Rapid Communication

First occurrence of the mysid *Hemimysis anomala* G.O. Sars, 1907 in Lake Stechlin, Germany

James W. E. Dickey[1,2,3,4], Jonathan M. Jeschke[2,3], Marén Lentz[1], Elizabeta Briski[4], Elžbieta Kazanavičiūtė[4,5], Stella A. Berger[1] and Jens C. Nejstgaard[1]

[1]*Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Department of Plankton and Microbial Ecology, Zur alten Fischerhütte 2, 16775 Stechlin, Germany*

[2]*Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Department of Evolutionary and Integrative Ecology, Müggelseedamm 301, 12587 Berlin, Germany*

[3]*Freie Universität Berlin, Institute of Biology, Königin-Luise-Straße 1-3, 14195 Berlin, Germany*

[4]*GEOMAR Helmholtz Centre for Ocean Research Kiel, Wischhofstraße 1-3, 24148 Kiel, Germany*

[5]*Lancaster University, Lancaster, LA1 4YW, UK*

ORCIDs: 0000-0001-7288-5555 (JWED), 0000-0003-3328-4217 (JMJ), 0000-0003-1896-3860 (EB), 0000-0002-8835-545X (SAB), 0000-0003-1236-0647 (JCN)

Corresponding author: James W. E. Dickey (jamesdickey03@gmail.com)

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Abstract

The Black, Azov and Caspian Seas are donor hotspots for non-native species, with many species from the region highly tolerant of abiotic stressors and able to successfully establish, spread and exert impacts around the world. Here we document a new introduction of the bloody red mysid shrimp, *Hemimysis anomala* G.O. Sars, 1907. Discovered for the first time in January 2023 in Lake Stechlin, Germany, at high densities, many questions surround its potential impacts in this deep, formerly oligotrophic, now meso-eutrophic lake of major geological, cultural and ecological importance. Using molecular and morphological identification, the identity of *H. anomala* from two sites in the lake was confirmed. Unlike other mysids normally detected over deeper waters in lakes at night, *H. anomala* has so far only been detected near the surface and at depths shallower than 30 m, but during both night and day, in winter. We outline vital areas for future research and the need for dedicated sampling methods by also highlighting a case study from Lake Müggelsee, Berlin, where the species has been known to exist for over 20 years without being caught in regular plankton tows.

Key words: ecological impact, food webs, invasive alien species, Mysidae, non-native species, Ponto-Caspian, zooplankton

Introduction

The anthropogenic relocation of animals and plants into ecosystems beyond their native ranges poses major threats to global biodiversity (Essl et al. 2020; Pyšek et al. 2020; IPBES 2023). The Ponto-Caspian region, featuring the Black, Azov and Caspian Seas, is a donor hotspot for invasive non-native species (Ricciardi and Rasmussen 1998; Cuthbert et al. 2020). Indeed, many species from this area exhibit wide tolerances for abiotic stressors and are therefore deemed prior-adapted to establish and exert major impacts in new environments (Casties et al. 2016, 2019; Paiva et al. 2018; Pauli et al. 2018). The success and proliferation of non-native species can negatively affect native species, often leading to competition for resources, predation, habitat alteration, or displacement from their natural habitat (Dick and Platvoet 2000; Grabowski et al. 2006). Assessment of the interaction between native and exotic species encompasses their ecophysiological characteristics, habitat preferences, and feeding habits (González-Ortegón et al. 2010).

Central and western European waterways in particular have been subject to the active and passive spread of Ponto-Caspian macroinvertebrates. Indeed, the 20th century saw spread facilitated by Peracarida transplantations in the former USSR, and then via canalisation and expanded shipping corridors through Europe (Soto et al. 2023). This "Ponto-Caspianization" has seen a number of high-profile species establish, spread and exert negative impacts in recipient ecosystems. "Invasional meltdown" has thus been proposed, whereby Ponto-Caspian non-native species have facilitated the establishment of others (Simberloff and Von Holle 1999; Gallardo and Aldridge 2015). For example, zebra mussels, *Dreissena polymorpha* (Pallas, 1771), have been found to provide shelter and suitable habitat structure for Ponto-Caspian amphipods, such as *Echinogammarus ischnus* (Stebbing, 1899), *Gammarus fasciatus* Say, 1818 (Ricciardi 2001) and *Dikerogammarus villosus* (Sowinsky, 1894) (Rolla et al. 2019), which in turn become food sources for Ponto-Caspian gobies, such as *Neogobius melanostomus* (Pallas, 1814) and *Ponticola kessleri* (Günther, 1861) (Polačik et al. 2009). Many species that have established in Europe have also gone on to establish in North America via transoceanic shipping (Ojaveer et al. 2002).

