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Rapid Communication

The introduced dark false mussel, *Mytilopsis leucophaeata* (Conrad, 1831) has spread in the northern Baltic Sea

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Abstract

The dark false mussel, *Mytilopsis leucophaeata,* has been found in very specific habitat in the Archipelago Sea (northern Baltic Sea) and now has spread. Between 2011 and 2015, we collected small numbers of *M. leucophaeata* at three sites 10 to 28 km apart in soft sediment habitats with pier structures and rocks in water 2–3 m deep. Previously, *M. leucophaeata* in the northern Baltic Sea was restricted to areas receiving cooling water discharge from nuclear power plants. Our findings were from areas without a source of heated water, and the closest known occurrence of *M. leucophaeata* is 120 km away. It is evident that this species is expanding its distribution in the Baltic Sea area and is not restricted to areas having anthropogenically-warmed water.

Key words: invasions, invasive species, invasive mussel, fouling, Finland

Introduction

The dark false mussel *Mytilopsis leucophaeata* (Conrad, 1831) is a member of the family Dreissenidae and originates from the Gulf of Mexico (Marelli and Gray 1983; Kennedy 2011). In Europe, *M. leucophaeata* was first detected in Antwerp Harbor, Belgium, in 1835 (Nyst 1835), and from there it has spread through anthropogenic means to the Netherlands, Germany, France, Britain, Spain, Ukraine, and most recently to the Baltic Sea (Kennedy 2011). In the Baltic Sea, *M. leucophaeata* was observed: in the Gulf of Finland, Finland, in 2003 (Laine et al. 2006); the Gulf of Bothnia, Finland in 2006 (Laine and Urho 2007); the Gulf of Gdańsk, Poland in 2010 (Dziubińska 2011); and the southern Bothnian Sea, Sweden in 2011 (Florin et al. 2013). In every case, the previous records of this species in the northern Baltic Sea were from areas close to nuclear power plant cooling water discharges.

Mytilopsis leucophaeata is a temperate species found in water temperatures between 5 ºC and 30 ºC (Laine et al. 2006; Verween et al. 2010; Kennedy 2011) and has a wide salinity tolerance that ranges from near freshwater to 20 (Verween et al. 2010; Kennedy 2011). In its native and non-native range, this filter feeding species usually is attached by byssal threads to a variety of substrates (e.g. oysters, submerged vegetation, soft-sediments, pier pilings, floating barges, sticks, rocks and bottles) (reviewed in Kennedy 2011).

Adult *M. leucophaeata* individuals can grow up to 27 mm shell length (3–6 mm/yr depending on shell length), but the growth rate of most individuals decreases substantially after they reach between 10–15 mm (Verween et al. 2006; Verween et al. 2010). While *M. leucophaeata* occurs in low densities in its native range (Kennedy 2011), populations can reach up to 28,000 individuals/m^2 in its introduced range in Finland (Laine et al. 2006). Kennedy (2011) suggests that the high densities observed in non-native locations may be due to rapid population growth over short time periods, as has been observed in other introduced populations in the Chesapeake Bay, USA (Bergstrom

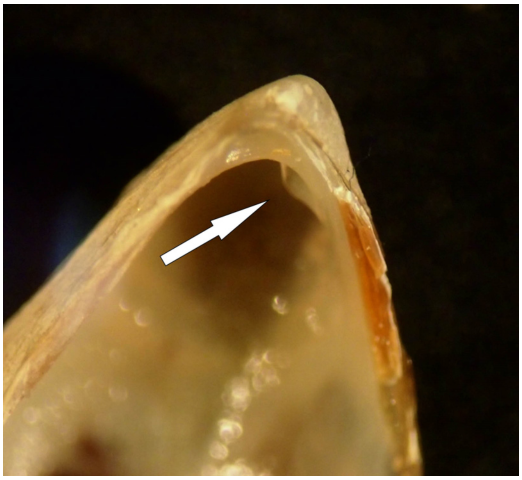

Figure 1. Inner shell of *Mytilopsis leucophaeata* illustrating (arrow) the tooth-like projection or apophysis. Photograph by Tiia Forsström.

Table 1. Number of collected *Mytilopsis leucophaeata* individuals from three crates in each location in each year.

