Research Article

New records and disappearance from old sites of narrow-clawed crayfish *Pontastacus leptodactylus* in northwestern Russia

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Citation: Berezina NA, Terentiev PM, Sharov AN, Maximov AA (2021) New records and disappearance from old sites of narrow-clawed crayfish *Pontastacus leptodactylus* in northwestern Russia. *BioInvasions Records* 10(4): 894–903, https://doi.org/10.3391/bir.2021.10.4.14

Received: 31 May 2021
Accepted: 20 September 2021
Published: 18 October 2021

Handling editor: Mikhail Son
Thematic editor: Karolina Bącela-Spychalska

Abstract

The narrow-clawed crayfish *Pontastacus leptodactylus* is known as a species expanding their range in northern areas of the Europe. This study aims to present new records, check the previously knows sites of *P. leptodactylus* records in the northwestern region of Russia (Karelia, Murmansk, and Arkhangelsk regions), and discuss possible reasons for its current range extension to the north and disappearance in southern locations of this region. Twenty years ago, the northern border of the *P. leptodactylus* range run from southern Finland to the east-north of Lake Ladoga, skirting to the north of Lake Onego, and further east to the Northern Dvina. To date, it disappeared widely from northern lakes and rivers being recorded only in 25% of previously known locations (mainly in southern Karelia), where this species was introduced and established in the 1920s–1970s. At the same time, during the last decade, *P. leptodactylus* was recorded more northern, in lakes at White Sea costs. Considering that some of the new sites of *P. leptodactylus* are located in uninhabited by humans areas, the reason due to which this crayfish extends its range close to the Arctic areas may be its natural dispersal. Local climate warming might also facilitate the successful adaptation and establishment of this species there.

Key words: species dispersal, alien species, northern regions, climate warming

Introduction

The narrow-clawed crayfish (also known as Danube crayfish, Galician crayfish or Turkish crayfish) is alien species for some currently occupied European countries, including northern Russia (Holdich 2002; Gherardi and Souty-Grosset 2017). The taxonomical status of narrow-clawed crayfish remains in the state of flux. Formerly considered *Astacus leptodactylus* (Eschscholtz, 1823) species complex, it is currently recognized as the *Pontastacus leptodactylus* (Souty-Grosset et al. 2006; Crandall and De Grave 2017). Brodski (1983) upgraded the old subgeneric name *Pontastacus* Bott, 1950 to generic status to denote the position of the species of Ponto-Caspian origin; after that, this genus name was widely used (Holdich ed. 2002). *Pontastacus leptodactylus* is considered indigenous in the eastern part of its range, i.e. south-eastern Europe and middle east (Köksal 1988; Harlioglu 2004; Pârvulescu et al. 2012). Due to high importance for aquaculture (Cilbiz et al. 2020) it has been introduced into many of the western European countries (Souty-Grosset et al. 2006; Gherardi and Souty-Grosset 2017).

In the nineteenth century, a fashion of eating crayfish was spreading from Paris eastwards across Europe (Reynolds and Souty-Grosset 2011). It was the golden era of crayfish eating when cookery books recommended many ways of crayfish cooking (Montagné 1963). A classic combination in nineteenth-century high-class French food was crayfish butter with chicken (Day 2008). The local species, the noble crayfish *Astacus astacus* (Linnaeus, 1758), had a significant cultural, social, and economic value in Fennoscandian countries, particularly in Sweden, which has the highest per capita consumption of freshwater crayfish worldwide (Gren et al. 2009). At that time, Finland was the major European exporter of crayfish to Europe and adjacent Russia (up to 20 million individuals were caught every year by the Finnish Fishery Association which was established in 1891. More than 70% of all captured crayfish were exported to Russia and other countries until the beginning of the twentieth century (Reynolds and Souty-Grosset 2011). However, a complex of factors such as the crayfish plague mainly caused by the oomycete *Aphanomyces astaci* Schikora led to the sharp decline in the abundance of the *A. astacus*, which is until now considered as threatened species in majority of European countries (Dannewitz et al. 2021). A decline in abundance of *A. astacus* was one of the main reasons for increased export and translocations of *P. leptodactylus*. In the second half of the 20^{th} century, *P. leptodactylus* has been introduced to waterbodies in more than 14 countries, including Sweden, Finland, Poland, Lithuania and northern Russia (Alexandrov 1966; Holdich et al. 1999; Skurdal and Taugbol 2002; Holdich and Pöckl 2007; Reynolds and Souty-Grosset 2011; Kouba et al. 2014; Jussila et al. 2020).