One such example is *Hemimysis anomala* G.O. Sars, 1907, the so-called bloody red mysid shrimp. Capable of surviving in a wide range of salinities and temperatures (Ricciardi et al. 2012), and establishing in lotic and lentic habitats (Ives et al. 2013), the species was deliberately stocked in reservoirs along the Dnieper and Volga Rivers to enhance food resources for fishes in the 1950s and 1960s. In the 1990s, it was discovered in the Baltic Sea (Salemaa and Hietalahti 1993), the river Neckar (Schleuter et al. 1998), the Rhine-Main-Danube river channel system (Wittmann 2007), and since then it has spread through mainland Europe and onto Great Britain and Ireland (Holdich et al. 2006; Minchin and Boelens 2010; Gallagher et al. 2015) as well as North America (Brooking et al. 2010; Yuille et al. 2012). Capable of reaching high densities, *H. anomala* has been linked with a wide range of impacts on recipient ecosystems (Ricciardi et al. 2012; Walsh et al. 2012). For example, predation has had negative effects on zooplankton biomass and diversity (Ketelaars et al. 1999), leading to competition with planktivorous and young-of-the-year fish (Ricciardi et al. 2012). Their generalist diet, known to include detritus, phytoplankton, benthic algae, zooplankton, other invertebrates, and conspecifics, allows them to survive when preferred food sources are limited (Evans et al. 2018). This generalism, as witnessed in other mysid species, has also led to it being predicted that they could also predate upon larval fish and eggs (Boscarino et al. 2020). Again, drawing from other mysid invasions, biomagnification of contaminants and transmission of parasites to higher trophic levels have been theorised (Ricciardi et al. 2012).

Here, we describe the January 2023 discovery of this widespread non-native mysid in Lake Stechlin, a groundwater-fed, isolated lake that is not connected to the extensive river-canal-lake systems in northern Brandenburg, Germany.

Materials and methods

Study system

As the deepest lake (69.5 m) in the Northeast German federal state Brandenburg, with a mean depth of 23.3 m, a volume of 96.9 × 10^6 m^3, and a surface area of 4.5 km^2, Lake Stechlin is of importance for reasons of culture, recreation, tourism and, as the home of the endemic Fontane cisco *Coregonus fontanae* Schulz & Freyhof, 2003 (Mehner and Kasprzak 2011) and the central European glacial relict copepod *Eurytemora lacustris* Poppe, 1887 (Kasprzak et al. 2005), biodiversity. This hard-water lake is located 80 km north of Berlin (53°10′N; 13°02′E) and was formed approximately 12,000 years ago after the Weichselian glaciation. Its water level is dictated by precipitation, evaporation, ground water inflow and temporal runoffs through the surrounding sand layers (Casper 1985; Casper and Koschel 1995). Previously oligotrophic, the past two decades have seen a rapid transition in trophic status to mesotrophy (Kröger et al. 2023), and now eutrophy (Mehner et al. 2024). This is most likely driven by internal legacy phosphorus release from sediments and climate change (Selmeczy et al. 2019; Kröger et al. 2023). Characeae algae were previously common down to 15 m depth (Schulz and Freyhof 2003), but there has been a shift to a macrophyte community typical of eutrophic lakes (Périllon et al. 2018). Further, the phytoplankton assemblage has drastically changed, with an increase in filamentous cyanobacteria (Kröger et al. 2023). Sediment in the lake is typically sandy in shallow areas and muddy in deeper areas. On the shore lies the Rheinsberg Nuclear Power Plant, which was built in the early 1960s but has been decommissioned since 1990, the research Department of Plankton and Microbial Ecology of the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB) that started as a limnological station in 1959, a fishery with docks, a diving station and a tourist boat rental site next to a public beach (Figure 1). The surrounding area is primarily beech, *Fagus sylvatica*, and pine, *Pinus sylvestris*, forest (Pöschke et al. 2018). Historically diversity-poor due to the once oligotrophic nature of the lake, water exchange between nearby lakes Gerlin and Nehmitz for cooling-water circulation of the nuclear power plant in 1965 led to an increase in species richness (408 to 502 species, primarily affecting communities of submerged plants, Casper 1985), which has since been supplemented further.

