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Research Article

Invasion of Finnish inland waters by the alien moss animal *Pectinatella magnifica* Leidy, 1851 and associated potential risks

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Abstract

Introduced alien species bring potential adverse impacts on biodiversity and ecosystem functions. International shipping is an important vector for such unintentional introductions in aquatic environments. Therefore, in addition to climate change and eutrophication, increasing international shipping may enhance the spread of alien species into areas which have not previously been considered prone to alien invasions. One example of such development might be the recent invasion of the moss animal *Pectinatella magnifica* into Finnish inland waters, which are generally considered to be hostile to alien species. We took advantage of observations made by the general public and recorded by environmental authorities to describe the invasion history of the species in Finland. The records of *P. magnifica* were almost exclusively from the Vuoksi watercourse, where the species was most likely introduced by international shipping ca 10–15 years ago. The species occurred mainly in the vicinity of ports of international shipping, but was also abundant in an area with only domestic cargo transport. Only one confirmed observation in Lake Kirkkojärvi was from outside the Vuoksi watercourse. Most colonies were found attached to landing stages or submerged, relatively rigid water plants, and the species seemed to avoid less rigid water plants, such as water lilies. Once established, the species may spread by vectors such as recreational boating or water birds and fish. The species poses some risks to the ecosystem, including a risk to farmed and wild salmonid fish by serving as a potential host for the myxozoan endoparasite *Tetracapsuloides bryosalmonae*, the causative agent for proliferative kidney disease (PKD), known to be detrimental for salmonid fish.

Key words: Bryozoan, citizen science, ballast water, invasion vector, Lake Saimaa, Vuoksi waterway

Introduction

Although dispersal of species into new areas is an ongoing natural process, concurrent deliberate or unintentional anthropogenic introduction of species beyond their ranges is generally considered an unwanted phenomenon. In underwater environments, non-native invasive species may proliferate long before their existence is even registered. Species introductions may have irreversible and uncontrollable adverse impacts on biodiversity and ecosystem functions. Not only can they displace native species by predation or competition, but they can also

transmit (parasitic) diseases harmful to native species and cause environmental or health-related impacts and economic costs, for example by biofouling (e.g. Bilton et al. 2001). Costs from all biofouling animals are estimated to be more than 250 million € per year worldwide (Nakano and Strayer 2014).

One such biofouling, invasive species is the bryozoan moss animal *Pectinatella magnifica* Leidy, 1851 (Figure 1). *P. magnifica* is considered a native species in North America, where it was first found near Philadelphia by Leidy (1851). Since then it has been recorded mostly in the North-Eastern part of the United States (e.g. Marsh and Wood 2001; Barnes

and Laue 2003; Taticchi et al. 2011; Michelene et al. 2014) and Canada (e.g. Ricciardi and Reisinger 1994). The first records from outside the United States were in 1883 in Germany near Hamburg (Kraepelin 1887; Zoric et al. 2015), since when it has spread into many other European countries, including Poland (Kaminski 1984), France (d’Hondt and Condé 1996), the Netherlands (Leuven et al. 2009), Austria (Bauer et al. 2010), Hungary (Balounová et al. 2011; Szekeres et al. 2013), Czech Republic (Balounová et al. 2011; Pazourek et al. 2016), Luxembourg (Massard et al. 2013) and Ukraine (Aleksandrov et al. 2014). The species spread seems to have accelerated during recent decades (e.g. Devin et al. 2005, Nottoghem 2009) and it is now reported also from Asia, including Japan (Mawatari 1973), South Korea (Jo et al. 2014; Jeong et al. 2015) and China (Wang et al. 2017).

