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Occurrence of *Gambusia holbrooki* Girard, 1859 (Poeciliidae) in Four Mediterranean River Estuaries of Turkey, Nursery Habitats of Several Native and Threatened Species

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Abstract: The aim of this study is to report the occurrence of the invasive alien Eastern mosquitofish *Gambusia holbrooki* in four Mediterranean river estuaries of Turkey (Manavgat, Göksu, Seyhan, and Ceyhan). The monitoring of fish communities carried out from 2014 to 2017 revealed the presence of *G. holbrooki* both with juveniles and adult specimens in all four estuaries. Along with *G. holbrooki* and other alien species a total of 24 native species at juvenile stages were recorded. Some of them, such as the critically endangered *Anguilla anguilla* and the endemic goby *Pomatoschistus anatoliae*, are of particular conservation interest and require specific attention. The presence of *G. holbrooki* in the studied estuaries that could serve as recruitment areas for the populations of the sensitive native and threatened species may act as additional threat for their survival and may distort the ecological equilibrium of the river estuary ecotones.

Key words: Alien species, spread, brackish water, native and threatened species.

Introduction

River estuaries are among the most productive aquatic ecosystems (Costanza et al. 1997) and play an essential ecological role as nursery and feeding areas for many species (Cooper et al. 1994, Marques et al. 2004). These ecosystems are particularly used by the juveniles of fish because of their favourable ecological characteristics such as the availability of food and refuges from potential predators that ensure the growth and survival of young specimens (Haedrich 1983, Miller 1985, Lenanton & Potter 1987, Beck et al. 2001).

Despite of the recognised importance of river estuaries in terms of biodiversity (Marchand 1980, Costa & Bruxelas 1989, Beck et al. 2001, Gillanders et al. 2003, Able 2005), they are among the most frequently modified and threatened aquatic environments (Blaber et al. 2000). Mediterranean estuaries play an acknowledged role as nursery areas for several commercially important fish species (Vasconcelos et al. 2010) but their richness in terms of biodiversity has not been assessed comprehensively due to their borderline position. In addition, during the last few decades several factors, including the climate change, anthropogenic activity and alien species have severely impacted these areas (Lotze et al. 2006, Streftaris & Zenetos 2006).

One of the biggest threats to the aquatic ecosystems is the introduction of invasive alien species that can negatively impact the native species and alter the long-term viability of the biodiversity ecotones (Goldberg 1995, Costa et al. 2002, Kennish 2002, Helfman 2007). Despite

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the ecological and economic impact of alien species that has been widely documented (Cambray 2003, Lintermans 2004, Garcia-Berthou & Moyle 2011), their introduction continues to be a common practice. Some of the alien species can have beneficial effects on the native ecosystems, but a number of these species becomes invasive and able to establish viable populations that can negatively impact the new environment (Mack et al. 2000, Cope & Winterbourn 2004, Johnson et al. 2009).

The Eastern mosquitofish *Gambusia holbrooki* Girard, 1859, and its congeneric *G. affinis* (Baird & Girard, 1853) are among the most invasive alien species, which have been widely introduced in several countries as a biological control agent for mosquito larvae (Krumholz 1948, Courtenay & Meffe 1989, Garcia-Berthou et al. 2005, Veenvliet 2007, Pyke 2008). Nevertheless, it has been found that both species affect negatively native and endangered fish, as well as the invertebrate species preying on them (Hurlbert et al. 1972, Hurlbert & Mulla 1981, Miura et al. 1984, Blaustein 1992, Schaefer et al. 1994, Lawler et al. 1999). Following the initial introductions, the species have become pests in many waterways around the world and are listed among the first 100 of the World's Worst Invasive Alien Species according to the Global Invasive Species Database (2019).

The introduction of *G. holbrooki* in several freshwater environments has become a serious threat to many endemic species in Europe (Kottelat & Freyhof 2007). This species, indeed, has rapid population growth potential and inhabits shallow ponds and edges of watercourses (Page & Burr 1991, Pyke 2005). Being able to tolerate a wide range of ecological conditions and habitat disturbances (Pyke 2008), it can also occur in brackish sloughs and coastal saltwater habitats (Arthington & Lloyd 1989, Froese & Pauly 2019).

