Discovering sanctuaries for the Endangered thick-shelled river mussel *Unio crassus* in Kaliningradskaya Oblast, Russia

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Abstract The thick-shelled river mussel *Unio crassus* is categorized as Endangered on the IUCN Red List, and searching for surviving populations is urgent. We surveyed for this species in Kaliningradskaya Oblast, a Russian territory lying between Poland and Lithuania, where empty shells of the species had been reported from two rivers. There are at least 125 rivers and numerous small streams in the region, and as a comprehensive survey of all of these watercourses is infeasible, we used a method developed for surveys of the freshwater pearl mussels *Margaritifera margaritifera* and *Margaritifera laevis*. This involved a remote assessment of the forests and lakes in the river basins to identify sites potentially suitable for *U. crassus* based on criteria used for pearl mussels, followed by site surveys. We surveyed six sites and discovered *U. crassus* in five of those, only two of which support healthy populations. The existence of other *U. crassus* populations in Kaliningradskaya Oblast is unlikely. This study underscores the critical role of riparian arboreal vegetation for freshwater mussels. The conservation of *U. crassus* in rivers surrounded by farmlands is challenging because of siltation, eutrophication and other processes that negatively impact the riverine environment. Even the abandonment of these farmlands does not necessarily lead to improvements in mussel survival. Any plans for the restoration of *U. crassus* will require concurrent restoration of riparian arboreal vegetation.

Keywords Farmland, forest, habitat, Kaliningradskaya Oblast, lake, remote assessment, thick-shelled river mussel, *Unio crassus*

Freshwater bivalves are declining globally (Lydeard et al., 2004), with numerous species threatened. One such species is the thick-shelled river mussel *Unio crassus*. It is categorized as Endangered on the IUCN Red List (Lopes-Lima et al., 2024b), although it appears to be a complex of cryptic species (Lopes-Lima et al., 2024a). *Unio crassus* is considered common in the eastern part of its range and is not included in the Red Data Book of Russia (Popov et al., 2017), although it is included in regional Red Books for Volgogradskaya Oblast, Kostromskaya Oblast, Mari El, Crimea (Mikhailov, 2018) and Saint-Petersburg city (Kiashko, 2018). Empty shells of *U. crassus* had been previously reported from two rivers in Kaliningradskaya Oblast (Manakov, 2018, 2020), a Russian territory lying between Lithuania and Poland, and we therefore surveyed this area using methods initially developed for other species.

Recent publications suggest declines of the species in Lithuania (Skujienė, 2018) and in several Russian territories (Mikhailov, 2018), and we expected a similar situation in Kaliningradskaya Oblast. This area, formerly East Prussia, has undergone extensive development, resulting in significant alterations of its river systems. The north-east of the oblast is a polder resembling those found in the Netherlands, characterized by wet, flat areas at or below sea level, intersected by a network of canals (Adamov, 2011). The remaining terrain is predominantly flat, with minor variations in elevation. The rivers, having been modified by hydraulic engineering, have weak currents and are mostly surrounded by farmland, resulting in eutrophication and siltation. Although many farms in the region were abandoned in the 1990s, since 2014 farmland acreage has been increasing (Fedorov, 2022).

With 125 rivers listed in the State Register of Water Bodies of Russia (2024) and numerous streams, a comprehensive survey of Kaliningradskaya Oblast is infeasible. However, this was also the case for the freshwater pearl mussels *Margaritifera margaritifera* and *Margaritifera laevis* in part of their range, yet hidden populations were successfully located (Popov, 2021a,b). The methods used in these studies could also be effective for surveying *U. crassus* as these species share common characteristics: inhabiting small, pure rivers, sensitivity to eutrophication, and susceptibility to water pollution, river canalization and siltation. To identify previously unknown populations of pearl mussels, we assessed potential habitats using indirect evidence. The principal criterion was the proportion of forest in a river basin. Pearl mussels are absent in rivers surrounded by agricultural lands, but are potentially present if the proportion of deforested banks is $< 22\%$ (Popov, 2021a). The presence of forest in the upper reaches of rivers is also critical. Even if the lower reaches are forested, deforestation in the upper reaches degrades mussel habitats. In northern Europe, rivers with pearl mussel populations typically have lakes at their sources. Lakes absorb heat during summer, warming the

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rivers that flow from them and providing optimal temperatures for pearl mussel reproduction. Lakes also reduce pollution and maintain the water supply. In addition, freshwater pearl mussels rarely coexist with other large bivalves, and this is probably also the case with *U. crassus*: at the Gulf of Finland several *U. crassus* habitats have been identified that do not have any other bivalve species (Popov, 2021a).