Pontastacus leptodactylus is highly fecund and fast-growing species (Cilbiz 2020; Kawai and Kouba 2020). For example, the number of eggs (matured and immature) in crayfish female (with a length of 69–126 mm) from Karelian lakes ranged from 75 to 325 pieces, averaging was 320 eggs per female (Alexandrov 1966). It can grow to very large size of up to 500 g wet weight and, reach high population densities (Souty-Grosset et al. 2006). To compare in global scale the fisheries-based production of *P. leptodactylus* increased notably from 1950 (487 t) to 2016 (15,782 t) as well as aquaculture-based production, which reached 852 t/year by 2016 (FAO 2018; Cilbiz et al. 2020). *Pontastacus leptodactylus* from Turkey (Svoboda et al. 2012; Kokko et al. 2018) as well as other European countries (Jussila et al. 2020; Ungureanu et al. 2020; Pacioglu et al. 2020) have been were documented chronically infected by *A. astaci.* At the same time, it exhibits elevated resistance toward *A. astaci* compared to other crayfish species (Svoboda et al. 2012).

The spread of *P. leptodactylus* to northwestern Russia has been going on for a long time. It is believed that it arrived in the north of Russia (the Svir and Severnaya Dvina rivers) from the Volga river basin in the 18th century due to the construction of three river-canal systems: Vyshnevolotsk water system, opened in 1709, Tikhvin, 1811 and Mariinsky, 1810. This river-canal net (the so-called Volga-Baltic waterways) connects the Ponto-Caspian region with the basins of the Baltic and White seas (Nikolaev and Zhitkov 1900). The first time of construction, in 1703–1709, was the Tveretskiy Canal, 2.6 km long, connecting the Ladoga and Volga basins. In 1774, *P. leptodactylus* was reported for the first time from the Sukhona River, the left tributary of the Severnaya Dvina (Birshtejn and Vinogradov 1934). Since 1829, the Sukhona River (which flows out of the Lake Kubenskoye) was connected to the White Sea through the Severo-Dvina Canal. In 1868, *P. leptodactylus* was confirmed in the Svir River basin, a part of the Volga-Baltic waterway (Kessler 1868). Kessler (1868) wrote that until the 1870s, this species was found exclusively in the Svir River and its tributaries.

Pontastacus leptodactylus settled in the lakes of Karelia after the 1870s, and a noticeable regional distribution took place at the beginning of the 20th century. In the 1920s–1970s, it was actively introduced for commercial purposes in northwestern Russia (former USSR) by the state fisheries institutions, in particular, to large Onego and Ladoga lakes, as well as in many small lakes of Karelia and Leningrad provinces (Gordeev 1965; Alexandrov 1966). Also, in Karelia, extensive movements and releases of crayfish by local people have taken place historically, especially from locations in the south to northern parts of the region (Novoseltsev 1994).

In the 1950s–60s, two lakes of Koncheozerskaya group, located to the north of the city of Petrozavodsk (Padozero and Gabozero), were chosen by the Federal State Institution Karelian basin Management for Fisheries and Conservation of Biological Resources ("Karelgosrybvod") for the reproduction of broodstock of *P. leptodactylus* and their further introductions to many small lakes of Karelia (Alexandrov 1966). These introductions were motivated by the disappearance of the indigenous *A. astacus* following crayfish plague outbreak.