With regard to Turkey, the oldest reported introduction of *G. holbrooki* is known from the early 20th century into Amik Lake (Hatay, Southern Turkey) (Geldiay & Balik 1988). So far, the species has been reported to occur in several freshwater systems throughout Turkey (Özuluğ et al. 2005, Erk'akan & Ozdemir 2011, Ergüden 2013, Özuluğ et al. 2013, Tarkan et al. 2015, Kurtul & Sari 2020), where it has been intentionally introduced (Geldiay & Balik 1988, Özuluğ et al. 2007) or spread from neighbouring countries (Aydin et al. 2011). There is scarce knowledge to date about the presence of *G. holbrooki* in the Mediterranean river estuaries of Turkey (Innal & Ozdemir 2012) and about the composition of the fish communities of these peculiar habitats in general (Akin et al. 2005, Kucuk et al. 2007, Innal & Ozdemir 2012).

This study aims to report the occurrence of *G. holbrooki* in four Mediterranean river estuaries of Turkey (Manavgat, Göksu, Seyhan, and Ceyhan) and to focus the attention on the native fish communities inhabiting the estuaries, which are of particular conservation interest, especially at juvenile stages, and which could be potentially threatened by the presence of this alien species.

Materials and Methods

The fish specimens were collected from four Turkish estuary systems located along the Mediterranean coast (Manavgat, Göksu, Seyhan, and Ceyhan) from 2014 to 2017, during different monitoring programmes aimed to investigate the fish fauna (Fig. 1). The fish were caught by a shore seine net: 10 m long, 2 m

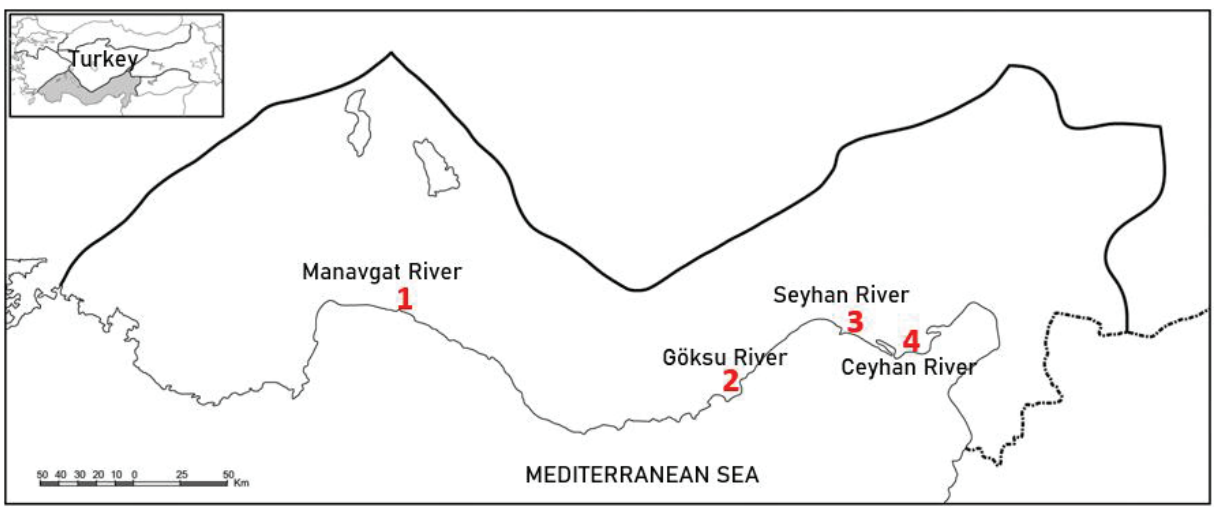

Fig. 1. Map of Turkey showing the sampling localities.

Table 1. List of the native fish species recorded at juvenile stages together with *Gambusia holbrooki* in the four studied estuaries. IUCN Red List categories: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; LC – Least Concern; DD – Data Deficient; and NE – Not Evaluated..

