volvi, is under taxonomic revision since it is genetically distinct from the other *Alburnus* species, including its sympatric *A. volviticus* in the Lake Volvi basin (Geiger *et al.*, 2014). Likewise, *Squalius* populations that have been introduced in Marathona reservoir and Stymphalia Lake, require genetic and morphological studies to clarify their taxonomic status.

Despite its drawbacks and limitations, the present study can inform policy makers on the necessity to draft and implement action plans for threatened fish species. In

cases of species with unresolved provenance or taxonomic status, relevant policies should suggest the application of precautionary actions, especially for localized taxa, pending taxonomical classification. Additionally, it can contribute in designing biologically-based fisheries management and serve to update relevant policies concerning lake and catchment area management. In this respect, the present study could contribute to a holistic national lake-river-wetland-estuary/lagoon conservation and management plan for fish species. By involving fish fauna in all domains of aquatic research, can balance/reverse the general view that conservation efforts (and economic resources) should be directed with priority to iconic and/or flagship animal species. In addition, such an inclusive and updated database is a necessary precondition for ecologists and water managers to identify trends of invasive species, using invasiveness screening and risk assessment tools for particular (microscale) risk assessment areas, to apply measures to combat the spread of invasive alien species and to disseminate robust information to regulators, the scientific community and general public. Ideally such species checklists should be made publicly available electronically (uploaded on a website) where one institution, organization or public agency should be responsible for the coordination and frequent updating of these lists.

Finally the fact that personal communication was a major source of our data reveals the need to more actively incorporate citizen science into environmental protection. This could assist in better research planning and be the first step to incorporate civic engagement and community involvement to environmental management which are essential to achieve high protection goals (Wagenet & Pfeffer, 2007). Within this framework, the possibility of conducting extensive interview surveys and the use of an online data collection application should be further explored.

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## Supplementary Data

The following supplementary information is available online for the article:

**Fig. S1:** Locations of lentic ecosystems which were fishless or fish presence data was unavailable (see also Table S1).

**Fig. S2:** Locations of lentic ecosystems with fish presence in Thrace Ecoregion. Numbers correspond to those presented in Table A2.

**Fig. S3:** Locations of lentic ecosystems with fish presence in the northern part of Macedonia - Thessaly Ecoregion. Numbers correspond to those presented in Table A3 and in part of Table A4.

**Fig. S4:** Locations of the studied lentic ecosystems with fish presence in the southern part of Macedonia - Thessaly Ecoregion. Numbers correspond to those presented in part of Table A4 and in Table A5.

**Fig. S5:** Locations of lentic ecosystems with fish presence in the Southeastern Adriatic Ecoregion. Numbers correspond to those presented in Table A6.

**Fig. S6:** Locations of lentic ecosystems with fish presence in the northern part of Ionian Ecoregion. Numbers correspond to those presented in Table A7 and in part of Table A8.

**Fig. S7:** Locations of lentic ecosystems with fish presence in the southern part of Ionian Ecoregion. Numbers correspond to most of those presented in Table A8.

**Fig. S8:** Locations of lentic ecosystems with fish presence in the western part of Western Aegean Ecoregion. Numbers correspond to most of those presented in Table A9.

**Fig. S9:** Locations of lentic ecosystems with fish presence in the eastern part of Western Aegean Ecoregion. Numbers correspond to some of those presented in Table A9.

**Fig. S10:** Locations of lentic ecosystems with fish presence in the Eastern Aegean Ecoregion. Numbers correspond to those presented in Table A10.

**Fig. S11:** Locations of lentic ecosystems with fish presence in the Cretan Ecoregion. Numbers correspond to those presented in Table A11.

**Table S1.** The main sources of retrieved data and the validity and accuracy evaluation for each lentic ecosystem included in this study (H = High, M = Moderate, L = Low, CE = Coastal electrofishing; BE = Boat electrofishing; TN = Trammel nets; GN = Gill nets; FN = Fyke nets; SN = Scoop nets; VC = Visual censuses; AC = Anglers catch; PC = Personal communication; PO = Personal observations; LR = Literature review; GL = Grey literature; NI = No info; UD = Unpublished data). The question mark (?) denotes lakes where there is no info about the presence of fish species, zero (0) denotes fishless lakes, one (1) denotes lakes where fish species are present and their taxonomic status is known and one f (1f) denotes lakes where fish species are present but their taxonomic status is unknown. Lake names sorted in alphabetical order.



## Appendix

**Table A1.** Checklist of the freshwater fish species in lentic ecosystems of Greece. CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Low Concern, DD: Data Deficient, NE: Non-Evaluated. Abbreviations in brackets [ ] denote species included in the corresponding category (IUCN or Habitats Directive), whose Greek populations are, however, introduced (e.g., *Acipenser gueldenstaedtii* that is included in the Habitats Directive, but introduced to Greece, is marked with [Y]), while the asterisk (\*) denotes native species that have only introduced populations in Greek lentic ecosystems.

a/a	Species	Authority	Common name	IUCN	Red Data Book	Habitats Directive	Endemicity
<b>Acipenseridae</b>							
1	<i>Acipenser gueldenstaedtii</i>	Brandt & Ratzeburg, 1833	Russian sturgeon	[CR]	-	[YES]	Alien
2	<i>Acipenser baerii</i>	Brandt, 1869	Siberian sturgeon	[EN]	-	[YES]	Alien
3	<i>Acipenser naccarii</i>	Bonaparte, 1836	Adriatic sturgeon	CR	NE	YES	Native*
<b>Anguillidae</b>							
4	<i>Anguilla anguilla</i>	(Linnaeus, 1758)	European eel	CR	NT	NO	Native
<b>Atherinidae</b>							
5	<i>Atherina boyeri</i>	Risso, 1810	Big-scaled sand smelt	LC	LC	NO	Native
<b>Blennidae</b>							
6	<i>Salaria economidisi</i>	Kottelat, 2004	Trichonis blenny	CR	LC	NO	Endemic
7	<i>Salaria fluviatilis</i>	(Asso, 1801)	Freshwater blenny	LC	LC	NO	Native
<b>Centrarchidae</b>							
8	<i>Lepomis gibbosus</i>	(Linnaeus, 1758)	Pumpkinseed	[LC]	-	[NO]	Alien
<b>Cichlidae</b>							
9	<i>Tilapia</i> sp.			-	-	-	Alien
<b>Clupeidae</b>							
10	<i>Alosa fallax</i>	(La Cepède, 1803)	Twaite shad	LC	DD	YES	Native
11	<i>Alosa macedonica</i>	(Vinciguerra, 1921)	Macedonian shad	VU	VU	YES	Endemic
12	<i>Alosa vistonica</i>	Economidis & Sinis, 1986	Thracian shad	CR	CR	YES	Endemic
<b>Cobitidae</b>							
13	<i>Cobitis arachthosensis</i>	Economidis & Nalbant, 1996	Arachthos spined loach	EN	EN	YES	Endemic
14	<i>Cobitis hellenica</i>	Economidis & Nalbant, 1996	Louros spined loach	EN	VU	YES	Endemic
15	<i>Cobitis meridionalis</i>	Karaman, 1924	Prespa spined loach	VU	VU	YES	Near Endemic
16	<i>Cobitis stephanidisi</i>	Economidis, 1992	Velestino spined loach	CR	CR	YES	Endemic
17	<i>Cobitis strumicae</i>	Karaman, 1955	Struma spined loach	LC	LC	YES	Endemic S. Balkans
18	<i>Cobitis trichonica</i>	Stephanidis, 1974	Trichonis spined loach	EN	LC	YES	Endemic
19	<i>Cobitis vardarensis</i>	Karaman, 1928	Vardar spined loach	LC	LC	YES	Endemic S. Balkans