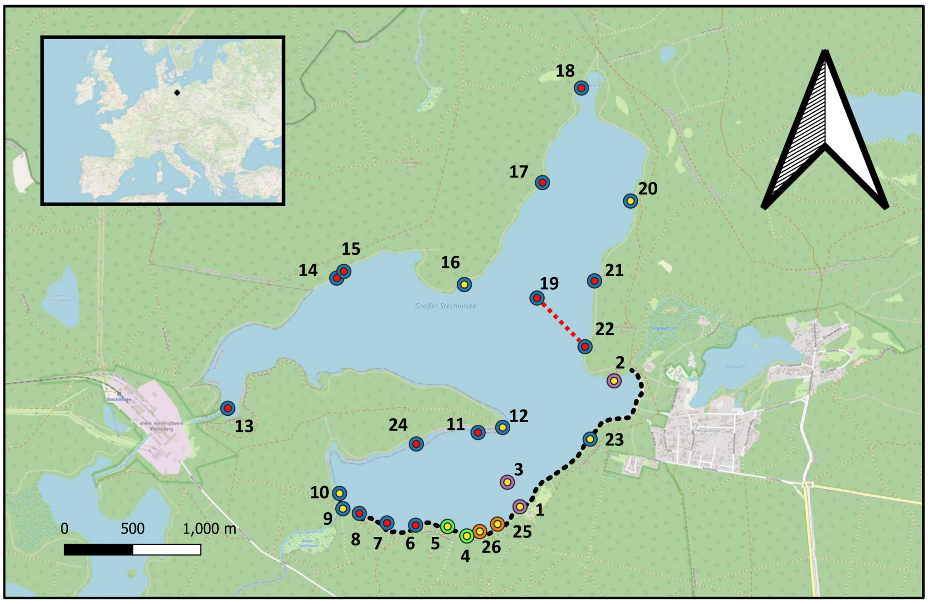

Figure 1. Map of sampling locations for *Hemimysis anomala* in Lake Stechlin between January and March 2023. Yellow dots indicate individuals caught and red dots indicate no individuals caught. The species was caught by hand net at points 1–3 (lilac circles), with point 1 being the original point where the species was initially found at the IGB docks, point 2 the fishery docks and point 3 the location of the LakeLab mesocosm facility/research platform. Points 4 and 5 (green circles) are locations where baited Wanzentraps were left out, and subsequently became bottle trap sampling locations. Baited bottle traps were used for all other points (blue circles), with points 25 and 26 (orange circles) being sites where the effect of bottle colour was tested. Note that in Jan 2023 variable numbers of individuals were witnessed, but not quantified, at nighttime using a flashlight from along the public beach south of point 2, all along the shoreline to point 10 (see black dotted line). An oblique net tow from point 19 to point 22 was performed, but with no *H. anomala* caught (see red dotted line). Dates and number of individuals trapped outlined as per Table 1. Source: Own data, OSM Standard 2023.

However, it should be noted that these lakes form a system that is not connected to the otherwise extensive river-channel-lake system across North East Germany, and therefore could be expected to be less exposed to non-native species.

Discovery and further sampling

The initial discovery of *H. anomala* occurred on the 18th January, 2023, with a large, dense swarm at the IGB jetty (53.14169; 13.029484, Figure 1: point 1, Supplementary material Videos 1, 2), aggregating mainly under a 3 × 3 m black floating dock (Jetfloat Dock Systems Inc., Canada). Upon finding the species, efforts were made to remove it by hand net, with approximately 10 kg wet weight initially removed. The swarm was monitored over subsequent weeks. Efforts were also made to determine the species at other sites in the lake, by combination of vertical and oblique tows using 0.5–0.7 m opening plankton nets with 500–1000 μm mesh sizes, swimming baited Wanzentraps, and 1 L bottle traps baited with fish food (Vitakraft, Germany). Sampling details and locations outlined as per Table 1 and Figure 1. Further inspection took place at night in January 2023 using a hand-held flashlight around the shoreline (Figure 2) where it was readily detected in shallow waters at several locations (Figure 1).

