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RAPID COMMUNICATION

Note on important and novel findings

The first finding of the red swamp crayfish *Procambarus clarkii* in Greece calls for rapid measures

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Abstract
This contribution presents the first record of the invasive non-native red swamp crayfish *Procambarus clarkii* (Girard, 1852) in Greece and the Balkans. The crayfish was found during a fish monitoring expedition in the lower reaches of the Vosvozis River, near the city of Komotini, Thrace (northeastern Greece). The finding of *P. clarkii* in Greece expands the southernmost geographical range of the species in the Balkans and calls for immediate actions in preventing its further expansion to other water bodies and towards strict control of aquarium trade.

Keywords Non-native · Freshwater · New record · Invasive species · Pet trade

Introduction

The red swamp crayfish *Procambarus clarkii* (Girard, 1852) is a widely distributed freshwater benthic crustacean, being now considered the most cosmopolitan freshwater crayfish species in the world (Gherardi 2006; Loureiro et al. 2015; Souty-Grosset et al. 2016). Native to northeastern Mexico and the southern USA, it has been introduced in all continents except Antarctica and Oceania (Gherardi 2006; Souty-Grosset et al. 2016). It is ranked in the top three among the ‘‘100 worst’’ alien species in Europe (Netwing et al. 2018) and it is listed as an invasive species of Union concern (European Commission2020). Species included in the Union list are subject to restrictions and measures and most EU countries have banned importation of live crayfish. Due to its biological and behavioral plasticity and dispersal patterns, it can colonize a wide range of environments, from rivers, lakes, reservoirs, ponds and irrigation channels, to brackish lagoons and estuaries (Casellato and Masiero 2011; Dörr et al. 2020; Gherardi 2007; Hobbs et al. 1989; Souty-Grosset et al. 2016). *P. clarkii* also inhabits terrestrial or semi-natural swamps, terrestrial humid zones, such as meadows or rice fields, and recently it was discovered for the first time in caves in Portugal and Italy (Mazza et al. 2014). It exhibits high rates of reproduction (parthenogenesis with low propagule pressure under some conditions), cyclical dimorphism between two sexual morphotypes not only in males but also in females (Hamasaki et al. 2020), high rates of aggression towards native as well as non-native crayfish species (Veselý et al. 2021), opportunistic feeding behavior, ability to withstand droughts by digging deep burrows (Arce and Dieguez-Uribeondo 2015; Guo et al. 2019) and high dispersion ability (Gherardi 2006; Kouba et al. 2021).

The negative impacts of *P. clarkii* on native aquatic plants and animals are well documented (e.g., Donato et al. 2018; Loureiro et al. 2015; Souty-Grosset et al. 2016; Twardochleb et al. 2013). Briefly, it acts as a keystone species in food webs, causing a significant decrease in biomass and biodiversity of native communities. It also alters habitat structure and eventually outplaces native as well as non-native crayfish species. Being a carrier of the oomycete *Aphanomyces astaci* Schikora, which is the causative agent of the ‘crayfish plague’ (Diéguez-Uribeondo and Soderhall 1993), *P. clarkii* may also lead to mass mortalities of astacids worldwide

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(Filipová et al. 2013; Martín-Torrijos et al. 2018, 2021; Peiró et al. 2016; Putra et al. 2018).

In Europe, the species was initially introduced from Louisiana to Spain in 1973 and 1974 (Oficialdegui et al. 2019) and during the last 50 years it established populations in at least 18 European countries/territories (Lipták et al. 2023a) through translocations and multiple secondary introductions. The most important vectors of introduction of the species are aquaculture, aquarium trade, accidental escapes from garden ponds, stocks intended for human consumption, or intentional releases to replace other crayfish species (e.g., Anastácio and Marques 1995). Its presence in captivity in Greece was first reported in 2011 (Papavlasopoulou et al. 2014), and despite being banned and listed as invasive species, several color varieties of *P. clarkii* are sold in pet shops in Greece via the internet. It is also widely present on the aquarium market in other European countries such as Germany, the Czech Republic, Poland, Italy, and Serbia (Lipták et al. 2023b; Maciaszek et al. 2019). The species' invasiveness risk was assessed as very high globally by AS-ISK (Vilizzi et al. 2021) and for the Eastern Mediterranean (Tarkan et al. 2021) and Greece by FISK (Papavlasopoulou et al. 2014).