*Continued*

Table A1 continued

a/a	Species	Authority	Common name	IUCN	Red Data Book	Habitats Directive	Endemicity
20	<i>Sabanejewia balcanica</i>	(Karaman, 1922)	Balkan golden loach	LC	LC	YES	Endemic S. Balkans
<b>Coregonidae</b>							
21	<i>Coregonus</i> sp.	Linnaeus, 1758	Whitefish	-	-	-	Alien
<b>Cyprinidae</b>							
22	<i>Abramis brama</i>	(Linnaeus, 1758)	Common bream	LC	LC	NO	Native
23	<i>Alburnoides prespensis complex</i>		Prespa spiralin species complex	-	-	-	Endemic S. Balkans
24	<i>Alburnoides prespensis</i>	(Karaman, 1924)	Prespa spiralin	VU	VU	NO	Endemic S. Balkans
25	<i>Alburnoides strymonicus</i>	(Chichkoff, 1940)	Strymon spiralin	NE	NE	NO	Endemic S. Balkans
26	<i>Alburnoides thessalicus</i>	Stephanidis, 1950	-	NE	NE	NO	Endemic S. Balkans
27	<i>Alburnus alburnus</i>	(Linnaeus, 1758)	European bleak	LC	LC	NO	Native*
28	<i>Alburnus belvica</i>	Karaman, 1924	Prespa bleak	VU	VU	NO	Near Endemic
29	<i>Alburnus macedonicus</i>	Karaman, 1928	Doiran bleak	CR	CR	NO	Near Endemic
30	<i>Alburnus</i> sp. Volvi		Volvi bleak	NE	NE	NO	Endemic
31	<i>Alburnus thessalicus</i>	Stephanidis, 1950	Thessaly bleak	LC	LC	NO	Endemic S. Balkans
32	<i>Alburnus vistonicus</i>	Freyhof & Kottelat, 2007	Vistonis shemaja	CR	CR	YES	Endemic
33	<i>Alburnus volviticus</i>	Freyhof & Kottelat, 2007	Yelartza shemaja	EN	EN	YES	Endemic
34	<i>Barbus balcanicus</i>	Kotlík, Tsigenopoulos, Ráb & Berrebi, 2002	Large spot barbel	LC	LC	YES	Endemic S. Balkans
35	<i>Barbus macedonicus</i>	Karaman, 1928	Macedonian barbel	DD	LC	YES	Endemic S. Balkans
36	<i>Barbus peloponnesius</i>	Valenciennes, 1842	Peloponnese barbel	LC	LC	YES	Near Endemic
37	<i>Barbus prespensis</i>	Karaman, 1924	Prespa barbel	LC	VU	YES	Endemic S. Balkans
38	<i>Barbus sperchiensis</i>	Stephanidis, 1950	Sperchios barbel	NT	NT	YES	Endemic
39	<i>Barbus strumicae</i>	Karaman, 1955	Strumica barbel	LC	LC	YES	Endemic S. Balkans
40	<i>Carassius auratus</i>	(Linnaeus, 1758)	Common goldfish	[LC]	-	[NO]	Alien
41	<i>Carassius gibelio</i>	(Bloch, 1782)	Prussian carp	[NE]	-	[NO]	Alien
42	<i>Chondrostoma prespense</i>	Karaman, 1924	Prespa nase	VU	VU	NO	Near Endemic
43	<i>Chondrostoma vardarense</i>	Karaman, 1928	Vardar nase	NT	LC	NO	Endemic S. Balkans
44	<i>Ctenopharyngodon idella</i>	(Valenciennes, 1844)	Grass carp	[NE]	-	[NO]	Alien
45	<i>Cyprinus carpio</i>	Linnaeus, 1758	European carp	VU	LC	NO	Native
46	<i>Cyprinus</i> cf <i>carpio</i> (koi)		Koi carp	-	-	-	Alien

Continued

Table A1 continued

a/a	Species	Authority	Common name	IUCN	Red Data Book	Habitats Directive	Endemicity
47	<i>Gobio bulgaricus</i>	Drensky, 1926	Aegean gudgeon	LC	LC	NO	Endemic S. Balkans
48	<i>Gobio feraeensis</i>	Stephanidis, 1973	Thessaly gudgeon	VU	VU	NO	Endemic
49	<i>Hypophthalmichthys molitrix</i>	(Valenciennes, 1844)	Silver carp	[NT]	-	[NO]	Alien
50	<i>Hypophthalmichthys nobilis</i>	(Richardson, 1845)	Bighead carp	[DD]	-	[NO]	Alien
51	<i>Ladigesocypris ghigii</i>	(Gianferrari, 1927)	Gizani	VU	EN	YES	Endemic
52	<i>Leucaspius delineatus</i>	(Hechel, 1843)	European sun bleak	LC	DD	NO	Native
53	<i>Leuciscus aspilus</i>	(Linnaeus, 1758)	Asp	LC	DD	YES	Native
54	<i>Luciobarbus albanicus</i>	(Steindachner, 1870)	Albanian barbel	LC	LC	YES	Endemic
55	<i>Luciobarbus graecus</i>	(Steindachner, 1896)	Greek barbel	EN	VU	YES	Endemic
56	<i>Pachychilon macedonicum</i>	(Steindachner, 1892)	Macedonian moranec	DD	LC	NO	Endemic S. Balkans
57	<i>Parabramis pekinensis</i>	(Basilewsky, 1855)	White amur bream	[NE]	-	[NO]	Alien
58	<i>Pelagus epiroticus</i>	(Steindachner, 1896)	Epirus minnow	CR	CR	YES	Endemic
59	<i>Pelagus marathonicus</i>	(Vinciguerra, 1921)	Marathon minnow	NT	EN	YES	Endemic
60	<i>Pelagus prespensis</i>	(Karaman, 1924)	Prespa minnow	EN	EN	YES	Near Endemic
61	<i>Pelagus stymphalicus</i>	(Valenciennes, 1844)	Stymphalia minnow	LC	LC	YES	Endemic
62	<i>Pelagus thesproticus</i>	(Stephanidis, 1939)	Thesprotian minnow	NT	NT	YES	Near Endemic
63	<i>Petroleuciscus borysthenicus</i>	(Kessler, 1859)	Black sea chub	LC	LC	NO	Native
64	<i>Petroleuciscus smyrnaeus</i>	(Boulenger, 1896)	Smyrna chub	LC	VU	NO	Endemic Asia Minor*
65	<i>Pseudorasbora parva</i>	(Temminck & Schlegel, 1846)	Topmouth gudgeon	[LC]	-	[NO]	Alien
66	<i>Rhodeus amarus</i>	(Bloch, 1782)	European bitterling	LC	LC	YES	Native
67	<i>Rhodeus meridionalis</i>	Karaman, 1924	Vardar bitterling	LC	LC	YES	Endemic S. Balkans
68	<i>Romanogobio elimeius</i>	(Kattoulas, Stephanidis & Economidis, 1973)	Greek stone gudgeon	LC	DD	YES	Endemic S. Balkans
69	<i>Rutilus panosi</i>	Bogutskaya & Iliadou, 2006	Acheloos roach	VU	LC	YES	Endemic
70	<i>Rutilus prespensis</i>	(Karaman, 1924)	Prespa loach	VU	VU	YES	Near Endemic
71	<i>Rutilus rutilus</i>	(Linnaeus, 1758)	Common roach	LC	LC	NO	Native
72	<i>Rutilus ylikiensis</i>	Economidis, 1991	Yliki roach	EN	VU	YES	Endemic
73	<i>Scardinius acarnanicus</i>	Economidis, 1991	Trichonis rudd	NT	LC	NO	Endemic
74	<i>Scardinius erythrophthalmus</i>	(Linnaeus, 1758)	European rudd	LC	LC	NO	Native
75	<i>Scardinius graecus</i>	Stephanidis, 1937	Greek rudd	CR	VU	YES	Endemic