No	Family	Species	IUCN Red List assessment	Population trend according to IUCN	Manavgat	Göksu	Seyhan	Ceyhan
1	Anguillidae	*Anguilla anguilla* (Linnaeus, 1758)	CR	decreasing	X	X	X	X
2	Atherinidae	*Atherina boyeri* Risso, 1810	LC	unknown			X	X
3	Blenniidae	*Parablennius sanguinolentus* (Pallas, 1814)	LC	stable	X			
4	Blenniidae	*Salaria fluviatilis* (Asso, 1801)	LC	stable	X			
5	Cyprinidae	*Garra culiciphaga* (Pellegrin, 1927)	LC	decreasing			X	
6	Cyprinidae	*Luciobarbus pectoralis* (Heckel, 1843)	LC	stable		X		X
7	Cyprinodontidae	*Aphanius fasciatus* (Valenciennes, 1821)	LC	decreasing		X	X	X
8	Engraulidae	*Engraulis encrasicolus* (Linnaeus, 1758)	LC	decreasing	X			X
9	Gobiidae	*Pomatoschistus anatoliae* Engin & Innal, 2017	NE	unknown	X	X	X	X
10	Leuciscidae	*Acanthobrama marmid* Heckel, 1843	LC	stable				X
11	Leuciscidae	*Alburnus baliki* Bogutskaya, Küçük & Ünlü, 2000	EN	decreasing	X			
12	Leuciscidae	*Squalius anatolicus* (Bogutskaya, 1997)	LC	decreasing	X			
13	Moronidae	*Dicentrarchus labrax* (Linnaeus, 1758)	LC	unknown	X	X	X	
14	Moronidae	*Dicentrarchus punctatus* (Bloch, 1792)	LC	unknown				X
15	Mugilidae	*Chelon auratus* (Risso, 1810)	LC	unknown	X	X	X	X
16	Mugilidae	*Chelon labrosus* (Risso, 1827)	LC	unknown		X	X	X
17	Mugilidae	*Chelon ramada* (Risso, 1827)	LC	unknown	X	X	X	X
18	Mugilidae	*Chelon saliens* (Risso, 1810)	LC	unknown	X	X	X	X
19	Mugilidae	*Mugil cephalus* Linnaeus, 1758	LC	stable	X	X	X	X
20	Soleidae	*Solea solea* (Linnaeus, 1758)	DD	stable			X	
21	Soleidae	*Synapturichthys kleinii* (Risso, 1827)	DD	unknown		X		
22	Sparidae	*Lithognathus mormyrus* (Linnaeus, 1758)	LC	stable	X			
23	Sparidae	*Sparus aurata* Linnaeus, 1758	LC	stable			X	
24	Syngnathidae	*Syngnathus acus* Linnaeus, 1758	LC	unknown			X	