In this contribution, the red swamp crayfish *P. clarkii* is reported for the first time in the wild, in Greece, constituting also the first record for the Balkans.

Methods

Four *P. clarkii* individuals were found in the mid-lower reach of the Vosvozis River, northeastern Greece (Fig. 1) during a routine EU Water Framework Directive monitoring on 15 May 2023. Specimens were photographed alive on-site and released back into the water (Fig. 2). Benthic habitat was mainly composed of gravel and sand, silt, and mud, and abundant filamentous algae, thus indicating eutrophic conditions. The fish fauna at the location is mainly represented by the Orpheus dace *Squalius orpheus*, the Bulgarian spined loach *Cobitis strumicae*, the Black Sea chub *Petroleuciscus borysthenicus*, the eastern mosquitofish *Gambusia holbrooki*, and the Prussian carp *Carassius gibelio*, and with lower numbers by the Aegean gudgeon *Gobio bulgaricus*, the critically endangered cyprinid *Alburnus vistonicus*, and the round-scaled barbel *Barbus cyclolepis*. There are no historical or present data related to any population of non-indigenous crayfish species in water bodies of the entire catchment area.

Vosvozis River is situated in the eastern part of Eastern Macedonia and Thrace Region, northeastern Greece, near the city of Komotini. With the catchment area of 340 km^2, this river has a total length of 53 km and discharges into the Ismarida Lake before entering the Thracian Sea (the northernmost part of the Aegean Sea). The main and most significant pollution sources come from industrial activities which discharge their wastewater directly into the river or in its tributaries, without any treatment by the domestic wastewater treatment plant of the city of Komotini and by private septic tanks (half of the population, 70,000 inhabitants, is served by such systems).

Physicochemical parameters at the sampling location were measured with a HANNA multiparameter water quality meter (HI98194, USA), while water samples were collected and transferred to Hellenic Centre for Marine Research (HCMR) laboratories for nutrient and major ion analysis.

Results and discussion

The physicochemical and habitat characteristics of the sampling locality are presented in Table 1. Water quality of the sampling site was poor, as classified according to the relevant quality index (Skoulikidis et al. 2006).

The particular reach of the Vosvozis River, where the individuals of *P. clarkii* were found, has been monitored for eight consecutive years since 2015 and the crayfish has never been previously detected. The coloration of the four individuals represents the 'neon red' crayfish aquarium breed, which is exclusively tank-raised. Based on its coloration, we came to a conclusion that the individuals were released by an aquarium hobbyist, possibly from Komotini city (c.f., Maciaszek et al. 2019), and survived at least until collection in the environment. However, during the subsequent sampling campaign of September 2023, where eight crayfish traps were deployed in a 200 m river stretch, no individuals were found. Thus, intensive and long-term monitoring of the river basin with both conventional field surveys and advanced molecular techniques such as the eDNA method, are needed to investigate (1) whether there is a viable and established population of *P. clarkii* in the river, and (2) whether the individuals previously migrated to/from Ismarida Lake, which is located few kilometers downstream from the sampling location, or any other upstream segments (Fig. 1). Once introduced in the wild, its spread is expected to be rapid through natural and/or anthropogenic dispersal, as indicated by the available literature (Gherardi 2006; Kouba et al. 2021). When detected, the management measures can include local removal with traps to lower the intraspecific density, hence lowering the tendency of a population to further spread. A targeted information campaign for the impacts of *P. clarkii* on aquatic species and ecosystems,