Continued

Table A1 continued

a/a	Species	Authority	Common name	IUCN	Red Data Book	Habitats Directive	Endemicity
76	<i>Squalius moreoticus</i>	(Stephanidis, 1971)	Stymphalia chub	EN	EN	NO	Endemic
77	<i>Squalius orpheus</i>	Kottelat & Economidis, 2006	Maritza chub	LC	LC	NO	Endemic S. Balkans
78	<i>Squalius pamvoticus</i>	(Stephanidis, 1939)	Pamvotis chub	LC	LC	NO	Near Endemic
79	<i>Squalius peloponensis</i>	(Valenciennes, 1844)	Peloponnese chub	LC	LC	NO	Endemic
80	<i>Squalius prespensis</i>	(Fowler, 1977)	Prespa chub	LC	LC	NO	Endemic S. Balkans
81	<i>Squalius</i> sp.			-	-	-	*
82	<i>Squalius</i> sp. Aaos		Aaos chub	NT	NE	NO	Endemic S. Balkans*
83	<i>Squalius vardarensis</i>	Karaman, 1928	Vardar chub	LC	LC	NO	Endemic S. Balkans
84	<i>Telestes beoticus</i>	(Stephanidis, 1939)	Beotian riffle dace	EN	EN	YES	Endemic
85	<i>Telestes pleurobipunctatus</i>	(Stephanidis, 1939)	Epiros riffle dace	LC	LC	YES	Near Endemic
86	<i>Tinca tinca</i>	(Linnaeus, 1758)	European tench	LC	DD	NO	Native
87	<i>Tropidophoxinellus hellenicus</i>	(Stephanidis, 1971)	Hellenic minnowroach	LC	LC	YES	Endemic
88	<i>Tropidophoxinellus spartiaticus</i>	(Schmidt-Ries, 1943)	Spartian minnowroach	VU	VU	YES	Endemic
89	<i>Vimba melanops</i>	(Heckel, 1837)	Dark vimba	DD	VU	NO	Endemic S. Balkans
<b>Cyprinodontidae</b>							
90	<i>Aphanius fasciatus</i>	(Valenciennes, 1821)	Mediterranean toothcarp	LC	LC	YES	Native
<b>Esocidae</b>							
91	<i>Esox lucius</i>	Linnaeus, 1758	Northern pike	LC	LC	NO	Native
<b>Gasterosteidae</b>							
92	<i>Gasterosteus gymnurus</i>	Cuvier, 1829	Western three-spine stickleback	LC	LC	NO	Native
<b>Gobiidae</b>							
93	<i>Economidichthys pygmaeus</i>	(Holly, 1929)	Western Greece goby	LC	LC	YES	Endemic
94	<i>Economidichthys trichonis</i>	Economidis & Miller, 1990	Trichonis dwarf goby	EN	LC	YES	Endemic
95	<i>Knipowitschia caucasica</i>	(Berg, 1916)	Caucasian dwarf goby	LC	LC	NO	Native
96	<i>Knipowitschia</i> sp.			-	-	-	Native
97	<i>Knipowitschia</i> sp. milleri			CR	VU	NO	Native
98	<i>Knipowitschia thessala</i>	(Vinciguerra, 1921)	Thessaly goby	EN	EN	NO	Endemic
99	<i>Millerigobius macrocephalus</i>	(Kolombatovic, 1891)	Large-headed goby	LC	NE	NO	Native
<b>Ictaluridae</b>							
100	<i>Ameiurus</i> cf. <i>nebulosus</i>			[LC]	-	[NO]	Alien
<b>Nemachelidae</b>							

Continued

Table A1 continued

a/a	Species	Authority	Common name	IUCN	Red Data Book	Habitats Directive	Endemicity
101	<i>Oxynoemacheilus bureschi</i>	(Drensky, 1928)	Struma stone loach	LC	LC	NO	Endemic S. Balkans
102	<i>Oxynoemacheilus pindus</i>	(Economidis, 2005)	Pindus stone loach	VU	VU	NO	Endemic S. Balkans
<b>Percidae</b>							
103	<i>Gymnocephalus cernua</i>	(Linnaeus, 1758)	Eurasian ruffe	[LC]	-	[NO]	Alien
104	<i>Perca fluviatilis</i>	Linnaeus, 1758	European perch	LC	LC	NO	Native
105	<i>Sander lucioperca</i>	(Linnaeus, 1758)	Pikeperch	LC	DD	NO	Native*
<b>Poeciliidae</b>							
106	<i>Gambusia holbrooki</i>	Girard, 1859	Eastern mosquitofish	[LC]	-	[NO]	Alien
107	<i>Poecilia latipinna</i>	(Lesueur, 1821)	Sailfin molly	[LC]	-	[NO]	Alien
<b>Polyodontidae</b>							
108	<i>Polyodon spathula</i>	(Walbaum, 1792)	Mississippi paddlefish	[VU]	-	[NO]	Alien
<b>Salmonidae</b>							
109	<i>Oncorhynchus kisutch</i>	(Walbaum, 1792)	Coho salmon	[NE]	-	[NO]	Alien
110	<i>Oncorhynchus mykiss</i>	(Walbaum, 1792)	Rainbow trout	[NE]	-	[NO]	Alien
111	<i>Salmo</i> cf. <i>trutta</i>	Linnaeus, 1758	Brown trout	[LC]	-	[NO]	Alien
112	<i>Salmo farioides</i>	Karaman, 1938	West Balkan trout	NE	VU	YES	Endemic S. Balkans
113	<i>Salmo letnica</i>	(Karaman, 1924)	Ohrid trout	[DD]	-	[NO]	Alien
114	<i>Salmo lourosensis</i>	Delling, 2011	Louros trout	NE	EN	YES	Endemic
115	<i>Salmo macedonicus</i>	(Karaman, 1924)	Macedonian trout	DD	DD	YES	Endemic S. Balkans
116	<i>Salmo pelagonicus</i>	Karaman, 1938	Pelagonian trout	VU	VU	YES	Endemic S. Balkans
117	<i>Salmo peristericus</i>	Karaman, 1938	Prespa trout	EN	EN	YES	Near Endemic
118	<i>Salmo</i> sp.			-	-	-	*
119	<i>Salvelinus fontinalis</i>	(Mitchill, 1814)	Brook charr	[NE]	-	[NO]	Alien
<b>Serrasalminidae</b>							
120	<i>Pygocentrus nattereri</i>	Kner, 1858	Red piranha	-	-	[NO]	Alien
<b>Siluridae</b>							
121	<i>Silurus aristotelis</i>	Garman, 1890	Aristotle's catfish	DD	LC	YES	Endemic
122	<i>Silurus glanis</i>	Linnaeus, 1758	Wels catfish	LC	LC	NO	Native

**Table A2.** Fish faunistic lists for the lentic ecosystems of Thrace Ecoregion (for the exact location of each lake see Fig. S2).