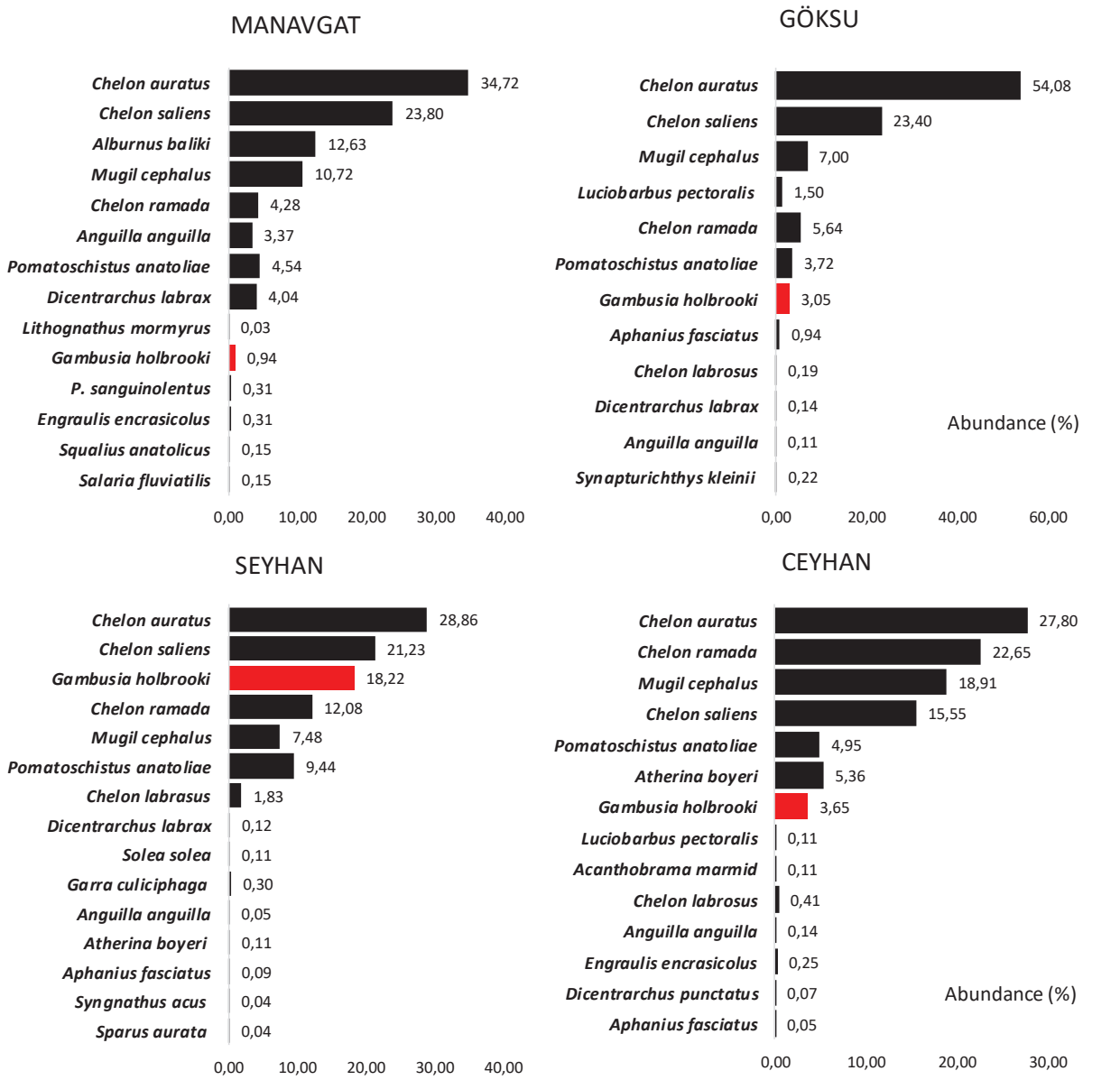

Fig. 2. Relative abundance (%) of alien *Gambusia holbrooki* and native fish species found to occur at juvenile stages in the four studied estuaries.

high, and 1.2 x 2 mm mesh size. In each of the four river estuaries, the different stations were selected and sampled as representatives of the different river habitats, including river mouths, canals and brackish water. After collection of the samples all the specimens were identified at species level according to the updated identification keys available in the literature (Geldiay & Balik 1988, Kottelat & Freyhof 2007).

Results

Gambusia holbrooki was recorded in all of the sampled estuaries where it occurred both with adult and juvenile specimens. The species was found mainly during the spring and summer seasons. Along with *G. holbrooki*, a total of 24 native fish species, belonging to 12 families, were found at juvenile stages in the four estuaries (Table 1).

Gambusia holbrooki was found to be particularly abundant in the Seyhan River system (18.22% of the total species), where it was the second most abundant fish after the native mugilid species (*Chelon auratus* and *C. saliens*) (Fig. 2). On the contrary, *G. holbrooki* occurred with lower abundances in Göksu (3.05%), Ceyhan (3.65%), and Manavgat (0.94%) estuaries (Fig. 2).

Among all sampled species, those which particularly require attention in terms of conservation

were the European eel *Anguilla anguilla,* listed as critically endangered according to the IUCN, the endangered *Alburnus baliki,* an endemic species known to occur only in the Manavgat River and the Turkish endemic goby *Pomatoschistus anatoliae*, a species which has been only recently described but not much studied and not yet evaluated by the IUCN (Table 1).

Discussion

This study reports the first occurrence of *G. holbrooki* in the estuaries of the rivers Ceyhan, Seyhan, Göksu, and Manavgat. With regard to Ceyhan and Seyhan river systems, *G. holbrooki* was previously reported to occur upstream of the dam lakes (Erk'akan & Ozdemir 2011, Alagöz Ergüden & Göksu 2012). Further studies are needed to find out whether the presence of *G. holbrooki* in the estuary areas of Ceyhan and Seyhan rivers could be due to a passive downstream spread of the species or due to new introduction/ release.

With regard to the Göksu and Manavgat rivers this study reports the first occurrence of *G. holbrooki* in the entire river systems. The previous studies on fish fauna of the Göksu River have not reported the presence of *Gambusia* sp. (Kucuk et al. 2007). Therefore, the occurrence of the species in the Göksu estuary could be due to a recent introduction. Regarding the Manavgat River, although no scientific study has ever indicated the occurrence of *G. holbrooki*, it is reported by the local media that the respective municipalities has recently released the species for biological control of mosquito larvae in some localities in the Manavgat basin. Further studies are encouraged to clarify the entity of these releases with the aim to involve the local administration and stakeholders and increase their knowledge about the risk posed by this species.

The introduction or spread of *G. holbrooki* into natural water bodies is a worldwide recognised threat and the deriving environmental cost there from could be extremely high (Pyke 2008). Previous experimental studies have demonstrated the negative effects of *Gambusia* sp. on other fish species (Arthington & Lloyd 1989, Courtenay & Meffe 1989, Galat & Robertson 1992, Ayala et al. 2007). Negative impact has been observed to occur through direct predation or physical injury. This pressure leads to decrease in survival and recruitment, with consequent reduction of the impacted population (Blaustein 1992, Schaefer et al. 1994), and even to local extinction (Arthington & Lloyd 1989, Courtenay & Meffe 1989, Galat & Robertson 1992). In addition, other researchers report that populations of some fish species have positively increased their density and status after natural or artificial reduction of *G. holbrooki* (Meffe 1983, Galat & Robertson 1992).