The surface of *P. magnifica* colony consists of tens to hundreds of rosettes, each formed by several zooids, which multiply by budding (e.g. Massard and Geimer 2008). The zooids lie on the surface of a more or less spherical gelatinous mass, weighing up to dozens of kilograms and with a diameter of up to two meters. The colonies are sessile, usually attached to various underwater substrata, such as macrophytes, submerged tree branches, stones, or concrete (Hubschman 1970; Choi et al. 2015) in lotic or lentic waters with currents (e.g. Choi et al. 2015). The species reproduces asexually by resistant stages, statoblasts, which overwinter and initiate new colonies. The young ciliate larval colonies have some potential for locomotion (Wilcox 1906; Williams 1921) or may float some distances with water currents enabling dispersal within water bodies, but the statoblast is the main dispersal stage of the species (e.g. Koletić et al. 2015). The floating and hooked statoblasts (Figure 2) can attach to the plumage of waterfowl or be eaten by and pass through the alimentary canal of water birds (Figuerola and Green 2002; Charalambidou et al. 2003) and fish (Markovic et al. 2009), enabling dispersal within and between water bodies. However, the vector for overseas expansion of the species range has most likely been ships transferring statoblasts in their ballast waters (e.g. Nehring 2005).

Historically, Finnish inland waters have not been prone to invasions by non-indigenous species because the low water temperatures, low nutrient concentrations, and soft water have formed natural barriers against invasions (Pienimäki and Leppäkoski 2004). Nowadays, environmental change (climate warming, nutrient enrichment) and greater international shipping are increasing the opportunities for species invasions that can endanger the ecological integrity of aquatic ecosystems (Pienimäki and Leppäkoski 2004).



Figure 1. Late summer *Pectinatella magnifica* colonies attached to common horse-tail (*Equisetum fluviatile*). Photograph: Antti Kanninen.



Figure 2. Hooked overwintering stage (statoblast) of *Pectinatella magnifica*. Visible is the “hyaline albuminoid mass” as described by Allman (1856, p. 82) or “cuticle” enclosing the spines and forming a “floatation ring” as illustrated by van der Waaij (2017) for *Cristatella mucedo* (http://www.microscopy-uk.org.uk/mag/artfeb10/mw-bryozo_statoblasts.html). Photograph: Kristiina Vuorio.

Perhaps as a manifestation of this tendency, *P. magnifica* has been recorded recently from several locations in the Vuoksi watercourse in eastern Finland, quite distant from the previously known more southern range of the species. This finding is somewhat unexpected considering the species is suggested to prefer warm waters. In their review, Pienimäki and Leppäkoski (2004) did not list the species even as a potential invader into Finnish inland waters.

Here we report the certified citizen records of *P. magnifica* and, based on these data, evaluate the history, vectors and potential risks of the species’ invasion of Finnish inland waters. We also conducted a pilot survey to evaluate habitat preferences and population densities of the species in one of its main areas of occupation in the Vuoksi watercourse.