Lakes	Nymfon		Lyra II		Gratini	Ismarida		Vistonis	Toxotes	Alatza Giola (Chrysoupoli)		Maries (Thassos)		Platanovrisi	Thisavros	Folia	Lefkogia	Katapyto	Kerkini	Koronia	Volvi	Sani	Kontias (Limnos)	
	N	A	A	N	N	N	N	A	A	N	A	A	A	A	A	A	A	A	A	N	N	N	N	A
Natural / Artificial	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18						
<i>Abramis brama</i>																				1				
<i>Alburnoides strymonicus</i>						1	1																	
<i>Alburnus alburnus</i>								2																
<i>Alburnus</i> sp. Volvi																								
<i>Alburnus vistonicus</i>				1c	1										1	1								
<i>Alburnus volviticus</i>																								
<i>Alosa fallax</i>					1																			
<i>Alosa macedonica</i>																								
<i>Alosa vistonica</i>					1c																			
<i>Ameiurus</i> cf. <i>nebulosus</i>																								
<i>Anguilla anguilla</i>	1			1	1		1														1c	1	1	1
<i>Aphanius fasciatus</i>	1?			1	1																			
<i>Atherina boyeri</i>				1	1																			
<i>Barbus strumicae</i>						1	1			1	2													
<i>Carassius auratus</i>													2											
<i>Carassius gibelio</i>				2	2		2				2													
<i>Chondrostoma vardarensense</i>						1	1				1													2
<i>Cobitis strumicae</i>				1e		1	1				1													
<i>Ctenopharyngodon idella</i>																								
<i>Cyprinus carpio</i>				1a	1		2			2	2	1	1	1	2	1	1	1						
<i>Esox lucius</i>																								
<i>Gambusia holbrooki</i>				2	2	2	2			2				1c										
<i>Gasterosteus gymmurus</i>				1						2	2													
<i>Gobio bulgaricus</i>				1e		1	1			1														
<i>Gymnocephalus cernua</i>																								
<i>Hypophthalmichthys molitrix</i>																								
<i>Knipowitschia caucasica</i>				1e																				

*Continued*

Table A2 continued

Lakes	Nymfon	Lyra II	Gratini	Ismarida	Vistonis	Toxotes	Alatza Giola (Chrysoupoli)	Maries (Thassos)	Platanovrisi	Thissavros	Folia	Lefkogia	Katatyto	Kerkini	Koronia	Volvi	Sani	Kontias (Limnos)
Natural / Artificial	N	A	A	N	N	A	N	A	A	A	A	A	A	A	N	N	N	A
Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
<i>Lepomis gibbosus</i>						2	2	2	2	2				2	2	2		
<i>Leucaspis delineatus</i>						1	1?											
<i>Leuciscus aspius</i>					2b									1		1		
<i>Oncorhynchus mykiss</i>						2d			2d	2d								
<i>Oxynoemacheilus bureschi</i>						1	1		1	1								
<i>Pachychilon macedonicum</i>															2			
<i>Perca fluviatilis</i>						2			2	2				1	1	1		
<i>Petroleuciscus borysthenicus</i>				1e														
<i>Pseudorasbora parva</i>									2	2				2	2			
<i>Rhodeus amarus</i>					1	1	1		1	1				1	1a	1a		
<i>Rutilus rutilus</i>					1	1?	1?		1	1				1	1	1		
<i>Salaria fluviatilis</i>					1										1c	1		
<i>Salmo macedonicus</i>									1	1								
<i>Sander lucioperca</i>														2				
<i>Scardinius erythrophthalmus</i>					1		1							1c		1		
<i>Silurus aristotelis</i>																2c		
<i>Silurus glanis</i>	1										2			1c	1c	1c		
<i>Squalius orpheus</i>		1		1e	1	1	1	2	1	1	2			1	1	1		
<i>Tinca tinca</i>	1						1							1?	1c	1c		
<i>Vimba melanops</i>														1	1	1		
<b>SUM</b>	<b>6</b>	<b>1</b>	<b>1</b>	<b>13</b>	<b>15</b>	<b>14</b>	<b>16</b>	<b>2</b>	<b>17</b>	<b>17</b>	<b>5</b>	<b>1</b>	<b>2</b>	<b>23</b>	<b>11</b>	<b>27</b>	<b>2</b>	<b>2</b>

1 = Native, confirmed presence;

1? = Presumably native, reported but unconfirmed presence;

2 = Introduced to the lake;

2? = Reported but unconfirmed introduction.

Notations are further given where taxonomic and native status uncertainty exists or where the population may be presumed extirpated, as follows:

a: Doubtful taxonomic status of population;

b: Doubt on native or introduced status;

c: Extirpated or possibly extirpated population;

d: Species that were/are introduced in a lake due to repeated stockings but with doubtful establishment success;

e: Species occurring partially in lakes and are mainly restricted to river's outflows entering a lake.

**Table A3.** Fish faunistic lists for the lentic ecosystems of Macedonia - Thessaly Ecoregion [1 of 3] (for the exact location of each lake see Fig. S3).

Lakes	Ag. Antonios		Doirani	Eleousa	Pentaplatanos	Metalio	Galazia lake	Agras	Vegoritis	Papadias	Skopos Reservoir	Petron	Vevis	Kolchiki	Zazari	Chimaditis	Perdikas	Milochori	Sissani	Germa	Vasseliada (Melissotopos)	
	Natural / Artificial	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
<i>Alburnoides thessalicus</i>				1						1												
<i>Alburnus macedonicus</i>		1							1													
<i>Alburnus thessalicus</i>			2						1													
<i>Ameiurus cf. nebulosus</i>			1c																			
<i>Anguilla anguilla</i>			1e				1	1	1	1					1e	1			1			
<i>Barbus balcanicus</i>																						
<i>Barbus macedonicus</i>				1																		
<i>Carassius auratus</i>	2					2																
<i>Carassius gibelio</i>	2	2	2	2	2	2	2	2	2	2?	2	2	2	2	2	2	2	2	2?	2	2	2
<i>Chondrostoma vardarensis</i>			1e	1																		
<i>Cobitis vardarensis</i>																						
<i>Coregonus sp.</i>									2a													
<i>Cyprinus carpio</i>	2	1	2	2	2	2		1	1	2	1	1	2	2	2	1	2	2	2	2	2	2
<i>Esox lucius</i>			1c		2			1	1			1		2	1	1	2	2				
<i>Gambusia holbrooki</i>		2	2	2					2			2			2	2						2
<i>Gobio bulgaricus</i>			1e	1					1e													2
<i>Lepomis gibbosus</i>	2			2					2			2										2
<i>Oncorhynchus kisutch</i>									2c													
<i>Oncorhynchus mykiss</i>								2d	2c				2?	2d							2d	2d
<i>Oxyoemacheilus bureschi</i>				2																		
<i>Pachytilon macedonicum</i>		1	1	1				1	1	1	1	1			1	1						
<i>Percu fluviatilis</i>		1	1						2	2	2	2			2	2	2		2	2	2	2
<i>Pseudorasbora parva</i>				2																		
<i>Pygocentrus nattereri</i>		2c																				
<i>Rhodeus meridionalis</i>		1a	1	1				1	1	1	1	1			1	1						
<i>Romanogobio elimeius</i>		1	1	1																		
<i>Rutilus rutilus</i>	2	1	1	1				1	1	1	1	1			1	1	2				2	2?
<i>Sabanejewia balcanica</i>		1						1														