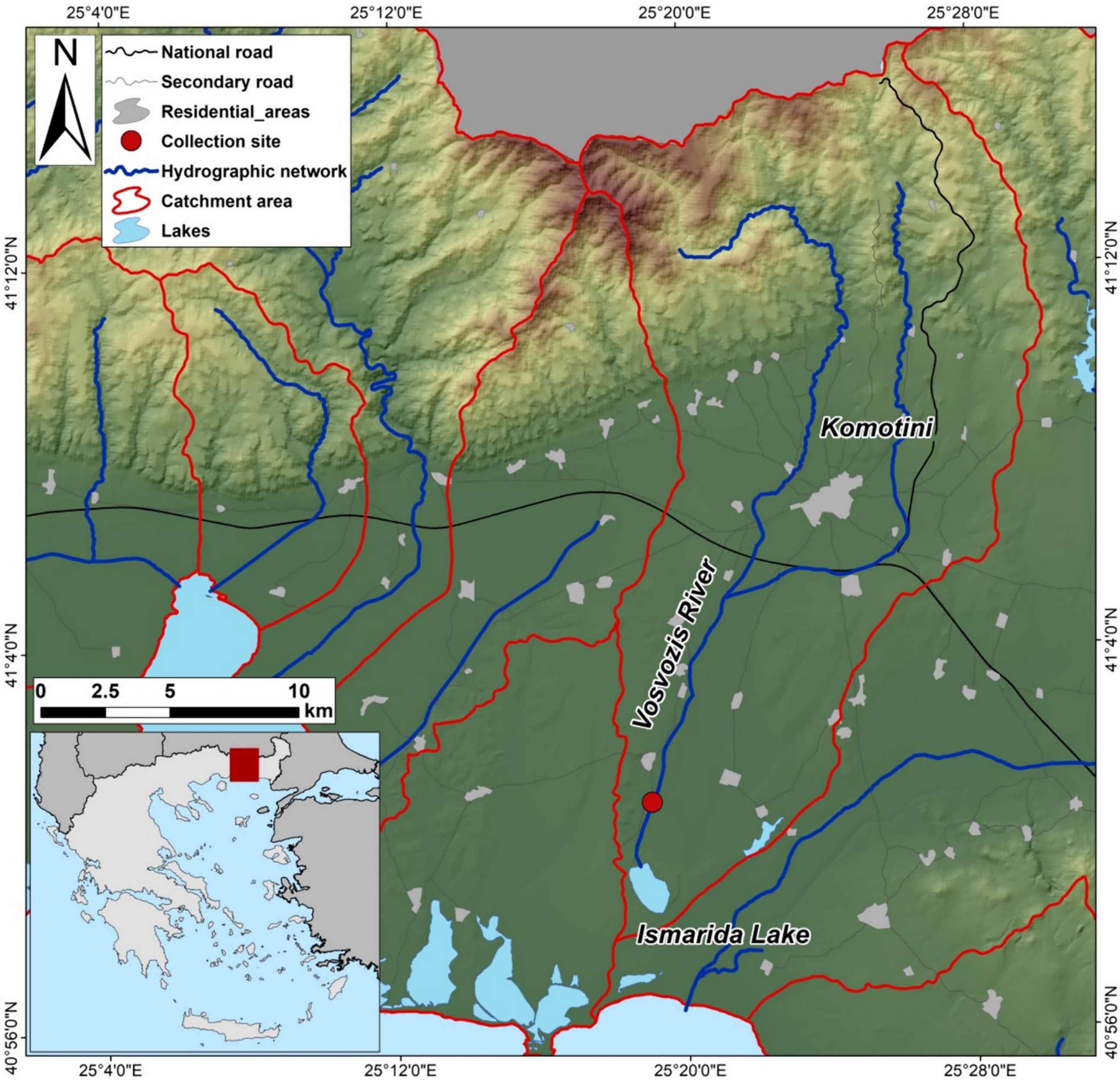

Fig. 1 Collection site of *P. clarkii* in Vosvozis River, Thrace (Greece)

but also for accompanied monetary costs (Kouba et al. 2022) are necessary to prevent secondary introductions. Yet, the ultimate eradication of the species is rarely achieved especially in riverine environments (e.g., Lidova et al. 2019). Therefore, public awareness and communication are also essential for preventing further species' introductions and translocations (Lipták et al. 2023c). Moreover, on the country-level, the predominant focus should be directed to the strict monitoring and control of illegal crayfish imports via the aquarium trade.