We first made a remote assessment of Kaliningradskaya Oblast using land-cover maps (Buchhorn et al., 2020; Federal Service of State Register, Cadastre and Cartography, 2024). *Diva GIS 7.5.0* (DIVA-GIS, 2012) was used for data processing. We plotted the forests and the rivers flowing through them, outlined the drainage areas, mapped the sources of inflows and estimated the configurations of forest and lakes with reference to previous studies on pearl mussels. From this, we compiled a list of watercourses where *U. crassus* could potentially be present, and then surveyed these locations during 5–15 June 2023. Surveys for pearl mussels indicated they are most common in certain microhabitats. We identified 1–2 m wide streams, and river bends (especially the inner side of the bend), as favourable locations, with the largest pearl mussel aggregations near sandbars where a stream enters a river and in the lower sections of riffles.

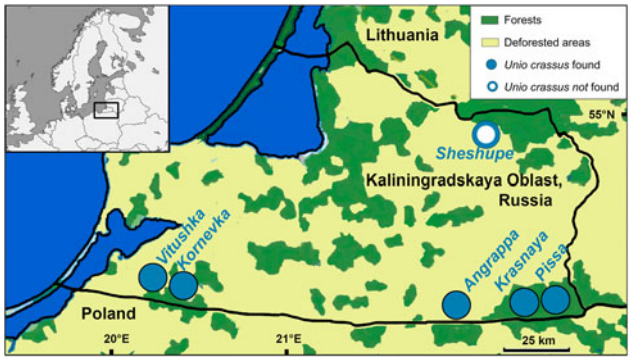

FIG. 1 Kaliningradskaya Oblast, a Russian territory lying between Lithuania and Poland, indicating the six rivers (Table 1) where we surveyed the thick-shelled river mussel *Unio crassus*.

We prioritized these microhabitats, surveying with an aquascope whilst wading, or by snorkelling.

In the remote assessment, we found a limited number of rivers with potentially suitable locations for *U. crassus*. Only the river Pissa appeared to provide ideal habitat, as it flows from a large lake surrounded by forest, and is also bordered by forest in its upper reaches. River Krasnaya also appeared to be potentially suitable as it flows through a forest, but the lake at its source is small and lies outside

TABLE 1 The six locations where we searched for the thick-shelled river mussel *Unio crassus* in Kaliningradskaya Oblast, Russia (Fig. 1), with details of forested banks, lakes, area surveyed and the area that had to be searched to find at least one mussel.

River (length, km)	Forests on the riverbanks	Lakes	Survey location	Surveyed area (m^2)	Area (m^2) searched to find at least one mussel
Sheshupe (298)	Forests border a 20 km section in the middle reaches but mostly on only one bank, except for two 1.5 km sections where both banks are forested.	1 km^2 lakes at the source, 200 km from the section bordered by forests	54°57′ N, 22°28′ E	500	None found
Vitushka (37)	A 10 km section in the lower reaches flows through a 100–500 m wide strip of forest; the drainage area of the upper reaches is forested. The source is located in a 4 km^2 forested area; banks of the middle reaches are deforested.	Three c. 1 ha lakes at the source; one 10 ha artificial lake in the middle reaches	54°27′ N, 20°01′ E	500	500 (a dead individual)
Kornevka (42)	A 1.5 km section in the upper reaches flows through a 100–300 m wide strip of forest, & downstream a 2 km section is forested on one bank, a 5.5 km section flows through a 100-m wide strip of forest, and a 2.5 km section flows through 2 km^2 of forest.	A c. 80 ha lake, 4 km from the upper section with forested banks	54°27′ N, 20°17′ E	500	250
Angrappa (169)	A 3.5 km section flows in the upper reaches through a 6.5 km^2 forested area; a 2.5 km section flows through a 2 km^2 forested area. Other banks are deforested.	A 104 km^2 lake 30 km from the section with forested banks	54°22′ N, 21°59′ E	500	250
Krasnaya (83)	Most of the drainage area of a 16 km section in the upper reaches is covered by forest.	An 80 ha lake 2 km from the section with forested banks	54°23′ N, 22°30′ E	200	10
Pissa (98)	Most of the drainage area of a 7 km section in the upper reaches is covered by forest; a section with forested banks lies at the source.	Flows from an 18 km^2 lake	54°27′ N, 22°38′ E	400	1