Continued



Table A3 continued

Lakes	Ag. Antonios		Doirani	Eleousa	Pentaplatanos	Metallio	Galazia lake	Agras	Vegortis	Papadias	Skopos Reservoir	Petron	Vevis	Kolchiki	Zazari	Chimaditis	Perdikas	Milochori	Sissani	Germa	Vasseliada (Melissotopos)
	Natural / Artificial	A	N	A	A	A	N	A	N	A	A	N	A	A	N	N	A	A	A	A	A
<b>Number</b>	<b>19</b>	<b>20</b>	<b>21</b>	<b>22</b>	<b>23</b>	<b>24</b>	<b>25</b>	<b>26</b>	<b>27</b>	<b>28</b>	<b>29</b>	<b>30</b>	<b>31</b>	<b>32</b>	<b>33</b>	<b>34</b>	<b>35</b>	<b>36</b>	<b>37</b>	<b>38</b>	
<i>Salmo cf. trutta</i>								2c													
<i>Salmo macedonicus</i>					1																
<i>Salmo pelagonicus</i>									1a					1?							
<i>Sabvelinus fontinalis</i>								2c													
<i>Scardinius erythrophthalmus</i>		1					1														
<i>Silurus glanis</i>		1	1				1	2								2c	2	2			
<i>Squalius vardarensis</i>		1	1				1	1									2				
<i>Tinca tinca</i>		1c					1	1			1c				1	1					
<i>Vimba melanops</i>			1																		
<b>SUM</b>	<b>5</b>	<b>20</b>	<b>19</b>	<b>2</b>	<b>4</b>	<b>1</b>	<b>13</b>	<b>20</b>	<b>5</b>	<b>1</b>	<b>11</b>	<b>2</b>	<b>5</b>	<b>11</b>	<b>15</b>	<b>7</b>	<b>4</b>	<b>6</b>	<b>6</b>	<b>6</b>	

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d: Species that were/are introduced in a lake due to repeated stockings but with doubtful establishment success;

e: Species occurring partially in lakes and are mainly restricted to river's outflows entering a lake.

**Table A4.** Fish faunistic lists for the lentic ecosystems of Macedonia - Thessaly Ecoregion [2 of 3] (for the exact location of each lake see Fig. S3 and S4).

Lakes	Kastoria (Orestida)		Vrachos	Aidonia	Exarchos	Ag. Georgios	Taxiarchis (Pigi Kamillas)	Polyftos	Sifkia	Assomata	Ag. Varvata	Ilarionas	Pontini	Paliochori	Itas	Kentro	Felli	Mavranaioi	Aimelanos	Karpero	Anoixi
	N	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
<b>Number</b>	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	
<i>Alburnoides thessalicus</i>							1				1										
<i>Alburnus thessalicus</i>											1										
<i>Anguilla anguilla</i>	2						1?	1	1?												
<i>Barbus balcanicus</i>							1	1	1?		1				2						
<i>Barbus macedonicus</i>							1	1			1										
<i>Carassius gibelio</i>	2						2	2	2		2										
<i>Chondrostoma vardarense</i>							1	1	1?		1										
<i>Coregonus</i> sp.							2a														
<i>Ctenopharyngodon idella</i>	2c																				
<i>Cyprinus carpio</i>	2	2	2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
<i>Cyprinus carpio</i> (koi)																		2?			
<i>Esox lucius</i>	2						2	2	2	1?								2			
<i>Gambusia holbrooki</i>	2						2	2?	2?												
<i>Gobio bulgaricus</i>							1														
<i>Hypophthalmichthys molitrix</i>	2c									2?											
<i>Hypophthalmichthys nobilis</i>	2c																				
<i>Lepomis gibbosus</i>	2	2																			
<i>Oncorhynchus mykiss</i>		2d	2	2d	2d	2d	2d	2	2?					2d	2	2	2d	2d	2d	2d	2d
<i>Perca fluviatilis</i>	1						1	1	1	1	1										
<i>Pseudorasbora parva</i>	2						2				2										
<i>Romanogobio elimeius</i>							1	1			1										
<i>Rutilus rutilus</i>	1	2					1	1	1?												
<i>Salmo</i> sp.								2?													
<i>Scardinius erythrophthalmus</i>	2c																				
<i>Silurus glanis</i>	1						1	1	1?												
<i>Squalius vardarenis</i>	1						1	1	1?		1										

*Continued*

Table A4 continued

Lakes	Natural / Artificial	N	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A			
Kastoria (Orestiada)		39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	
Vrachos																						
Aidonia																						
Exarchos																						
Ag. Georgios																						
Taxiarchis (Pigi Kamillas)																						
Polytytos																						
Sifkia																						
Assomata																						
Ag. Varvara																						
Iarionas																						
Pontini																						
Palaiochori																						
Itzas																						
Kentro																						
Felli																						
Mavranatoi																						
Aimelianos																						
Karpero																						
Anoixi																						
<b>Number</b>		<b>39</b>	<b>40</b>	<b>41</b>	<b>42</b>	<b>43</b>	<b>44</b>	<b>45</b>	<b>46</b>	<b>47</b>	<b>48</b>	<b>49</b>	<b>50</b>	<b>51</b>	<b>52</b>	<b>53</b>	<b>54</b>	<b>55</b>	<b>56</b>	<b>57</b>	<b>58</b>	
<i>Tinca tinca</i>		2																				
<i>Vimba melanops</i>																						
<b>SUM</b>		<b>16</b>	<b>4</b>	<b>2</b>	<b>1</b>	<b>2</b>	<b>1</b>	<b>19</b>	<b>15</b>	<b>13</b>	<b>4</b>	<b>11</b>	<b>1</b>	<b>2</b>	<b>1</b>	<b>2</b>	<b>1</b>	<b>4</b>	<b>2</b>	<b>1</b>	<b>2</b>	

1 = Native, confirmed presence;  
 1? = Presumably native, reported but unconfirmed presence;  
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 2? = Reported but unconfirmed introduction.