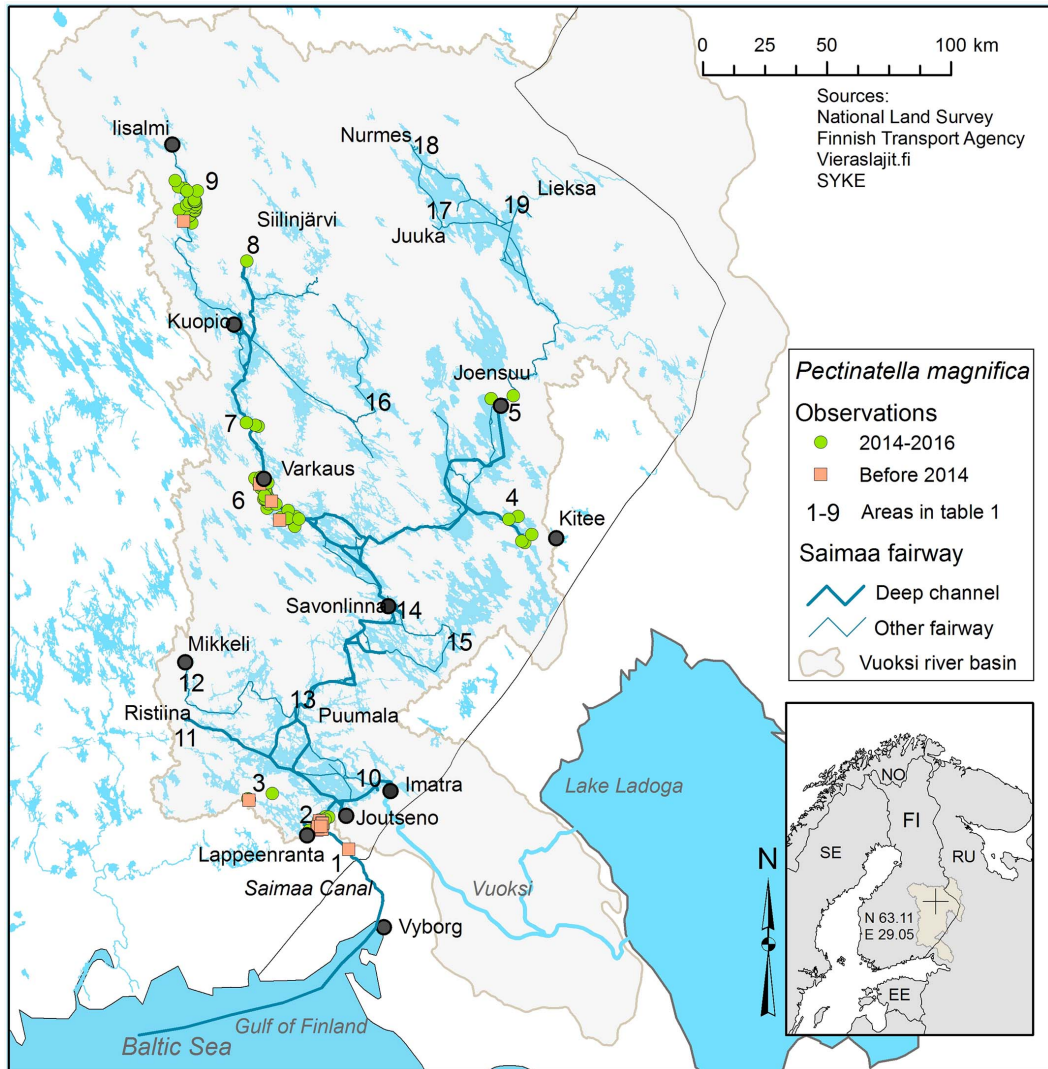


Figure 3. Spread of *Pectinatella magnifica* in Finland (Vuoksi river basin). Orange squares represent observations prior to the year 2014 and green circles represent observations received in 2014–2016. The Saimaa fairway is marked with a blue line. Numbers 1–9 refer to areas of *Pectinatella magnifica* occurrence. Numbers 10–19 refer to areas with no observations. The general water quality of the areas is shown in the Supplementary material Table S1.

Materials and methods

Site description

The Vuoksi watercourse (Figure 3) is situated in South-East Finland and consists of several major lakes, including the fourth-largest freshwater lake in Europe, Lake Saimaa (water area 4400 km², shoreline length 13700 km) encompassing several distinct basins (e.g. South Saimaa, Orivesi, Puruvesi, Haukivesi, Yövesi, Pihlajavesi, and Pyhäselkä). The Vuoksi watercourse is inhabited by several endangered or threatened species. The endangered Saimaa ringed seal, one of only four freshwater seal species in the

world, is endemic to the lake. Several endangered salmonid fish species, including the critically endangered Saimaa landlocked salmon, live in the area (Rassi et al. 2010).

The natural outlet, the River Vuoksi (discharge 600 m³s⁻¹) drains to Lake Ladoga in Russia, and is blocked by two dams at Imatra close to the border, and two other dams on the Russian side, preventing any shipment or upstream migration of organisms. However, the man-made Saimaa Canal, from the city of Lappeenranta to the Bay of Vyborg, connects the watercourse to the Baltic Sea. The Canal is used not only for recreational boating but also for international import and export shipping, transporting wood,

minerals, metals, pulp and other goods. Information about shipping fairways in the Vuoksi watercourse was obtained from the open database of the Finnish Transport Agency.