In the 1960s, the northern border of the *P. leptodactylus* distribution passed from the south of Finland to the east to north of Lake Ladoga, skirting Lake Yanisyarvi and the lower tributaries of the eastern part of Lake Ladoga, continuing downward in a southeast direction to the northern tributaries of the Svir River (see Alexandrov 1966). Further, the border passed along Lake Onego with adjacent lakes in its northwestern part and from the eastern side of these lakes to the south (except for the Onega River), approaching the lower sections of Severnaya Dvina River.

This study examines the current distribution of *P. leptodactylus* in northern Russia (Karelian, Murmansk, and Arkhangelsk regions), exploring previously reported locations (following Alexandrov 1966) as well as new sites.

Table 1. Abundance and mean carapace length of *Pontastacus leptodactylus* in existing populations. Abundance was measured in ind./trap; the mean carapace length (CL) and maximal carapace length (CL max) for of male* and female** are provided.

Locality	Year	Abundance (mean ± SD)	CL (mean ± SD, mm)	CL max (mm)
Archangelsk Region				
Lekshmozero	2009	5 ± 4	100.6 ± 15.7	120*
Kenozero	2009	9 ± 4	103.4 ± 14.9	122*; 109**
Bereznik	2010	10 ± 3	105.6 ± 11.3	120*; 110**
Kovozero	2010	8 ± 2	111.5 ± 14.2	130*; 110**
Solovetsky Archipelago[1]				
Bolshoe Krasnoe	2015	1	–	46**
Svyatoe	2016	3	–	no data
Republic of Karelia				
Petrozavodsk pond	2009	4 ± 1	97.7 ± 13.2	119*
Gomselga	2012	16 ± 2	100.8 ± 14.7	118*; 114**
Vendjury	2011	6 ± 4	105.2 ± 14.5	119*; 110**
Lake Krugloe (White Sea coast)	2020	1	–	108**
Murmansk Region				
Semenovskoe	2018	2 ± 1	106.4 ± 11.3	118*
Imandra	2020	1	–	120*

[1] according to Borovikova et al. (2016, 2017).

Materials and methods

Field surveys of lakes in studied regions (Supplementary material Table S1) were carried out in May–September of 2009–2020. Altogether, 43 sites were visited by authors. Distribution data on Solovetsky Island (lakes Bolshoye Krasnoe and Svyatoe) were taken from Borovikova et al. (2016, 2017). Additional information on *P. leptodactylus* records has been taken from reports of Fishery Institutions (VNIRO, Karelrybvod, Karelian and Kola Research Centres of the Russian Academy of Sciences, among others) and personal interviews with fishermen. Three to five standard cylindrical traps (30 × 60 cm) for crayfish baited with fresh small fish were exposed for 4–6 hours on each studied locations. Active sampling with manual inspection of potential refuges in shallow waters (< 1 m) was also conducted. In recent records (2018 and later on; Krugloe, Imandra, and Semenovskoe lakes), crayfish were caught by benthic gill net (18–36 mm mesh size) or during scuba diving.

In addition, material (a single pereopod from 10–20 individuals) for molecular analysis was collected from studied water bodies (Table 1, except the last three localities). Species identity was confirmed as *P. leptodactylus* using mtDNA by Dr. Martin Bláha, University of South Bohemia in České Budějovice, Czech Republic. Analyses of phylogenetic relationships among these *P. leptodactylus* populations (unpublished data) showed several new haplotypes allocated within eastern European lineage *sensu* Maguire et al. (2014).

The abundance was calculated as a mean number of adult crayfish individuals per trap ± SD. The carapace length (CL) was measured from the tip of the rostrum to the posterior margin end of the carapace using a ruler with an accuracy of 1 mm. The mean CL (± SD) and maximal CL were determined. Small crayfish (less than 75 mm) were sporadic or not caught in traps, so it was difficult to estimate the minimum CL.

Results

Monitored sites, both previously known to harbour populations of the *P. leptodactylus*, as well as new localities visited during this study are shown in Figure 1. Altogether 52 locations in lakes. rivers and ponds in the Karelian, Archangelsk, and Murmansk regions were inspected. In 2018–2020, *P. leptodactylus* was found at three new northern locations such as Lake Krugloe (just 30 km below the Polar cycle) and the Arctic lakes: Imandra and Semenovskoe (Table 1).