Location	2011	2012	2014	2015
Kaarina	0	18	54	12
Lapila	3	3	11	2
Naantali	0	22	26	11

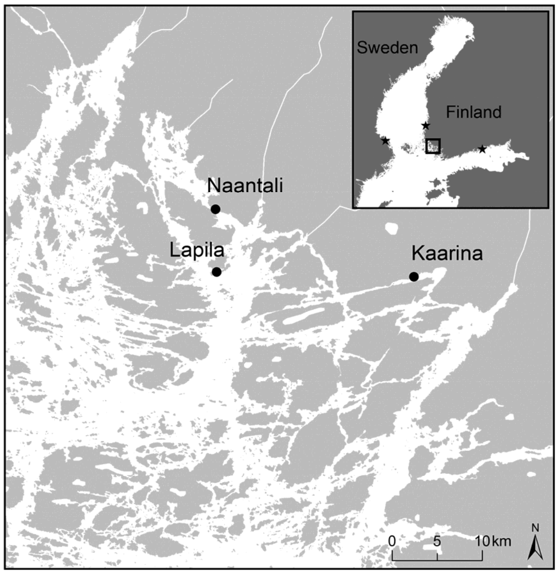

Figure 2. Map of *Mytilopsis leucophaeata* records in the northern Baltic Sea. Stars are previous records from nuclear power plant areas (2003–2011) and black dots our observations from Kaarina (N 60º24′ E 22º26′), Lapila (N 60º23′ E 22º02′), and Naantali (N 60º27′ E 22º01′) in the Finnish Archipelago Sea from 2011–2015.

et al. 2009). This rapid population growth may be due to the introduced populations occuring in warm waters discharged from nuclear power plants (Verween et al. 2005; Laine et al. 2006; Laine and Urho 2007; Florin et al. 2013). Growth and reproduction of *M. leucophaeata*, like other mussels, is dependent on temperature (Verween et al. 2006).

Here we present occurrence data of *M. leucophaeata* in the Archipelago Sea (the northern Baltic Sea) between 2011 and 2015. This is the first finding of *M. leucophaeata* in the northern Baltic Sea outside of a nuclear power plant cooling water discharge area.

Methods and results

In May of each year (2011–2015; except for 2013), plastic collecting crates (30 × 30 × 30 cm) containing autoclaved oyster shells from Maryland, USA, were deployed at 2–3m depths at three locations in the Archipelago Sea (Kaarina N 60º 24′ E 22º26′; Lapila N 60º23′ E 22º02′ and Naantali N 60º27′ E 22º01′, Figure 2). We deployed 3 crates per location (for more details, see Fowler et al. 2013 and Forsström et al. 2015). Initially, the yearly monitoring of these crates was only aimed at following the population growth of the introduced crab *Rhithropanopeus harrisii* (Gould, 1841) The monitoring locations were chosen from sites the crabs were known to occur, and crates were examined each July and September. However, after the first observation of *M. leucophaeata* individuals in the crates in 2011, the presence of *M. leucophaeata* was also monitored.

As the first *M. leucophaeata* individuals that were found were small, and the identification of the species using only morphological characteristics is challenging, the species was identified using DNA barcoding. DNA analyses were done in the Center of Evolutionary Applications, University of Turku, Finland. DNA was extracted from one whole individual using NucleoSpin Tissue-kit (Macherey-Nagel) according to the standard protocol of the manufacturer. A 659 bp fragment in the standard barcoding (COI) region was amplified and sequenced with primers LCO1490 and HCO2198 (Folmer et al. 1994). The sequence was identified as *M. leucophaeata* with a 100% match using the BOLD Identification System (http://www.boldsystems.org/index.php/IDS_OpenIdEngine). After confirming the identity of the species in 2011 using DNA barcoding, all subsequent *M. leucophaeata* collected were identified based on the morphological characteristics of the apophysis (Figure 1) (Marelli and Gray 1983; Laine et al. 2006).

Table 2. Average size, SD, and range of *Mytilopsis leucophaeata* collected from three crates in each location in September 2014 and 2015.

	2014				2015			
Location	n	Average size (mm)	SD	Range	n	Average size (mm)	SD	Range
Kaarina	49	6.05	1.08	3.97–8.25	12	3.2	1.07	2.06–5.86
Lapila	9	6.75	2.70	2.77–10.64	2	4.1	0.42	3.68–4.53
Naantali	26	6.49	1.96	2.66–11.42	10	4.14	0.81	3.05–5.14

After the first observation of *M. leucophaeata* at a single site in 2011, multiple individuals were found every year in all three locations on crates placed in a soft sediment habitat with pier structures and rocks (Table 1). In 2011, only three individuals were found across the sites, whereas 43 were found in 2012, 90 in 2014 and 25 in 2015. We measured 84 mussels collected in 2014 and 24 mussels collected in 2015 with an electronic caliper (Table 2). The observed number of mussel in 2014 ranged between 1 and 20 individuals per crate, with the mean number of 11 individuals attached to the crate or the oyster shells inside the crate. In 2015, the observed number ranged between 0 and 6 individuals per crate with mean number of 3 individuals. All the individuals in each year were found during September, indicating that the settlement occurs sometime between July and September.