Fig. 2 *P. clarkii* female individuals from Vosvozis River, Thrace (Greece)

Table 1 Physicochemical and habitat characteristics of the *P. clarkii* collection site in Vosvozis River, Thrace (Greece)

Parameters (units)	Values
pH	7.57
Water temperature (°C)	15.9
Conductivity (μS/cm)	492
Total dissolved solids (mg/L)	247
Salinity (ppt)	0.24
Turbidity (NTU)	14.98
Saturated oxygen (%)	81.49
Dissolved oxygen (mg/L)	8.01
Biochemical oxygen demand (mg/L)	0.3
Cl^- (mg/L)	40.22
Si (mg/L)	6.22
N-NH_4 (mg/L)	1.962
N-NO_2 (mg/L)	0.329
N-NO_3 (mg/L)	2.821
Dissolved inorganic nitrogen (mg/L)	5.112
Total nitrogen (mg/L)	5.364
P-PO_4 (mg/L)	0.286
Total phosphorus(mg/L)	0.303
Gravel and sand (2–64 mm) (%)	50
Mud (0.0625–2 mm) (%)	20
Silt and clay (< 0.0625 mm) (%)	30
Aquatic vegetation (%)	40 (filamentous algae)
Canopy cover (%)	0
Physicochemical quality	Poor

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Data availability Not applicable.

References

Anastácio PM, Marques JC (1995) Population biology and production of the red swamp crayfish *Procambarus clarkii* (Girard) in the lower Mondego river valley, Portugal. J Crustac Biol 15:156–168. https://doi.org/10.2307/1549018

Arce JA, Diéguez-Uribeondo J (2015) Structural damage caused by the invasive crayfish *Procambarus clarkii* (Girard, 1852) in rice fields of the Iberian peninsula: a study case. Fundam Appl Limnol 186:259–269. https://doi.org/10.1127/fal/2015/0715

Casellato S, Masiero L (2011) Does *Procambarus clarkii* (Girard, 1852) represent a threat for estuarine brackish ecosystems of northeastern Adriatic coast (Italy)? J Life Sci 5:549–554

Commission E (2020) Invasive alien species of union concern. Publications office of the European union, Luxembourg, p 42

Diéguez-Uribeondo J, Soderhall K (1993) *Procambarus clarkii* Girard as a vector for the crayfish plague fungus, *Aphanomyces astaci* Schikora. Aquacult Fish Manage 24:761–765. https://doi.org/10.1111/j.1365-2109.1993.tb00655.x

Donato R, Rollandin M, Favaro L, Ferrarese A, Pessani D, Ghia D (2018) Habitat use and population structure of the invasive red swamp crayfish *Procambarus clarkii* (Girard, 1852) in a protected area in northern Italy. Knowl Manag Aquat Ecosyst 419:12. https://doi.org/10.1051/kmae/2018002

Dörr AJM, Scalici M, Caldaroni B, Magara G, Scoparo M, Goretti E, Elia AC (2020) Salinity tolerance of the invasive red swamp crayfish *Procambarus clarkii* (Girard, 1852). Hydrobiologia 847:2065–2081. https://doi.org/10.1007/s10750-020-04231-z

Filipová L, Petrusek A, Matasová K, Delaunay C, Grandjean F (2013) Prevalence of the crayfish plague pathogen *Aphanomyces astaci* in populations of the signal crayfish *Pacifastacus leniusculus* in France: evaluating the threat to native crayfish. PLoS One 8:e70157. https://doi.org/10.1371/journal.pone.0070157

Gherardi F (2006) Crayfish invading Europe: the case study of *Procambarus clarkii*. Mar Freshw Behav Physiol 39:175–191. https://doi.org/10.1080/10236240600869702

Gherardi F (2007) Understanding the impact of invasive crayfish. In: Gherardi F (ed) Biological invaders in inland waters: profiles, distribution, and threats. Springer, Rotterdam, pp 507–542