Ayala et al. (2007) investigated the negative effect of *G. affinis* on the endangered cyprinid the least chub *Iotichthys phlegethontis* (Cope, 1874). They found that aggression by *G. affinis* can force the cohabiting species move toward less suitable habitats characterised, for example, by a higher exposure to the predators or scarce availability of resources. These reports are particularly interesting in the case of the four Mediterranean estuaries considered in the present study, because among the native fish found to occur together with *G. holbrooki* there were species of particular conservation interest such as *A. anguilla* or the endemics *A. baliki* and *P. anatoliae*. The presence of *G. holbrooki* in these localities that could serve as recruitment areas for the populations of the mentioned sensitive native species, may represent an additional threat to their survival and may distort the ecological equilibrium of the river estuaries ecotones. Previous researchers have already reported the occurrence of other alien fish species in the four investigated rivers (Kucuk et al. 2007, Erk'akan & Ozdemir 2011, Alagöz Ergüden & Göksu 2012).

Ayala et al. (2007) also reported that the intensity of predation of *G. affinis* on *I. phlegethontis* decreases with the chub's increase in size. This indicates that small size species or species in juvenile stages are the most vulnerable to the impact of *G. affinis*. With regard to the four examined estuarine systems, some small size species such as *Aphanius fasciatus*, *Parablennius sanguinolentus* and *Salaria fluviatilis* were found to occur together with *G. holbrooki*. The populations of these small size species, although currently not listed as threatened by the IUCN, may be potentially impacted by the presence of *G. holbrooki* and deserve special attention.

Previous studies reported that *G. affinis* and *G. holbrooki* are not more effective than the native predators of mosquitoes and that their wide use as biological control agents is not strongly justified by the final results (Washino 1968, Reed & Bryant 1975). In some cases their biological control is considered to be even ineffective (Lloyd et al. 1986). Currently, it is widely accepted that the effect of the species as a mosquitos' predator is minimal and the presence of the species may even exacerbate the problem, due to its voracious appetite for mosquito larvae (Allen et al. 2002). More specifically, some

authors reported that under laboratory conditions, species of the genus *Aphanius* are more useful than *G. affinis* in preying on mosquitoes (Homski et al. 1994, Al-Akel & Sullman 2011). Further studies are needed to evaluate in field whether the native species like *A. fasciatus* could act as effective predators of mosquitoes compared to *G. holbrooki* and whether the presence of this species have affected the populations of the native species in the studied habitats.

Once established, *G. holbrooki* is difficult to eliminate because it can rapidly colonise new areas, increase in numbers and repopulate areas after reduction (Hildebrand 1919, Self 1940, Lloyd et al. 1986). Moreover, it has been reported that when introduced in a new habitat *G. holbrooki* can spread to a level to become one of the most abundant fish species (Arthington & Milton 1983, Kilby 1955, Morton et al. 1988, Webb & Joss 1997) as it was observed in the present study for the Seyhan estuary.

Taking in consideration all of the above, the best method to reduce the negative impact of *G. holbrooki* is to control their further spread through banning the intentional release by mosquito-control agencies and continue the monitoring of the estuary habitats, which are important for the survival of a great number of marine and freshwater native species.

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References

Able K. W. 2005. A re-examination of fish estuarine dependence: Evidence for connectivity between estuarine and ocean habitats. Estuarine, Coastal and Shelf Science 64 (1): 5–17.

Akin S., Buhan E., Winemiller K. O. & Yilmaz H. 2005. Fish assemblage structure of Koycegiz Lagoon–Estuary, Turkey: Spatial and temporal distribution patterns in relation to environmental variation. Estuarine, Coastal and Shelf Science 64 (4): 671–684.

Alagöz Ergüden S. & Göksu M. Z. L. 2012. The fish fauna of the Seyhan Dam Lake (Adana). Journal of FisheriesSciences. com 6 (1): 39–52.

Al-Akel A. S. & Sullman E. M. 2011. Biological control agent for mosquito larvae: Review on the killifish, *Aphanius dispar dispar* (Rüppel, 1829). African Journal of Biotechnology 10 (44): 8683–8688.

Allen G. R., Midgley S. H. & Allen M. 2002. Field guide to the freshwater fishes of Australia. Perth, Australia: Western Australian Museum, 394 p.

Arthington A. H. & Lloyd L. N. 1989. Introduced Poeciliidae in Australia and New Zealand. In: Meffe G. K. & Snelson S. S. (Ed.) Evolution and Ecology of Livebearing Fishes (Poeciliidae). New York: Prentice-Hall, pp. 333–348.