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 a: Doubtful taxonomic status of population;  
 b: Doubt on native or introduced status;  
 c: Extirpated or possibly extirpated population;  
 d: Species that were/introduced in a lake due to repeated stockings but with doubtful establishment success;  
 e: Species occurring partially in lakes and are mainly restricted to river's outflows entering a lake.

**Table A5.** Fish faunistic lists for the lentic ecosystems of Macedonia - Thessaly Ecoregion [3 of 3] (for the exact location of each lake see Figure S4).

Lakes	Trikokkia	Katakali	Bara	Dassochoiri	Logga	Gitzi (Kefalovriso)	Argyropouli (Mati Tyrnavos)	Gyrtoni	Omorfochori	Eleftherios	Platykampos	Dimitras	Glafki	Niamata	Kastri	Kalamaki	Karla	Smokovo
Natural / Artificial	A	A	A	A	A	N	A	A	A	A	A	A	A	A	A	A	A	A
Number	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
<i>Alburnoides thessalicus</i>								1										
<i>Alburnus thessalicus</i>								1		1				1		1	1	
<i>Alosa fallax</i>																		1
<i>Anguilla anguilla</i>																		1c
<i>Barbus balcanicus</i>					2													
<i>Barbus macedonicus</i>								1										
<i>Barbus sperchiensis</i>								1										1
<i>Carassius gibelio</i>			2		2			2								2	2	2
<i>Chondrostoma vardarensis</i>								1										1c
<i>Cobitis stephanidisi</i>																		1?
<i>Cobitis vardarensis</i>										1								1
<i>Cyprinus carpio</i>		2	2	2	2	2	2	2		2				2		2	2	2
<i>Cyprinus carpio</i> (koi)																		2
<i>Gambusia holbrooki</i>							2?	2	2	2	2	2	2			2	2	
<i>Gobio feraeensis</i>																		1e
<i>Knipowitschia thessala</i>										1			1	1				1
<i>Lepomis gibbosus</i>								2		2	2			2	2	2	2	2
<i>Oncorhynchus mykiss</i>	2d	2d																
<i>Pachychilon macedonicum</i>								1								1	1	
<i>Pelagus marathonicus</i>								1?										
<i>Perca fluviatilis</i>			2															2
<i>Rhodeus meridionalis</i>								1										
<i>Rutilus rutilus</i>								1										1
<i>Salmo</i> sp.					2a													
<i>Scardinius erythrophthalmus</i>																		1c
<i>Silurus glanis</i>					2			1										1
<i>Squalius vardarensis</i>								1										1
<i>Vimba melanops</i>								1										1
<b>SUM</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>1</b>	<b>5</b>	<b>1</b>	<b>2</b>	<b>16</b>	<b>1</b>	<b>6</b>	<b>2</b>	<b>1</b>	<b>2</b>	<b>4</b>	<b>1</b>	<b>6</b>	<b>18</b>	<b>7</b>

1 = Native, confirmed presence;

1? = Presumably native, reported but unconfirmed presence;

2 = Introduced to the lake;

2? = Reported but unconfirmed introduction.

Notations are further given where taxonomic and native status uncertainty exists or where the population may be presumed extirpated, as follows:

a: Doubtful taxonomic status of population;

b: Doubts on native or introduced status;

c: Extirpated or possibly extirpated population;

d: Species that were/are introduced in a lake due to repeated stockings but with doubtful establishment success;

e: Species occurring partially in lakes and are mainly restricted to river's outflows entering a lake.

**Table A6.** Fish faunistic lists for the lentic ecosystems of Southeastern Adriatic Ecoregion (for the exact location of each lake see Fig. S5).

Lakes	Megali Prespa	Mikri Prespa	Aoos Springs
	Natural / Artificial Number	N	N
	<b>77</b>	<b>78</b>	<b>79</b>
<i>Acipenser baeri</i>			2c
<i>Acipenser gueldenstaedtii</i>			2c
<i>Alburnoides prespensis</i> complex			1
<i>Alburnoides prespensis</i>	1	1	
<i>Alburnus belvica</i>	1	1	
<i>Anguilla anguilla</i>	1c	1c	1
<i>Barbus prespensis</i>	1	1	1
<i>Carassius auratus</i>		2a	
<i>Carassius gibelio</i>	2a	2a	2
<i>Chondrostoma prespense</i>	1	1	
<i>Cobitis meridionalis</i>	1	1	
<i>Ctenopharyngodon idella</i>	2c		
<i>Cyprinus carpio</i>	2	2	2
<i>Economidichthys pygmaeus</i>	2	2	
<i>Esox lucius</i>	2c		
<i>Gambusia holbrooki</i>	2	2	
<i>Hypophthalmichthys molitrix</i>	2c		
<i>Lepomis gibbosus</i>	2	2	2
<i>Oncorhynchus mykiss</i>	2c		2d
<i>Oxynoemacheilus pindus</i>			1
<i>Parabramis pekinensis</i>	2c		
<i>Pelagus prespensis</i>	1	1	
<i>Pseudorasbora parva</i>	2	2	
<i>Rhodeus amarus</i>	2a,b	2a,b	
<i>Rutilus prespensis</i>	1	1	
<i>Salmo farioides</i>			1
<i>Salmo letnica</i>	2c		
<i>Salmo peristericus</i>	1		
<i>Silurus glanis</i>	2c		
<i>Squalius prespensis</i>	1	1	
<i>Squalius</i> sp. Aoos			2
<i>Tinca tinca</i>	2	2	
<b>SUM</b>	<b>25</b>	<b>18</b>	<b>12</b>

1 = Native, confirmed presence;

1? = Presumably native, reported but unconfirmed presence;

2 = Introduced to the lake;

2? = Reported but unconfirmed introduction.

Notations are further given where taxonomic and native status uncertainty exists or where the population may be presumed extirpated, as follows:

a: Doubtful taxonomic status of population;

b: Doubts on native or introduced status;

c: Extirpated or possibly extirpated population;

d: Species that were/are introduced in a lake due to repeated stockings but with doubtful establishment success;

e: Species occurring partially in lakes and are mainly restricted to river's outflows entering a lake.

**Table A7.** Fish faunistic lists for the lentic ecosystems of Ionian Ecoregion [1 of 2] (for the exact location of each lake see Figure S6).