Guo W, Kubec J, Veselý L, Hossain MS, Buřič M, McClain R, Kouba A (2019) High air humidity is sufficient for successful egg incubation and early post-embryonic development in the marbled crayfish (*Procambarus virginalis*). Freshw Biol 64:1603–1612. https://doi.org/10.1111/fwb.13357

Hamasaki K, Osabe N, Nishimoto S, Dan S, Kitada S (2020) Sexual dimorphism and reproductive status of the red swamp crayfish *Procambarus clarkii*. Zool Studies 59:e7. https://doi.org/10.6620/ZS.2020.59-07

Hobbs HH, Jass JP, Huner JV (1989) A review of global crayfish introductions with particular emphasis on two North American species (Decapoda, Cambaridae). Crustaceana 56: 299–316. http://www.jstor.org/stable/20104461

Kouba A, Lipták B, Kubec J, Bláha M, Veselý L, Haubrock PJ, Oficialdegui FJ, Niksirat H, Patoka J, Buric M (2021) Survival, growth, and reproduction: comparison of marbled crayfish with four prominent crayfish invaders. Biology 10:422. https://doi.org/10.3390/biology10050422

Kouba A, Oficialdegui FJ, Cuthbert RN, Kourantidou M, South J, Tricarico E, Gozlan RE, Courchamp F, Haubrock PJ (2022) Identifying economic costs and knowledge gaps of invasive aquatic crustaceans. Sci Total Environ 813:152325. https://doi.org/10.1016/j.scitotenv.2021.152325

Lidova J, Buric M, Kouba A, Velisek J (2019) Acute toxicity of two pyrethroid insecticides for five non-indigenous crayfish species in Europe. Vet Med (praha) 64:125–133. https://doi.org/10.17221/136/2018-VETMED

Lipták B, Prati S, Oficialdegui FJ, Apfelová M, Pekárová S, Kautman J, Janský V, Kouba A (2023a) Springing up like mushrooms: established populations of invasive red swamp crayfish in Slovakia. https://doi.org/10.21203/rs.3.rs-3515877/v1. (unpublished)

Lipták B, Zorić K, Patoka J, Kouba A, Paunović M (2023b) The aquarium pet trade as a source of potentially invasive crayfish species in Serbia. Biologia 78:2147–2155. https://doi.org/10.1007/s11756-023-01347-0

Lipták B, Kouba A, Patoka J, Paunović M, Prokop P (2023c) Biological invasions and invasive species in freshwaters: Perception of the general public. Hum Dimens Wildl 29:48–63. https://doi.org/10.1080/10871209.2023.2177779

Loureiro TG, Anastácio PMSG, Araujo PB, Souty-Grosset C, Almerão MP (2015) Red swamp crayfish: biology, ecology and invasion—an overview. Nauplius 23:1–19. https://doi.org/10.1590/S0104-64972014002214

Maciaszek R, Bonk M, Strużyński W (2019) New records of the invasive red swamp crayfish *Procambarus clarkii* (Girard, 1852) (Decapoda: Cambaridae) from Poland. Knowl Manag Aquat Ecosyst 420:39. https://doi.org/10.1051/kmae/2019033

Martín-Torrijos L, Kawai T, Makkonen J, Jussila J, Kokko H, Diéguez-Uribeondo J (2018) Crayfish plague in Japan: a real threat to the endemic *Cambaroides japonicus*. PLoS ONE 13:e0195353. https://doi.org/10.1371/journal.pone.0195353

Martín-Torrijos L, Martínez-Ríos M, Casabella-Herrero G, Adams SB, Jackson CR, Diéguez-Uribeondo J (2021) Tracing the origin of the crayfish plague pathogen, *Aphanomyces astaci*, to the Southeastern United States. Sci Rep 11:9332. https://doi.org/10.1038/s41598-021-88704-8

Mazza G, Reboleira ASPS, Goncalves F, Aquiloni L, Inghilesi AF, Spigoli D, Stoch F, Taiti S, Gherardi F, Tricarico E (2014) A new threat to groundwater ecosystems: first occurrences of the invasive crayfish *Procambarus clarkii* (Girard, 1852) in European caves. J Cave Karst Stud 76:62–65. https://doi.org/10.4311/2013LSC0115