Arthington A. H. & Milton D. A. 1983. Effects of urban development and habitat alterations on the distribution and abundance of native and exotic freshwater fish in the Brisbane region, Queensland. Australian Journal of Ecology 8 (2): 87–101.

Ayala J. R., Rader R. B., Belk M. C. & Schaalje G. B. 2007. Ground-truthing the impact of invasive species: spatiotemporal overlap between native least chub and introduced western mosquitofish. Biological Invasions 9: 857–869.

Aydin H., Gaygusuz Ö., Tarkan A. S., Top N., Emiroğlu Ö. & Gürsoy Gaygusuz Ç. 2011. Invasion of freshwater bodies in Marmara Region (NW-Turkey) by nonnative gibel carp, *Carassius gibelio* (Bloch, 1782). Turkish Journal of Zoology 35: 829–836.

Beck M. W., Heck K. L., Able K. W., Childers D. L., Eggleston D. B., Gillanders B. M. Halpern B., Hays C. G., Hoshino K., Minello T. H., Orth R. J., Sheridan P. F. & Weinstein M. P. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51 (8): 633–641.

Blaber S. J. M., Cyrus D. P., Albaret J.-J., Ching C. V., Day J. W. Elliott M., Fonseca M. S., Hoss D. E., Orensanz J., Potter I. C. & Silvert W. 2000. Effects of fishing on the structure and functioning of estuarine and nearshore ecosystems. ICES Journal of Marine Science 57 (3): 590–602.

Blaustein L. 1992. Larvivorous fishes fail to control mosquitoes in experimental rice plots. Hydrobiologia 232 (3): 219–232.

Cambray J. A. 2003. Impact on indigenous species biodiversity caused by the globalisation of alien recreational freshwater fisheries. Hydrobiologia 500: 217–230.

Cooper J. A. G., Ramm A. E. L. & Harrison T. D. 1994. The estuarine health index: A new approach to scientific information transfer. Ocean & Coastal Management 25 (2): 103–141.

Cope N. J. & Winterbourn M. J. 2004. Competitive interactions between two successful molluscan invaders of freshwaters: an experimental study. Aquatic Ecology 38: 83–91.

Costa M. J. & Bruxelas A. 1989. The structure of fish communities in the Tagus Estuary, Portugal, and its role as a nursery for commercial fish species. Scientia Marina 53 (2–3): 561–566.

Costa M. J., Cabral H. N., Drake P., Economou A. N., Fernandez-Delgado C., Gordo L., Marchand J. & Thiel R. 2002. Recruitment and production of commercial species in estuaries. In: Elliott M. & Henderson P. A. (Ed). Fishes in estuaries. USA: Blackwell, pp. 54–123.

Costanza R., D'Arge R., De Groot R., Farber S., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R. V., Paruelo J., Raskin R. G., Sutton P. & van den Belt M. 1997. The value of the world's ecosystem services and natural capital. Nature 387 (6630): 253–260.

Courtenay W. R & Meffe G. K. 1989. Small fish in strange places: A review of introduced poeciliids. In: Meffe G. K. & Snelson F. F. (Eds.) Ecology and Evolution of Livebearing Fishes. New York: Prentice-Hall, pp. 319–332.

Ergüden S.A. 2013. Age, growth, sex ratio and diet of eastern

mosquitofish *Gambusia holbrooki* Girard, 1859 in Seyhan Dam Lake (Adana/Turkey). Iran Journal Fish Science 12 (1): 204–218.

Erk'akan F. & Ozdemir F. 2011. Revision of the fish fauna of the Seyhan and Ceyhan River basins in Turkey. Research Journal of Biological Sciences 6 (1): 1–8.

Froese R. & Pauly D. 2019. FishBase. World Wide Web electronic publication. www.fishbase.org, version (04/2019).

Galat D. L. & Robertson B. 1992. Response of endangered *Poeciliopsis occidentalis sonoriensis* in the Rio Yaqui drainage, Arizona, to introduced *Gambusia affinis*. Environmental Biology of Fishes 33: 249–64.

Garcia-Berthou E. & Moyle P. B. 2011. Rivers. In: Simberloff D. & Rejmánek M. (Eds.) Berkeley & Los Angeles: University of California Press, pp. 609–612.

Garcia-Berthou E., Alcaraz C., Pou-Rovira Q., Zamora L., Coenders G. & Feo C. 2005. Introduction pathways and establishment rates of invasive aquatic species in Europe. Canadian Journal of Fisheries and Aquatic Sciences 62 (2): 453–463.