Lakes	Natural / Artificial		80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	
<i>Acipenser baeri</i>																									
<i>Acipenser gueldenstaedtii</i>																									
<i>Acipenser naccarii</i>																									
<i>Anguilla anguilla</i>																									
<i>Barbus peloponnesius</i>																									
<i>Carassius auratus</i>																									
<i>Carassius gibelio</i>																									
<i>Cobitis arachthosensis</i>																									
<i>Cobitis hellenica</i>																									
<i>Ctenopharyngodon idella</i>																									
<i>Cyprinus carpio</i>																									
<i>Cyprinus carpio</i> (koi)																									
<i>Economidichthys pygmaeus</i>																									
<i>Gambusia holbrooki</i>																									
<i>Gasterosteus gymnaurus</i>																									
<i>Hypophthalmichthys molitrix</i>																									
<i>Hypophthalmichthys nobilis</i>																									
<i>Knipowitschia caucasica</i>																									
<i>Knipowitschia</i> sp.																									
<i>Luciobarbus albanicus</i>																									
<i>Oncorhynchus mykiss</i>																									
<i>Pelagus epiroticus</i>																									
<i>Pelagus thesproticus</i>																									
<i>Polyodon spathula</i>																									
<i>Rutilus panosi</i>																									

Continued

Table A7 continued

Lakes	Natural / Artificial	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101
<i>Salaria fluviatilis</i>									1														
<i>Salmo fario</i> ides	1c																		1				
<i>Salmo lourosensis</i>																1							
<i>Scardinius acarnanicus</i>																1	2a,b						
<i>Silurus aristotelis</i>				2	2									2									
<i>Silurus glanis</i>				2	2				2														
<i>Squalius pamvoiticus</i>				1	1				1							1?			1	1	1		
<i>Squalius peloponnensis</i>																							
<i>Telestes pleurobipunctatus</i>	1								1							1?	1		1	1	1		
<i>Tilapia</i> sp.																							
<i>Tinca tinca</i>	2		3	5	22	1	3	2	10	2	1	1	2	8	2	5	7	2	9	7	5	5	3
<b>SUM</b>		<b>9</b>	<b>3</b>	<b>5</b>	<b>22</b>	<b>1</b>	<b>3</b>	<b>2</b>	<b>10</b>	<b>2</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>8</b>	<b>2</b>	<b>5</b>	<b>7</b>	<b>2</b>	<b>9</b>	<b>7</b>	<b>5</b>	<b>5</b>	<b>3</b>

1 = Native, confirmed presence;

1? = Presumably native, reported but unconfirmed presence;

2 = Introduced to the lake;

2? = Reported but unconfirmed introduction.

Notations are further given where taxonomic and native status uncertainty exists or where the population may be presumed extirpated, as follows:

a: Doubtful taxonomic status of population;

b: Doubts on native or introduced status;

c: Extirpated or possibly extirpated population;

d: Species that were/are introduced in a lake due to repeated stockings but with doubtful establishment success;

e: Species occurring partially in lakes and are mainly restricted to river's outflows entering a lake.

**Table A8.** Fish faunistic lists for the lentic ecosystems of Ionian Ecoregion [2 of 2] (for the exact location of each lake see Fig. S6 and S7).

Lakes	Natural / Artificial		Tavropos (Plastr)																Ladonas (Alfos)				Valyra (Pamisos)			
	N	A	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	
<i>Anguilla anguilla</i>	1		2	1	1	1	1		1	1	1?	1?	1	1	1	1	1	1	1	1	1?					1
<i>Atherina boyeri</i>	1					1			2c			1	1													
<i>Barbus peloponnesius</i>				1	1	1	1			1	1?	1e						1	1	1	1			1	1	1
<i>Carassius auratus</i>					2	2	2			2	2							2	2	2	2					
<i>Carassius gibelio</i>			2	2	2	2	2			2	2	2	2	2	2			2	2	2	2					
<i>Cobitis trichonica</i>			1									1	1	1	1											
<i>Coregonus</i> sp.									2a									2c								
<i>Ctenopharyngodon idella</i>								2	2	2	2	2	2	2	2c			2c		2c						
<i>Cyprinus carpio</i>	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2			2	2	2	2	2	2	2	2	2
<i>Economidichthys pygmaeus</i>												1	1	1	1											
<i>Economidichthys trichonis</i>												1	1	1	1											
<i>Gambusia holbrooki</i>	2	2	2	2	2	2	2	2	2c	2c		2	2	2	2	2		2	2	2	2	2	2	2	2	2
<i>Hypophthalmichthys molitrix</i>																										
<i>Hypophthalmichthys molitrix</i>	1a													1a	1a											2
<i>Knipowitschia</i> sp.																										
<i>Knipowitschia</i> sp. Milleri												1														
<i>Lepomis gibbosus</i>										2																2
<i>Luciobarbus albanicus</i>	1?	1	1	1	1	1	1	1	1	1	1?	1	1	1	1			1								2
<i>Oncorhynchus kisutch</i>																										
<i>Oncorhynchus mykiss</i>						2d			2c		2d															
<i>Pelagus symphalicus</i>	1								2d	1	1	1	1	1	1			1	1	1?	1?	2	1	1	1	1
<i>Perca fluviatilis</i>										2																
<i>Pseudorasbora parva</i>					2	2	2	2	2			2	2	2	2			2								
<i>Rhodeus meridionalis</i>												2	2	2	2											
<i>Rutilus panosi</i>		1	1	1	1	1	1	1	1	1	1	1	1	1	1											
<i>Salaria economidisi</i>	1											1	1	1	1											
<i>Salaria fluviatilis</i>														1a				1	1	1	1	1	1	1	1	1
<i>Salmo farioides</i>										1	1	1?														1

Continued



Table A8 continued

Lakes	Natural / Artificial		Volukaria	Amvrakia	Stratos	Kastraki	Kremasta	Dafnozouara	Stefaniada	Tavropos (Plastira)			Mornos	Evinos	Trichonis	Ozoros	Lysimachia	Alexaina	Avithos	Pinos Pel.	Alfos	Ladonas (Alfos)	Tsivlos	Doxa (Feneos)	Stymphalia	Megalopolis (Trapezous)	Valyra (Pamisos)	
	N	N	N	N	A	A	A	A	N	A	A	A	A	A	N	N	N	N	N	N	A	A	A	N	A	N	A	A
<b>Number</b>	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124					
<i>Salvelinus fontinalis</i>								2c																				
<i>Scardinius acarnanicus</i>	1	1	1	1							1	1	1															
<i>Silurus aristotelis</i>	1	1									1	1	1															
<i>Silurus glanis</i>					2			2			2c																	
<i>Squalius moreoticus</i>																									1c			
<i>Squalius peloponensis</i>	1	1	1	1	1	1	1	1	1	1?	1	1	1	1	1	1	1	1	1b		2a					1		
<i>Telestes pleurobipunctatus</i>			1	1	1	1	1	1	1	1?	1	1	1	1	1	1	1	1										
<i>Tinca tinca</i>	2	2?			2			2			2		2														2	
<i>Tropidophoxinellus hellenicus</i>			1	1							1	1	1															
<i>Tropidophoxinellus spartiaticus</i>																												
<b>SUM</b>	<b>9</b>	<b>11</b>	<b>14</b>	<b>9</b>	<b>15</b>	<b>5</b>	<b>1</b>	<b>17</b>	<b>8</b>	<b>8</b>	<b>23</b>	<b>16</b>	<b>21</b>	<b>2</b>	<b>1</b>	<b>13</b>	<b>9</b>	<b>12</b>	<b>5</b>	<b>2</b>	<b>4</b>	<b>2</b>	<b>8</b>					

1 = Native, confirmed presence;

1? = Presumably native, reported but unconfirmed presence;

2 = Introduced to the lake;

2? = Reported but unconfirmed introduction.

Notations are further given where taxonomic and native status uncertainty exists or where the population may be presumed extirpated, as follows:

a: Doubtful taxonomic status of population;

b: Doubts on native or introduced status;

c: Extirpated or possibly extirpated population;

d: Species that were/are introduced in a lake due to repeated stockings but with doubtful establishment success;

e: Species occurring partially in lakes and are mainly restricted to river's outflows entering a lake.