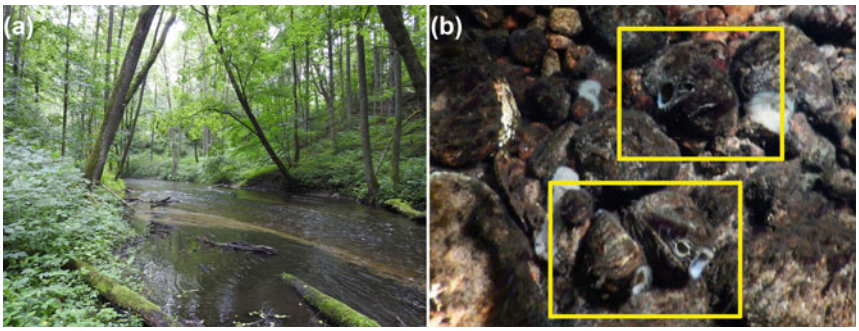

PLATE 1 (a) Pissa River, Kaliningradskaya Oblast, Russia (Fig. 1), and (b) thick-shelled river mussels *Unio crassus* on the bottom of the river.

the forest. Four other rivers have small areas of forest in the upper or middle reaches and lakes at their sources, although the lakes are distant from the forested areas (Table 1).

We found *U. crassus* in five of the six rivers (Fig. 1, Table 1). It was most common in the Krasnaya and Pissa rivers (Plate 1), and scarce in three other rivers. In the Sheshupe river, where we did not locate *U. crassus*, we found the bivalves *Unio pictorum* and *Anodonta* sp. in riffles, potentially precluding the presence of *U. crassus*. The empty shells that we found demonstrated the main diagnostic characteristics of *U. crassus* (thick shell, two teeth). The cryptic species belonging to the *U. crassus* complex (Lopes-Lima et al., 2024b) are indistinguishable by their external characteristics, but the species in the five rivers in Kaliningradskaya Oblast is most likely *U. crassus* sensu stricto, as specimens from neighbouring areas of Lithuania and Poland have been described as this species.

All of the forests through which the six rivers pass are natural, with no monoculture tree plantations. The predominant trees are broad-leaved, with spruce *Picea abies* and pines *Pinus sylvestris* in small numbers. The forests around the Pissa and Krasnaya rivers are particularly well preserved. This area has been a designated game hunting area since the 16th century and has been under protection since then (Fedorov, 1990). The rivers in which we found low densities of *U. crassus* show that even a small section of the upper reaches of a river flowing through forest can support a small population of this species. Further deforestation, however, could lead to extirpation of *U. crassus*.

Unio crassus inhabits a broader range of habitats, including deeper rivers, than pearl mussels (Vaessen et al., 2021). Further refinement of the assessment and survey methods used in this study is therefore required for the survey of larger areas. Nonetheless, for Kaliningradskaya Oblast and similar regions the methods are probably adequate given that the combination of lakes and forested river banks indicates potential presence of the species, and mitigates to some degree the negative influences of farmland on river ecosystems.

Our study underscores the importance of forests for the conservation of riverine mussels. While emphasis is often focused on ground-level microhabitats (Stoeckl & Geist, 2016; Vaessen et al., 2021), lack of host fishes (Taeubert et al., 2012), water pollution, and habitat alteration and degradation (Downing et al., 2010), many other negative influences result from deforestation. Forested river banks help prevent soil erosion, maintaining optimal river bed and water conditions. The presence of trees on riverbanks increases fish abundance, as both living trees and fallen trunks create diverse habitats for fish. Shading by trees is also crucial for preventing excessive macrophyte growth, which can be detrimental to mussels. Any plans for the restoration of *U. crassus* will require concurrent restoration of riparian arboreal vegetation.

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Conflicts of interest None.

Ethical standards No specific approval was required for this research. We avoided any accidental introduction or distribution of invasive or pathogenic organisms and adopted existing IUCN Species Survival Commission guidelines; research was non-intrusive and no animals were killed. The research abided by the *Oryx* guidelines on ethical standards.

Data availability Data are available upon reasonable request to the corresponding athor.

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