Table 1. Table outlining the initial findings of the species in Lake Stechlin (1a), and subsequent trapping by baited Wanzentraps (1b) and bottle traps (1c) between January and March 2023.

a) Landing net								
Date	Point							Coordinates
18/01/2023	1							53.14169, 13.029484
27/01/2023	2							53.149964, 13.039799
5/02/2023	3							53.1433, 13.0281
b) Swimming Wanzentrap with food								
Date	Point	Date/time in	Date/time out	Duration (days)	Details	Place	Individuals caught	Coordinates
09/02/2023	4	09/02/2023 14:00	10/02/2023 14:00	1	0,5m depth	between IGB UBA	10	53.139769,13.023662
09/02/2023	5	09/02/2023 14:00	10/02/2023 14:00	1	1 m depth	between IGB UBA	20	53.140393, 13.021547
c) 1L Bottletrap with food fixed to an iron bar into the sediment								
Date	Point	Date/time traps set	Date/time traps retrieved	Duration (days)	Details	Place	Individuals caught	Coordinates
14/02/2023	4	14/02/2023 14:00	15/02/2023 14:00	1	bottom, 0,3 m depth		2	53.139769, 13.023662
14/02/2023	5	14/02/2023 14:00	15/02/2023 14:00	1	near bottom		1	53.140393, 13.021547
14/02/2023	6	14/02/2023 14:00	15/02/2023 14:00	1	near bottom		0	53.140477, 13.018047
14/02/2023	7	14/02/2023 14:00	15/02/2023 14:00	1	near bottom		0	53.140621, 13.014900
14/02/2023	8	14/02/2023 14:00	15/02/2023 14:00	1	near bottom		0	53.141256, 13.011874
14/02/2023	9	14/02/2023 14:00	15/02/2023 14:00	1	near bottom	Leddern Brück	2	53.141562, 13.010068
15/02/2023	10	15/02/2023 15:00	17/02/2023 13:00	1.92	near bottom		2	53.142568, 13009705
15/02/2023	11	15/02/2023 15:00	17/02/2023 13:00	1.92	near bottom		0	53.146569, 13.024886
15/02/2023	12	15/02/2023 15:00	17/02/2023 13:00	1.92	bottom		13	53.146903, 13.027584
22/03/2023	13	21/3/23 10:00	22/3/23 10:00	1.00	bottom	KKW Kanal, big stones	0	53.148162,12.997459
22/03/2023	14	21/3/23 10:00	22/3/23 10:00	1.00	bottom	stony	0	53.156717,13.009409
22/03/2023	15	21/3/23 10:00	22/3/23 10:00	1.00	bottom	reed	0	53.157155,13.010174
22/03/2023	16	21/3/23 10:00	22/3/23 10:00	1.00	bottom	stony	2	53.156294,13.023388
22/03/2023	17	21/3/23 10:00	22/3/23 10:00	1.00	bottom	stony	0	53.162992,13.031948
22/03/2023	18	21/3/23 10:00	22/3/23 10:00	1.00	bottom	stony, sandy	0	53.169205,13.036211
22/03/2023	19	21/3/23 10:00	22/3/23 10:00	1.00	deep point	under the raft	0	53.155408,13.031348
23/03/2023	20	22/3/23 10:00	23/3/23 14:00	1.17	bottom	stony	1	53.161784,13.041599
23/03/2023	21	22/3/23 10:00	23/3/23 14:00	1.17	bottom	reed	0	53.156533,13.037647
23/03/2023	22	22/3/23 10:00	23/3/23 14:00	1.17	bottom	stony	0	53.152209,13.036613
23/03/2023	23	22/3/23 10:00	23/3/23 14:00	1.17	bottom	stony	1	53.146130,13.037173
23/03/2023	24	22/3/23 10:00	23/3/23 14:00	1.17	bottom	sandy, stony, reed	0	53.145815,13.018124
d) IL bottletraps in different colours								
24/03/2023	25 (Brown)	23/3/23 14:00	24/3/23 14:00	1.00	bottom	stony	15	
24/03/2023	26 (Transparent)	23/3/23 14:00	24/3/23 14:00	1.00	bottom	stony	6	

Morphological and molecular identification of the species

Initial morphological identification of the collected *H. anomala* was primarily based on the red colouration from chromatophores and the broad, uncleft telson, featuring two distal spines on posterior corners and short spines along the outer margins (Ketelaars et al. 1999; Figure 3). However, further identifiable features of *H. anomala* include well-developed third, fourth and fifth male pleopods, an elongated fourth male pleopod with a long exopodite and a reduced endopodite, and a spineless, oblong antennal scale with long plumose

Figure 2. Inspection of nearshore habitats at nighttime with a hand-held flashlight also revealed swarms of *Hemimysis anomala* individuals, typically 5–15 m away from the shoreline and around logs and amongst cobbles. Photo by Stella A. Berger, January, 2023.