The species has been recorded in 25 locations (Figure 1, Table S1). Among them, there are 12 locations where *P. leptodactylus* was initially introduced and established in the 1960s–70s (Alexandrov 1966). Using in this calculation all 45 sites where *P. leptodactylus* was formerly known, we could conclude a relatively high level of its disappearance from formerly known locations, i.e. approximately from ¾ of lakes. At the same time, it has spread to some new areas in the last decade (Table 1, all locations excepting two lakes Gomselga and Vendjury). *Pontastacus leptodactylus* was recorded in the Archangelsk region, in the lakes Kenozero and Lekshmozero of the Onega River basin, and Bereznik and Kovozero lakes of the Severnaya Dvina basin and at White Sea coasts and some new locations in Karelia (Figure 1, Table 1). Table 1 shows abundance and size characteristics of *P. leptodactylus* in these locations. Population density varied considerably between localities. The population of occurred as the most abundant in the Shuya River basin (Lake Gomselga), where it was introduced more than 60 years ago.

Discussion

To date, narrow-clawed crayfish was not found in 75% of the lakes, where it was recorded by Alexandrov (1966) in the 1960s (Figure 1). According to Alexandrov (1966) in the cases of Karelian lakes commercial catches were 3–5 times exceeded the permitted amounts, that can facilitate the decrease in population abundance of this crayfish. At the same time, *P. leptodactylus* still exists in some Karelian lakes. For example, in the 1920–1940s it was introduced into small lakes of the Konchezerskaya group in Karelia (Gordeev 1965), where several lakes (e.g., Gomselga, Konchezero, Galeozero) remain inhabited by this species. *Pontastacus leptodactylus* spread widely and became a common species in small lakes in the basin of the Shuya, Padas, Suna, Lizhma, and Vodla rivers. According to Borovikova et al. (2016), *P. leptodactylus* was absent in the White Sea region before the 2000s and