Geldiay R. & Balik S. 1988. Freshwater fishes of Turkey. [Türkiye Tatlısu Balıkları Kitabı I. Baskı.] İzmir: Ege Üniversitesi Basım Evi, 519 p. (In Turkish)

Gillanders B. M., Able K. W., Brown J. A., Eggleston D. B. & Sheridan P. F. 2003. Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. Marine Ecology Progress Series 247: 281–295.

Global Invasive Species Database 2019. Downloaded from http://www.iucngisd.org/gisd/100_worst.php

Goldberg E. D. 1995. Emerging problems in the coastal zone for the twenty-first century. Marine Pollution Bulletin 31 (4–12): 152–158.

Haedrich R. L. 1983. Estuarine fishes. In: Ketchum B. (Ed.) Ecosystems of the World. Estuarine and Enclosed Seas. Amsterdam: Elsevier, pp. 183–207.

Helfman G. S. 2007. Fish conservation: A guide to understanding and restoring global aquatic biodiversity and fishery resources. Washington, DC: Island Press, 584 p.

Hildebrand S. F. 1919. Fishes in relation to mosquito control in ponds. Public Health Reports (1896–1970) 34 (21): 1113–1128.

Homski D., Goren M. & Gasith A. 1994. Comparative evaluation of the larvivorous fish *Gambusia affinis* and *Aphanius dispar* as mosquito control agents. Hydrobiologia 284: 137–146.

Hurlbert S. H. & Mulla H. S. 1981. Impacts of mosquitofish (*Gambusia affinis*) predation on plankton communities. Hydrobiologia 83: 125–51.

Hurlbert S. H., Zedler J. & Fairbanks D. 1972. Ecosystem alteration by mosquitofish (*Gambusia affinis*) predation. Science 175 (4022): 639–641.

Innal D. & Ozdemir D. 2012. Species composition of fish community in Kundu Estuary (Antalya – Turkey) and their length-weight relationships. Asian Journal of Animal and Veterinary Advances 7 (11): 1191–1197.

Johnson B. M., Arlinghaus R. & Martinez P. J. 2009. Are we doing all we can to stem the tide of illegal fish stocking? Fisheries 34 (8): 389–394.

Kennish M. J. 2002. Environmental threats and environmental future of estuaries. Environmental Conservation 29 (1): 78–107.

Kilby J. D. 1955. The fishes of two Gulf coastal marsh areas of Florida. Tulane Studies in Zoology 2: 175–247.

Kottelat M. & Freyhof J. 2007. Handbook of European freshwater fishes. Cornol, Switzerland, and Berlin, Germany: Kottelat and Freyhof, 646 p.

Krumholz L. A. 1948. Reproduction in the western mosquitofish *Gambusia affinis* and its use in mosquito control. Ecological Monographs 18 (1): 1–43.

Kucuk F., Gümüş E., Gülle I. & Güçlü S. S. 2007. The fish fauna of the Göksu River (Turkey): Taxonomic and zoogeographic features. Turkish Journal of Fisheries and Aquatic Sciences 7: 53–63.

Kurtul I. & Sari H. M 2020. Length–weight relationships of invasive mosquitofish (*Gambusia holbrooki* Girard, 1859) in 23 river basins of Turkey. Turkish Journal of Zoology 44: 324–334.

Lawler S. P., Dritz D., Strange T. & Holyoak M. 1999. Effects of introduced mosquitofish and bullfrogs on the threatened California Red-Legged Frog. Conservation Biology 13 (3): 613–622.

Lenanton R. C. J. & Potter I. C. 1987. Contribution of estuaries to commercial fisheries in temperate Western Australia and the concept of estuarine dependence. Estuaries 10 (1): 28–35.

Lintermans M. 2004. Human-assisted dispersal of alien freshwater fish in Australia. New Zealand Journal of Marine and Freshwater Research 38 (3): 481–501.

Lloyd L. N., Arthington A. H. & Milton D. A. 1986. The mosquitofish – a valuable mosquito-control agent or a pest? In: Kitching R. L. (Ed.) The Ecology of Exotic Animals and Plants. Some Australian Case Histories. Brisbane: Wiley, pp. 6–25.

Lotze H. K., Lenihan H. S., Bourque B. J., Bradbury R. H., Cooke R. G., Kay M. C., Kidwell S. M., Kirby M. X., Peterson C. H. & Jackson J. B. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312 (5781): 1806–1809.

Mack R. N., Simberloff D., Lonsdale W. M., Evans H., Clout M. & Bazzaz F. 2000. Biotic invasions: Causes, epidemiology, global consequences and control. Ecological Applications 10 (3): 689–710.