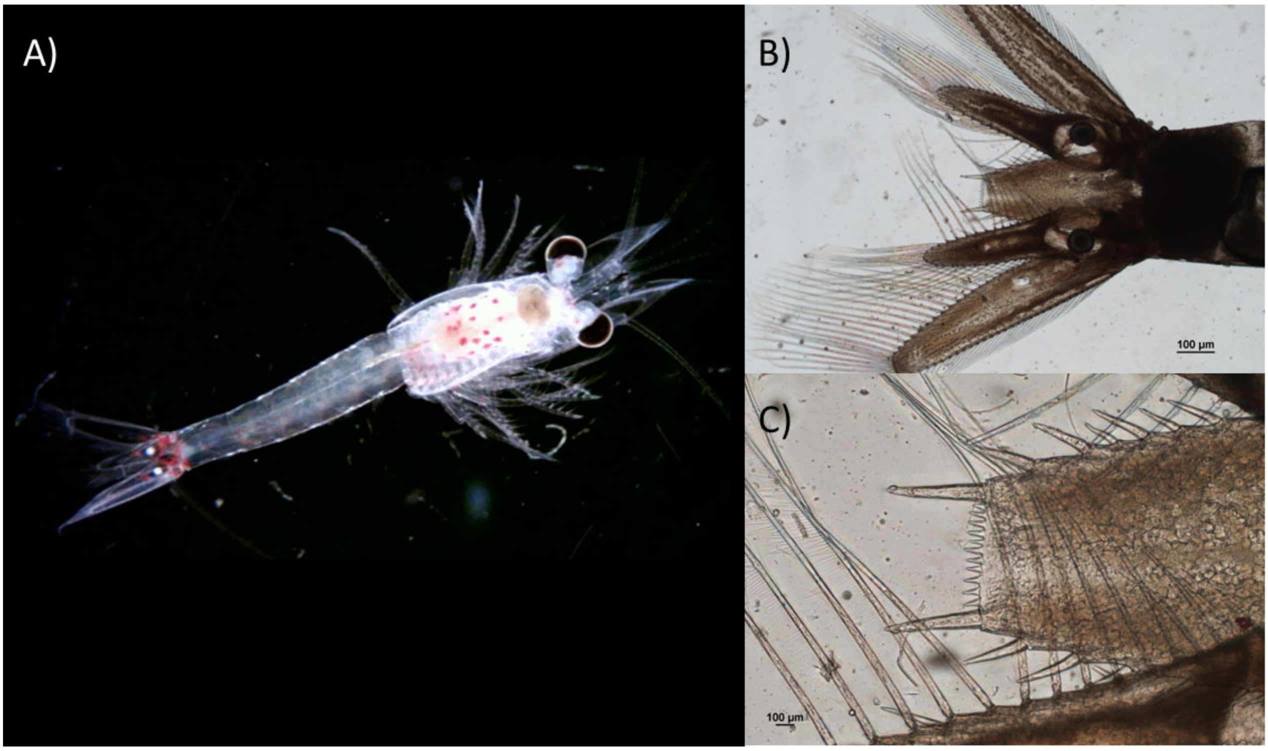

Figure 3. A) *Hemimysis anomala* individual from Lake Stechlin (Microphoto by Marén Lentz, January 2023). B) and C) of telson morphology (Microphoto by Benjamin Schupp, February 2023).

setae on the proximal portion of the outer margin (see Ketelaars et al. 1999 and references therein for further illustration). We aimed to confirm the species identity by molecular DNA barcoding, sequencing the mitochondrial cytochrome *c* oxidase subunit I (COI). Individuals collected from two locations