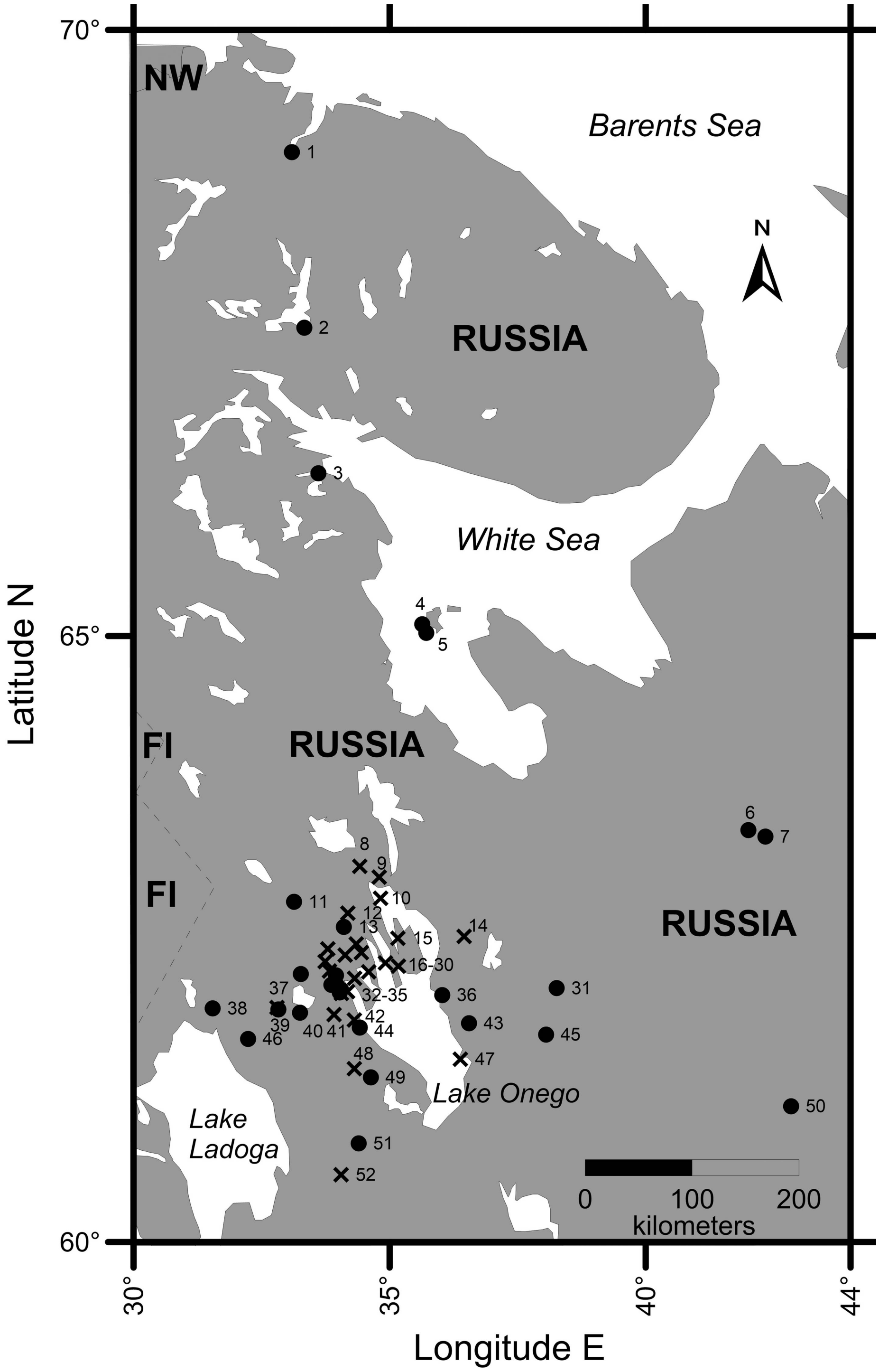

Figure 1. Geographical locations of currently confirmed records (dark circles) of the narrow-clawed crayfish, *Pontastacus leptodactylus,* and its former records that were not confirmed by this study (dark crosses) in the northwestern region of Russia. Lakes: 1 – Semenovskoe, 2 – Imandra, 3 – Krugloe, 4 – Bolshoe Krasnoe, 5 – Svyatoe, 6 – Bereznik, 7 – Kovozero, 8 – Krivozero, 9 – Khizhozero, 10 – Onego (Povenetskay Guba), 11 – Sovdozero, 12 – Shaidomskoe, 13 – Lizhmozero, 14 – Ukshozero, 15 – Padmozero, 16 – Kedrozero, 17 – Sundozero, 18 – Tarasmozero, 19 – Sandal, 20 – Pyalozero, 21 – Lelikozero, 22 – Yandozero, 23 – Munozero; 24 – Onego (Kondopozhskay Guba), 25 – Nigozero, 26 – Vendjury, 27 – Pertozero, 28 – Rovkozero, 29 – Gallezero, 30 – Gabozero, 31 – Kenozero, 32 – Konchezero, 33 – Padozero, 34 – Gomselga, 35 – Angozero, 36 – Kupetskoe (Shalitsa), 37 – Vekshelskie lakes, 40 – Syamozero, 41 – Padozero, 42 – Onego (Petrozavodskaya Guba),), 44 – Petrozavodsk city pond, 45 – Lekshmozero, 47 – Muromskoe, 51 – Urozero. Rivers: 38 – Uksunjoki, 39 – Kirikijarvi, 43 - Vodla (Pudozh), 46 – Kolatselga, 48 – Shapsha, 49 – Ivenka River near Shapsha village, 50 – Kokshenga, 52 – Shapsha (for details see Supplementary material Table S1).

appeared there only a decade ago. In 2016, the northernmost points of its distribution were two lakes (Bolshoye Krasnoe and Svyatoe) on Solovetsky Island in the White Sea (Borovikova et al. 2017).