**Table A9.** Fish faunistic lists for the lentic ecosystems of Western Aegean Ecoregion (for the exact location of each lake see Figures S8 and S9).

Lakes	Panagiotiko	Megalo Zireli	Mikro Zireli	Paraskevorema	Paralimni	Yliki	Dervenochori	Tritsi Park	Vouliagmeni	Beletsi	Marathona	Schinias	Dystos	Karystos	Taka	Marathi (Mykonos)	Eggares (Naxos)	Myulopota	Livadi (Astypalea)
	Natural / Artificial	A	N	N	A	N	N	A	A	N	A	A	A	N	A	A	A	A	A
Number	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143
<i>Acipenser gueldenstaedtii</i>																2c			
<i>Anguilla anguilla</i>					1	1		1	1	1		1	1	1			1		
<i>Carassius auratus</i>								2				2						2c	2a
<i>Carassius gibelio</i>				2		2		2							2				
<i>Ctenopharyngodon idella</i>					2c	2c													
<i>Cyprinus carpio</i>	2				2	2		2			2		2		2			2c	2
<i>Cyprinus carpio</i> (koi)								2											
<i>Economidichthys pygmaeus</i>											2				2				
<i>Gambusia holbrooki</i>							2	2			2	2	2	2	2				
<i>Hypophthalmichthys molitrix</i>					2c	2c										2c			
<i>Hypophthalmichthys nobilis</i>					2c	2c													
<i>Knipowitschia caucasica</i>															1a				
<i>Lepomis gibbosus</i>										2					2				
<i>Luciobarbus graecus</i>					1	1				2	2								
<i>Millerigobius macrocephalus</i>									1										
<i>Pelagus marathonicus</i>		1	1		1	1					1	1							
<i>Pelagus stymphalicus</i>															1				
<i>Poecilia latipinna</i>									2										
<i>Rutilus panosi</i>															2				
<i>Rutilus ylikiensis</i>					1	1					1								
<i>Scardinius graecus</i>					1	1				2	2								
<i>Silurus aristotelis</i>					2	2													
<i>Squalius vardarensis</i>											2a								
<i>Telestes beoticus</i>					1	1													
<b>SUM</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>11</b>	<b>12</b>	<b>1</b>	<b>6</b>	<b>3</b>	<b>4</b>	<b>8</b>	<b>4</b>	<b>3</b>	<b>3</b>	<b>7</b>	<b>2</b>	<b>1</b>	<b>2</b>	<b>2</b>

1 = Native, confirmed presence;

1? = Presumably native, reported but unconfirmed presence;

2 = Introduced to the lake;

2? = Reported but unconfirmed introduction.

Notations are further given where taxonomic and native status uncertainty exists or where the population may be presumed extirpated, as follows:

a: Doubtful taxonomic status of population;

b: Doubts on native or introduced status;

c: Extirpated or possibly extirpated population;

d: Species that were/are introduced in a lake due to repeated stockings but with doubtful establishment success;

e: Species occurring partially in lakes and are mainly restricted to river's outflows entering a lake.

**Table A10.** Fish faunistic lists for the lentic ecosystems of Eastern Aegean Ecoregion (for the exact location of each lake see Fig. S10).

Lakes	Mithimna (Lesvos)	Eressos (Lesvos)	Mytilinion - Roggia (Samos)	Vathes (Ikaria)	Limnopygi (Kos)	Pezi - Raches (Ikaria)	Nanon lake (Rhodes)	Apolaktias (Rhodes)	Gadouras (Rhodes)
Natural / Artificial	A	A	A	A	N	A	N	A	A
Number	144	145	146	147	148	149	150	151	152
<i>Anguilla anguilla</i>	1			1	2				1
<i>Carassius auratus</i>				2		2			
<i>Carassius gibelio</i>						2		2	
<i>Ctenopharyngodon idella</i>								2c	2?
<i>Cyprinus carpio</i>		2?				2	2	2	2
<i>Gambusia holbrooki</i>			2		2		2		2?
<i>Hypophthalmichthys molitrix</i>								2c	2?
<i>Ladigesocypris ghigii</i>							1c	1e	1e
<i>Oncorhynchus mykiss</i>		2?							
<i>Petroleuciscus smyrnaeus</i>		2							
<i>Salaria fluviatilis</i>				1e					
<i>Squalius sp.</i>		2a							
<b>SUM</b>	<b>1</b>	<b>4</b>	<b>1</b>	<b>3</b>	<b>2</b>	<b>3</b>	<b>3</b>	<b>5</b>	<b>6</b>

1 = Native, confirmed presence;

1? = Presumably native, reported but unconfirmed presence;

2 = Introduced to the lake;

2? = Reported but unconfirmed introduction.

Notations are further given where taxonomic and native status uncertainty exists or where the population may be presumed extirpated, as follows:

a: Doubtful taxonomic status of population;

b: Doubts on native or introduced status;

c: Extirpated or possibly extirpated population;

d: Species that were/are introduced in a lake due to repeated stockings but with doubtful establishment success;

e: Species occurring partially in lakes and are mainly restricted to river's outflows entering a lake.

**Table A11.** Fish faunistic lists for the lentic ecosystems of the Crete Ecoregion (for the exact location of each lake see Fig. S11).

Lakes	Agias	Kournas	Potamon	Faneromeni - Messara	Zaros	Gergeri	Limnopygi Almyros	Chalavriano	Armanogia	Amourgelon	Partiron	Ini - Machera	Keras	Livada (Thrapsano)	Aposselemis	Ligara (Mochos)	Bramianon	Ziros
Natural / Artificial	A	N	A	A	A	A	N	A	A	A	A	A	A	A	A	N	A	N
Number	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170
<i>Anguilla anguilla</i>	1	1	1	1	1											1		
<i>Atherina boyeri</i>		1					1									2		
<i>Carassius auratus</i>	2	2	2						2	2	2	2		2	2	2	2	
<i>Carassius gibelio</i>		2																
<i>Ctenopharyngodon idella</i>				2c	2c													
<i>Cyprinus carpio</i>			2	2	2	2				2?	2?	2			2	2?	2?	
<i>Gambusia holbrooki</i>	2	2	2		2			2	2	2	2	2		2	2	2	2?	2
<i>Hypophthalmichthys molitrix</i>				2c	2c													
<i>Oncorhynchus mykiss</i>		2?			2d													
<i>Salaria fluviatilis</i>		1											1					
<b>SUM</b>	<b>3</b>	<b>7</b>	<b>4</b>	<b>4</b>	<b>6</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>3</b>	<b>3</b>	<b>1</b>	<b>2</b>	<b>5</b>	<b>3</b>	<b>3</b>	<b>1</b>

1 = Native, confirmed presence;

1? = Presumably native, reported but unconfirmed presence;

2 = Introduced to the lake;

2? = Reported but unconfirmed introduction.

Notations are further given where taxonomic and native status uncertainty exists or where the population may be presumed extirpated, as follows:

a: Doubtful taxonomic status of population;

b: Doubts on native or introduced status;

c: Extirpated or possibly extirpated population;

d: Species that were/are introduced in a lake due to repeated stockings but with doubtful establishment success;

e: Species occurring partially in lakes and are mainly restricted to river's outflows entering a lake.