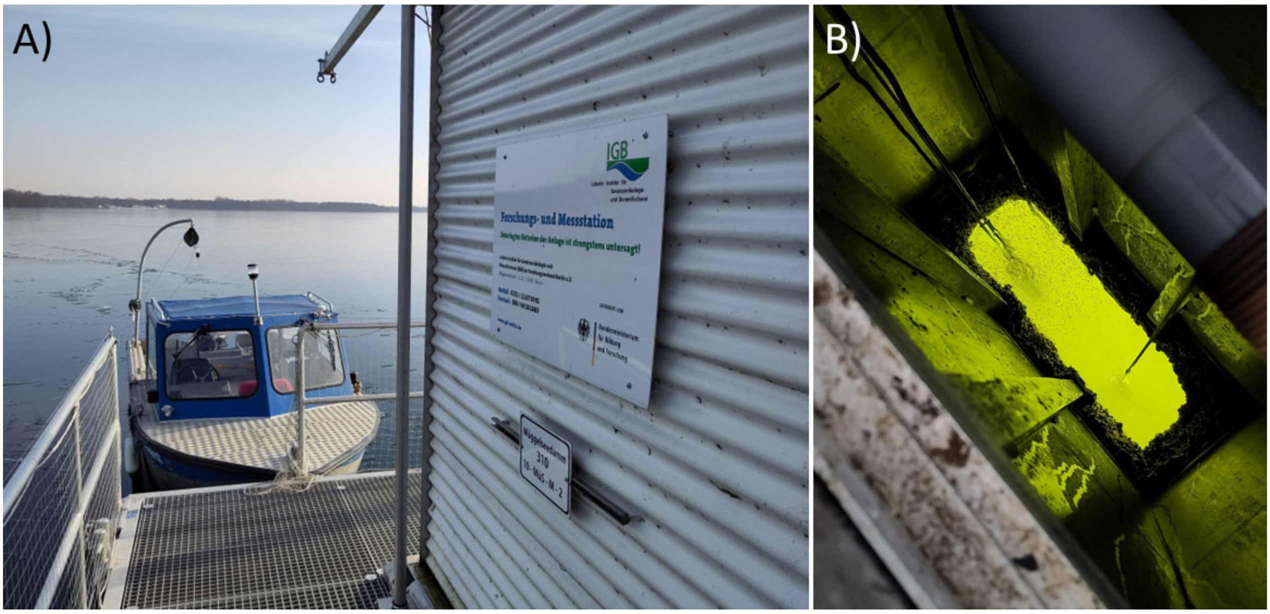

Figure 4. Müggelsee, Berlin's largest lake, as a case study example of a location where *Hemimysis anomala* (a sample of individuals were also identified using the methods applied to the Stechlin samples in this study) is known to have established, but has remained undetected in regular sampling. The species is found year-round at a monitoring station (Messstation Müggelsee) located 300 metres from the north shore (A), congregating in a shaft for raising and lowering equipment (B), The species is found here year-round (Thomas Hintze, *pers. comm.*) and is known to have been there since 2002. This is the only known location of it in the lake to date.

in Lake Stechlin, the IGB jetty (19 individuals: Figure 1, point 1) and the fishery docks (22 individuals: Figure 1, point 2) were used for both types of identification (note that another sample from Lake Müggelsee, Berlin, was also confirmed using this method: addressed in Figure 4). In the case of molecular identification, DNA was successfully extracted from 32 individuals using the DNeasy Blood & Tissue Kit (Qiagen, Germany) following the manufacturer's instructions. A fragment of COI was amplified using universal primer pair LCO1490 (5'-GGTCAACAAATCATAAAGATAT TGG-3') and HCO2198 (5'-TAAACTTCAGGGTGACCAAAAAATCA-3') (Folmer et al. 1994). PCR reactions were conducted following Dickey et al. (2023), with PCR products sequenced on a Sanger sequencing platform (Applied Biosystems, USA) at Eurofins Genomics (Kiel, Germany). Raw sequences were assembled and trimmed using CodonCode Aligner v 3.7.1 (Codon Code Corporation), and each sequence was blasted on NCBI (Altschul et al. 1990) and referenced at BOLD (Ratnasingham and Hebert 2007).