Marchand J. 1980. Seasonality abundance and diversity of the ichthyofauna of the lower Loire Estuary in 1977–1978 (France). Annales de l'Institut océanographique (Paris) 56: 127–137.

Marques M., da Costa M. F., Mayorga M. I. D. & Pinheiro P. R. C. 2004. Water environments: anthropogenic pressures and ecosystem changes in the Atlantic drainage basins of Brazil. Ambio 33 (1–2): 68–77.

Meffe G. K. 1983. Attempted chemical renovation of an Arizona springbrook for management of the endangered Sonoran topminnow. North American Journal of Fisheries Management 3 (3): 315–321.

Miller J. M. 1985. Effects of freshwater discharges into primary nursery areas for juvenile fish and shellfish: Criteria for their protection. Pp. 64–84. In: Gilliam W., Miller J., Pietrafesa L. & Skaggs W. (Eds.), Water Management and Estuarine Nurseries, UNC Sea Grant Publ. UNC-SG-WP-85-2.

Miura T., Takahashi R. M. & Wilder W. H. 1984. Impact of the mosquitofish (*Gambusia affinis*) on a rice-field ecosystem when used as a mosquito control agent. Mosquito News 44: 510–517.

Morton R. M., Beumer J. P. & Pollock B. R. 1988. Fishes of a subtropical Australian saltmarsh and their predation upon mosquitoes. Environmental Biology of Fishes 21: 185–194.

Özuluğ N., Altun Ö. & Meriç N. 2005. On the fish fauna of Lake İznik (Turkey). Turkish Journal of Zoology 29: 371–375.

Özuluğ M., Tarkan A. S., Gaygusuz Ö. & Gürsoy Ç. 2007. Two new records for the fish fauna of lake Sapanca basin (Sakarya, Turkey). Journal of Fisheries Sciences 1 (3): 152–159.

Özuluğ M., Saç G. & Gaygusuz Ö. 2013. New distribution areas for invasive *Gambusia holbrooki*, *Carassius gibelio* and *Pseudorasbora parva* (Teleostei) from Turkey. Istanbul University Journal of Fisheries and Aquatic Sciences 28 (1): 1–22. (In Turkish, English summary)

Page L. M. & Burr B. M. 1991. A field guide to freshwater fishes of North America and North of Mexico. Boston: Houghton Mifflin Company, 432 p.

Pyke G. H. 2005. A review of the biology of *Gambusia affinis* and *G. holbrooki*. Reviews in Fish Biology and Fisheries 15: 339–365.

Pyke G. H. 2008. Plague minnow or mosquito fish? A review of the biology and impacts of introduced *Gambusia* species. Annual Review of Ecology, Evolution, and Systematics 39: 171–191.

Reed D. E. & Bryant T. J. 1975. Fish population studies in Fresno County rice fields. Proceedings and Papers of the Annual Conference of the California Mosquito Control Association 43: 139–141.

Schaefer J. F., Heulet S. T. & Farrell T. M. 1994. Interactions between two poeciliid fishes (*Gambusia holbrooki* and *Heterandria formosa*) and their prey in a Florida marsh. Copeia 1994 (2): 516–520.

Self J. T. 1940. Notes on the sex cycle of *Gambusia affinis affinis*, and its habits and relation to mosquito control. The American Midland Naturalist 23 (2): 393–398.

Streftaris N. & Zenetos A. 2006. Alien marine species in the Mediterranean – the 100 'Worst Invasives' and their ımpact. Mediterranean Marine Science 7 (1): 87–118.

Tarkan A. S., Marr S. M. & Ekmekçi F. G. 2015. Non-native and translocated freshwater fish species in Turkey. FiSHMED Fishes in Mediterranean Environments 003: 28 p.

Vasconcelos R. P., Reis-Santos P., Maia A., Fonseca V., França S., Wouters N., Costa M. J. & Cabral H. N. 2010. Nursery use patterns of commercially important marine fish species in estuarine systems along the Portuguese coast. Estuarine, Coastal and Shelf Science 86 (4): 613–624.

Veenvliet P. 2007. Species identity of *Gambusia* (Pisces: Poeciliidae) introduced to Slovenia. Natura Sloveniae 9 (1): 43–46.

Washino R. K. 1968. Predator prey studies in relation to an integrated mosquito control program: a progress report. Proceedings and Papers of the Annual Conference of the California Mosquito Control Association 36: 33–34.

Webb C. & Joss J. 1997. Does predation by the fish *Gambusia holbrooki* (Atheriniformes: Poeciliidae) contribute to declining frog populations? Australian Journal of Zoology 30 (3): 316–323.