Nentwig W, Bacher S, Kumschick S, Pysek P, Montserrat Vila M (2018) More than "100 worst" alien species in Europe. Biol Invasions 20:1611–1621. https://doi.org/10.1007/s10530-017-1651-6

Oficialdegui FJ, Clavero M, Sánchez MI, Green AJ, Boyero L, Michot TC, Kawai T, Lejeusne C (2019) Unravelling the global invasion routes of a worldwide invader, the red swamp crayfish (*Procambarus clarkii*). Freshwater Biol 64:1382–1400. https://doi.org/10.1111/fwb.13312

Papavlasopoulou I, Perdikaris C, Vardakas L, Paschos I (2014) Enemy at the gates: introduction potential of non-indigenous freshwater crayfish in Greece via the aquarium trade. Cent Eur J Biol 9:11–18. https://doi.org/10.2478/s11535-013-0120-6

Peiró DF, Almerão MP, Delaunay C, Jussila J, Makkonen J, Bouchon D, Araujo PB, Souty-Grosset C (2016) First detection of the crayfish plague pathogen *Aphanomyces astaci* in South America: a high potential risk to native crayfish. Hydrobiologia 781:181–190. https://doi.org/10.1007/s10750-016-2841-4

Putra MD, Bláha M, Wardiatno Y, Krisanti M, Yonvitner JR, Kamal MM, Mojžišová M, Bystřický PK, Kouba A, Kalous L, Petrusek A, Patoka J (2018) *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. Aquat Conserv Mar Freshw 28:1434–1440. https://doi.org/10.1002/aqc.2970

Skoulikidis N, Amaxidis Y, Bertahas I, Laschou S, Gritzalis K (2006) Analysis of factors driving stream water composition and synthesis of management tools—a case study on small/medium Greek catchments. Sci Total Envir 362:205–241. https://doi.org/10.1016/j.scitotenv.2005.05.018

Souty-Grosset C, Anastacio PM, Aquiloni L, Banha F, Choquer J, Chucholl C, Tricarico E (2016) The red swamp crayfish *Procambarus clarkii* in Europe: impacts on aquatic ecosystems and human well-being. Limnologica 58:78–93. https://doi.org/10.1016/j.limno.2016.03.003

Tarkan AS, Tricarico E, Vilizzi L, Bilge G, Ekmekçi FG, Filiz H, Giannetto D, İlhan A, Killi N, Kirankaya ŞG, Koutsikos N, Kozic S, Kurtul I, Lazzaro L, Marchini A, Occhipinti-Ambrogi A, Perdikaris C, Piria M, Pompei L, Sari H, Smeti E, Stasolla G, Top N, Tsiamis K, Vardakas L, Yapici S, Yoğurtçuoğlu B, Copp GH (2021) Risk of invasiveness of non-native aquatic species in the eastern Mediterranean under current and projected climate conditions. Eur Zool J 88:1130–1143. https://doi.org/10.1080/24750263.2021.1980624

Twardochleb LA, Olden JD, Larson ER (2013) A global meta-analysis of the ecological impacts of nonnative crayfish. Freshwater Sci 32:1367–1382. https://doi.org/10.1899/12-203.1

Veselý L, Ruokonen TJ, Weiperth A, Kubec J, Szajbert B, Guo W, Ercoli F, Bláha M, Buřič M, Hämäläinen H, Koubaet A (2021) Trophic niches of three sympatric invasive crayfish of EU concern. Hydrobiologia 848:727–737. https://doi.org/10.1007/s10750-020-04479-5

Vilizzi L, Copp GH, Hill JE, Adamovich B, Aislabie L, Akin D, Semenchenko V (2021) A global-scale screening of non-native aquatic organisms to identify potentially invasive species under current and future climate conditions. Sci Total Environ 788:147868. https://doi.org/10.1016/j.scitotenv.2021.147868