Our records of the narrow-clawed crayfish in Arctic areas during last years show that this species of southern origin turned out to be cold tolerant. Hydrological alterations, which may be exacerbated by climate change, directly or indirectly affect population dynamics and geographical distribution of species (Stenseth et al. 2002). Current climate changes have a high potential to affect aquatic biota through various processes that are especially notable in the northern lakes (Rautio et al. 2008; Sharov et al. 2014; Maximov et al. 2021). In northern Russia (Karelia), the long-term trend showed an increase in the average annual air temperature by 1 °C and increased annual precipitation by 20–70 mm between the 1960s and 1990s (Nazarova 2014). The consequence of such changes in the temperature regime has been a prolongation of the ice-free period in Karelian water bodies by 10–20 days in the last decade (Efremova et al. 2013). Analysis of long-term data sets in different lakes showed that changing climate variables correlated closely with biotic indices (Jyväsjärvi and Hämäläinen 2014; Sharov et al. 2014; Maximov et al. 2021). Prolonged ice-free period, increased winter air temperature, and nutrient contents as main consequences of climate warming in freezing lakes (Woolway et al. 2019) can influence the biota, affecting directly or indirectly the population dynamics and species geographical distribution.

Because of warming, the sum of water temperatures effective for biota (above 10 °C) increased. Within ten years, the dates of passing water surface temperature through 10 °C are shifted by 1.4–1.7 days in spring 1.0–2.3 days in autumn (Efremova et al. 2013). The prolonged period of “biological summer”, milder and wetter winter climate in the study region can facilitate higher biotic production (Jyväsjärvi and Hämäläinen 2014).

The warming also favours the reproduction in *P. leptodactylus*, which occurs at the water temperature of 7–12 °C (Skurdal and Taugbøl 2002). The highest spermatozoa production in *P. leptodactylus* was found at lower temperatures (7.5 and 11 °C) compared to 19 °C (Farhadi and Harlıoglu 2018). Thus, the summer temperatures of northern lakes (7–16 °C, from late May to September) may well support reproduction of this species.

Due to human-mediated introductions, occasional transfers, and interconnection of waterways, *P. leptodactilys* appeared in the northwestern regions of Russia and further spread actively due to natural spread along rivers and canals. Considering that some of the records are in unpopulated areas, occasional moving between water bodies by live organisms (water birds) may have implications for increasing the rate at which this crayfish spreads. It is known the cases of crayfish transfer between water bodies with ducks (Águas et al. 2014; Anastácio et al. 2014) and other animals whose life is connected with water.

Analysis of the current distribution of *P. leptodactylus* in northwestern Russia showed very restricted areas of its existence, that left unclear the question of its status in northern regions of Russia: is it a threatened species that needs to be included in the list of protected species, or a tolerant species using its biological features to successfully extend its range northward and requiring effective management programs to control its spread? In the future, we can expect an expansion of its range due to a warming climate in northern latitudes, as well as the possible restoration of extinct populations in lakes of Karelia.

Acknowledgements

Authors thank to Nikolay V. Sharov, Alexander Peskov and Sergey Kleverov for help with sampling. We greatly appreciate the constructive criticism and comments from two anonymous reviewers, which helped us to improve the first version of manuscript.

Authors' contribution

Conceived and designed the study: N. Berezina. Performed the study: N. Berezina, P. Terentiev, A. Sharov. Analyzed the data: N. Berezina, A. Maximov. Wrote and revised the paper: N. Berezina, P. Terentiev with input from other co-authors.

Funding declaration

This study was funded by the Russian Foundation of Basic Research, project 19-04-01000. N. Berezina and A. Maximov also were partly supported by of the Ministry of Science and Higher Education of the Russian Federation (AAAA-A17-117021310121-0) and A. Sharov by West-Siberian Interregional Science and Education Center's project No 89-DON (2).

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Supplementary material

The following supplementary material is available for this article:

Table S1. Studied locations with coordinates, population status of the crayfish *Pontastacus leptodactylus* and year of investigation.

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