Results and discussion

Sequences resulted in ≥ 98% similarity with *H. anomala* at two databases as shown in Supplementary material Appendix 1, confirming our identification. Over the following eight weeks after the initial discovery, the swarm appeared to re-stock during daytime in the shadow under the floating platform, however in decreasing abundances. A further 5.5 kg wet weight (26th January), 5.3 kg (10th February), 2.8 kg (17th March), 0.25 kg (20th March) and 0.002 kg (24th March) were removed during daytime, with no further subsequent restocking observed. It was also noted that keeping the dock lights on for a week appeared to attract more *H. anomala* than when these lights were switched off for the same period. At noon on the 27th January, a smaller swarm was found beside the fishery docks on the eastern shoreline (53.149964; 13.039799; Figure 1, point 2). Follow-up sampling revealed a similar concentration under the LakeLab mesocosm platform (5th February, nighttime: 53.1433; 13.0281; Figure 1, point 3). While individuals of *H. anomala* were frequently found close to or under wooden and stone structures in the lake during daytime, inspection at nighttime with a hand-held flashlight also revealed smaller numbers of individuals, distributed typically 5–15 m away from the shoreline and around logs and amongst cobbles (Figures 1, 2). In contrast, the vertical tows at the deepest point or oblique tows ending more than 50–100 m from the shore have not caught any *H. anomala* during this time. Subsequent successful sampling has stemmed from the baited bottle traps deployed around the Lake Stechlin shoreline (Table 1; Figure 1). In all, available data from Lake Stechlin between January and March 2023 suggest that *H. anomala* are typically found in shallow waters both day and night during this period of time, but so far not in water deeper than approximately 30 m.

Despite the species having been present in Germany since the 1990s, this confirmation of a new location for the species may have potential implications for the native biodiversity in the unique Lake Stechlin. While the species has been studied extensively over the past two decades, major knowledge gaps remain. The European literature was deemed insufficient at the time to enable predictions of *H. anomala* impacts in North America (Ricciardi et al. 2012), and since then research on the species has predominantly come from across the Atlantic. However, some differences have already been noted between North American and European populations of the species, with Boscarino et al. (2020) noting the "rare daytime swarming behavior in open waters in shaded littoral areas" (the behaviour also observed in Lake Stechlin and, for example, Alsace, France: Dumont 2006) as a reason for sometimes inconsistent findings between studies from the two continents. With time spent in pelagic versus benthic zones shown to have an influence on the stomach contents of *H. anomala* (Borcherding et al. 2006), there may be trophic differences and impact implications stemming from this. Fish species present in Lake Stechlin include the Fontane cisco (*Coregonus fontanae* Schulz & Freyhof, 2003), the European cisco (*Coregonus albula* Linnaeus, 1758), bream (*Abramis brama* Linnaeus, 1758), bleak (*Alburnus alburnus* Linnaeus, 1758), carp (*Cyprinus carpio* Linnaeus, 1758), roach (*Rutilus rutilus* Linnaeus, 1758), ruffe (*Gymnocephalus cernua* Linnaeus, 1758) and perch (*Perca fluviatilis* Linnaeus, 1758), which are all known to feed on zooplankton within their lifetimes (Casper 1985; Schulz and Freyhof 2003). *Hemimysis anomala* has been linked to the decline of cladocerans, ostracods and rotifers in a Dutch reservoir (Ketelaars et al. 1999), and a shift from a cladoceran-dominated to a copepod-dominated system in mesocosm experiments (Sinclair et al. 2016). With this in mind, it is unknown how Lake Stechlin's planktivorous fish community, and other species in this historically mysid-devoid ecosystem more broadly, will be affected by the arrival. With Lake Stechlin having two *Coregonus* species, it is worth highlighting that in Lake Michigan the mysid *M. diluviana* Audzijonyte & Väinölä, 2005 is known to feed upon the larvae of *Coregonus hoyi* Milner, 1874 (Seale and Binkowski 1988). While the presence of the endemic Fontane cisco in waters deeper than 30 m may provide spatial separation from *H. anomala* (although we note the potential dangers of introducing another deep-water mysid, *M. relicta*, found elsewhere in northern Germany: Scharf and Koschel 2004), the European cisco inhabits shallower depths (< 25 m) and may therefore experience stronger interactions (Schulz and Freyhof 2003). Indeed, Walsh et al. (2010) hypothesised a "trophic triangle" between the mysid, zooplankton and planktivorous fishes in North American nearshore waters, with it potentially forming a high-energy novel prey item, but questions surround whether any Lake Stechlin resident fishes will incorporate this intraguild competitor into their diets, and when. The most likely contender is perch, with previous studies in Europe having demonstrated it to be a ready consumer of the species (Ketelaars et al. 1999; Borcherding et al. 2006; Gallagher et al. 2015). Future interactions with other emerging planktivorous non-native species will also be of interest, and one such example is *Craspedacusta sowerbii* (Lankester, 1880) which has previously been observed in the neighbouring Lake Dagow, as well as lakes in and around Berlin, suggesting expansion potential (Marchessaux et al. 2021).