Discussion

All of the previous detections of *M. leucophaeata* in the northern Baltic Sea are from areas which receive cooling water discharge (i.e., warmed water) from nuclear power plants. In a previous study, however, Laine et al. (2006) predicted that *M. leucophaeata* could establish adult populations outside waters affected by the cooling water discharge area. According to our observations, this species is now expanding its distribution in the northern Baltic Sea. Since our first observation of *M. leucophaeata* at a single site in 2011, the mussels have been repeatedly observed in three sites lacking nuclear power plant cooling water discharge area and over 120 km to the nearest nuclear power plant.

It remains unknown whether *M. leucophaeata* occurred in the Archipelago Sea area prior to 2011 and remained unobserved, as the density of this species in our collection crates seems to vary substantially between years (Table 1). Extensive field studies in the Archipelago Sea, due to the vicinity of Archipelago Research Institute and the repeated SCUBA diving inventories in the vicinity of the site of our first observation prior to 2011, did not detect any *M. leucophaeata*. However, non-detection cannot act as a proof of absence. It should be noted that the actual distribution range is likely wider than presented in this study, as we only focused on three monitoring locations.

M. leucophaeata may have first spread to the Archipelago Sea either naturally from the surrounding areas, or it may have been transported by anthropogenic means. The nearest known populations of *M. leucophaeata* are over 120 km and 270 km away from the study sites. Natural introduction of the species is possible as the larvae of *M. leucophaeata* can spend two weeks as plankton (Siddall 1980), and they have been found in the water column in the Netherlands between late May and mid-November at highly variable densities (2,169–5,273 larvae m^{-3}) (Verween et al. 2005). However, if natural dispersion occurred from these sites, earlier observations of *M. leucophaeata* individuals should have been noted between the nearest populations and our sites as there have been field surveys in the intervening areas.

As we have repeatedly detected recently settled *M. leucophaeata* since 2011, it is evident that the larvae are successfully settling around the Finnish Archipelago Sea. Future studies will be needed to determine whether the larvae originate from established and reproducing populations in the local area or whether they are being reintroduced to the area yearly from an outside source. In the Archipelago Sea, the water salinity is about 6, and the water temperature varies from 4°C during winter to 20°C during summer months (Leppäranta and Myrberg 2009). Therefore, the required temperature of 13°C for spawning is met annually (Verween et al. 2005). It is currently unknown whether adults can survive winter sea water temperatures outside of a cooling water discharge area, as the data presented here represent juveniles that settled between July and September of the same calendar year. Previously, introduced populations of *M. leucophaeata* have survived temperatures as low as 6.8°C (Verween et al. 2010) in the Netherlands and 5°C in Finland (Laine et al. 2006), but native populations in the United States have been reported to survive in water temperatures as low as 0°C (Weiss et al. 1978; Jordan and Sutton 1984). Therefore, it is possible that adults may have established populations outside of the cooling water discharge area, and we have observed settled larvae from these populations.

The *M. leucophaeata* individuals collected in the Archipelago Sea were larger in size than individuals found in Poland (1.4–4.9 mm; Dziubińska 2011) but smaller than those found in Sweden (6–23 mm; Florin et al. 2013). According to Verween et al. (2006), the yearly growth rate of *M. leucophaeata* is 3–6 mm, but Florin et al. (2013) observed individuals up to 16 mm shell length attached to substrate between July and September of the same year. The largest individuals collected in our study (11 mm) suggest that the growth rate of settling larvae is higher in the northern Baltic Sea, which supports the observation by Florin et al. (2013) on Swedish side of the Baltic Sea. *M. leucophaeata* as small as 10 mm shell length have been reported to be reproductively mature in the waters of the Netherlands (Vorstman 1933), suggesting that the largest individuals found at our sites could be the source of the next cohort of larvae.

Interestingly, in 2011, *M. leucophaeata* individuals were also found for the first time in the southern Bothnian Sea in Sweden (approximately 200 km from the sites in this study) (Florin et al. 2013) and in 2010 in the Gulf of Gdansk in the southern Baltic Sea (700 km from the sites in this study) (Dziubińska 2011). Considering our observations and the other reports in the Baltic Sea during the past years, it is evident that this species is expanding its distribution in the Baltic Sea. The reason why the introductions seem to have occurred almost simultaneously and the source population/s of the introductions are both questions requiring additional study.

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