Lake Stechlin is experiencing changes in nutrient content, an increasing anoxic deep-water layer and increasing water temperature (Musan et al. 2024). However, it is unclear how these environmental shifts will affect *H. anomala*. While Daufresne et al. (2007) linked the establishment of the species in the Rhône River to a long-term period of warming, a 2003 heat wave and associated oxygen decrease, the species is deemed to have a relatively high oxygen requirement of around 4 mg O_2/L (Wittmann 2007). Wittmann and Ariani (2009) found the species at oxygen levels of 4.56 mg O_2/L in eastern France, however none were found between 1998 and 2007 from frequent sampling of the Kuchelau Harbour of the Danube in Vienna when oxygen levels ranged between 4 and 5 mg O_2/L.

Going forward, it could be beneficial to update the *H. anomala* "haplotype network" laid out by Audzijonyte et al. (2008). That study found three distinct clusters present in its native range, finding a phylogeographical split between the Danube and other Ponto-Caspian river basins, with the Danube lineage establishing in the UK and USA, and previously distinct lineages now intermixed in the Rhine and the waters linked to the German Mittellandkanal. An updated study could answer valuable questions about the origins of the Lake Stechlin population. Further, visual and molecular gut content analysis (e.g. Nejstgaard et al. 2008) of the species and native potential predators, such as perch, will help answer vital questions about the role of the species in Lake Stechlin's food web at this early stage. Early insights into how the impacts of the species might change seasonally (for example as the ontogenetic makeup of the population changes over time – algae are more prominent in the diets of juveniles: Pérez-Fuentetaja and Wuerstle 2014) and in the future under climate change could be elucidated from lab experiments assessing predation rates across relevant abiotic contexts using methods such as functional response (Barrios-O'Neill et al. 2014; Dick et al. 2014; Dickey et al. 2021) and prey-switching trials (Cuthbert et al. 2018; Joyce et al. 2019; McCard et al. 2021).

Finally, there is also a crucial need to acknowledge and learn from the situation in nearby Müggelsee, Berlin's largest lake (approximately 100 km away from Lake Stechlin). Here, the species is known to have been present for over twenty years, however individuals have only casually been observed within the shaft of a monitoring platform (Figure 4). This swarm is found here throughout the year, but the extent of its broader distribution within the lake, if indeed there is one, remains unknown as the species has never been picked up by regular plankton tows. Unlike in Müggelsee, evidence from Lake Stechlin indicates seasonal differences in habitat, with the dense swarm initially discovered in January found to have decreased in size between January and March, coinciding with rising temperatures and the assumed onset of fish predation on zooplankton in the lake (as in Rogissart et al. 2023). This combination of seasonal changes, potential population differences and ineffective sampling methods highlights that the non-native range of *H. anomala*, and indeed other non-native mysid species, may be far greater than currently known, with targeted, year-round sampling required. With that in mind, there is a need for a coordinated programme to monitor this species, and one that overcomes the typical shortcomings of such initiatives which can be short-term, fragmented, reactive and geographically limited (Pergl et al. 2020). A broad spectrum of monitoring and sampling techniques for monitoring populations of the species are available, ranging from simple baited bottle traps, which have proven successful in catching individuals in Lake Stechlin and can easily be replicated elsewhere, to acoustic cameras as utilised by Rogissart et al. (2023). The next step is thus to extend the sampling effort both within Lake Stechlin and to other waterbodies throughout Germany.

Authors' contribution

JWED, JCN and JMJ conceived the study, with JWED preparing the initial manuscript. ML discovered the *H. anomala* with further sampling conducted by ML, JCN, SAB. Microscopy analysis and imaging of the samples was performed by ML, with DNA sequencing performed by EK and EB. All authors provided valuable input into the development of the final manuscript and have given approval for publication.

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Supplementary material

The following supplementary material is available for this article:

Appendix 1: Partial sequences of c oxidase subunit 1 (COI) gene for sampled *H. anomala* from Lake Stechlin and Müggelsee.

Video 1: GoPro video footage of *H. anomala* under boat dock in Lake Stechlin. January 2023. (1/2)

Video 2: GoPro video footage of *H. anomala* under boat dock in Lake Stechlin. January 2023. (2/2)

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