Water quality data (nutrients, chlorophyll *a*, transparency, water colour, turbidity, pH, alkalinity and conductivity; Table S1) were collated from the water quality database of the Finnish Environment Institute (Syke) for each area where *P. magnifica* was recorded. The data represent summer seasons (June–September) of the years 2000–2016, the depth of 0–2 m and several sampling sites in each area. We collated similar data also for ten reference areas, which are close to harbours with cargo shipping or along shipping fairways or popular recreational boating waterways, and thereby among the most potential sites of invasion, but where the species had not been reported. We used Mann Whitney U-test to evaluate if the water quality variables differed between these two groups of areas in the Vuoksi watercourse and thence, whether the occurrence of *P. magnifica* might be associated with water quality.

Records of *Pectinatella magnifica*

The “jelly brain” moss animal *Pectinatella magnifica* easily captures public attention due to its large size and distinctive appearance. The last few years have seen increasing sightings by fishermen, boaters and holidaymakers spending time on the lake or its shoreline. During the warm summer of 2014, the species became locally abundant and received a lot of attention in local and national media. Thus, a description of the species was added to the Finnish national Invasive Alien Species Portal (IASP; <http://www.vieraslajit.fi>) in 2014. Since then, members of the general public have been able to record their observations into the portal. We collected these records as well as observations reported to the Finnish Environment Institute (Syke) and to the local environmental authorities (Centres for Economic Development, Transport and the Environment and city environmental officers). All records were quality controlled by checking photographs and descriptions reported to the IASP. Records with inadequate or missing information or those that were otherwise doubtful were checked by environmental authorities in the field.

In Lake Onkivesi (area 9 in Figure 3) citizen observations suggested development of abundant *P. magnifica* populations and the spread of the species has raised particular concern among the local public. In August 2016, a pilot survey was conducted in Lake Onkivesi, with the aim of obtaining more detailed population estimates and information on the

habitat preferences of the species. In addition, the established subareas of area 9 would serve as a reference for future quantitative monitoring. Three separate subareas were selected in the northern, north-eastern and southern parts of the lake basin, covering altogether ca 14 km of the shoreline (Figure 4). Within each subarea, 18 or 20 sampling sites (width 30 meters and length 15 meters, 450 m²) were selected at equal intervals along the shoreline. At each site, the colonies were counted and weighed, and the substratum and depth of attachment for each colony were recorded. In addition, two ca. 500 m transects along the shoreline were selected in the north and north-east subareas within the densest populations of the species. These transects, covering an area from the shoreline to the outer edge of macrophyte vegetation, were traversed by wading and boat, recording the location of each colony by GPS. If no vegetation was present, the stony part of the littoral was checked for *P. magnifica* colonies. A subsample of the colonies was weighed in the field using a hand scale.

Results

Water quality

The water colour of the basins with *P. magnifica* observations ranged from clear to humus-stained brownish (Table S1). Nutrient (12–58 µgL⁻¹ total P and 315–861 µgL⁻¹ total N) and chlorophyll-*a* (5.5–36 µgL⁻¹) concentrations reflected a range from oligotrophy (area 4, Orivesi) to eutrophy (area 9, Onkivesi). In the Saimaa Canal and near the city of Lappeenranta (areas 1–2) conductivity was increased due to pulp and paper industry effluent. Turbidity was highest in Lake Onkivesi (area 9) and in the Saimaa Canal (area 1). Alkalinity was low across the basins, ranging from 0.12 to 0.25 mmolL⁻¹ and pH ranged from 6.3 to 8.8, with lowest values in the most humic areas (Table S1). Recent ecological status classification (based on data from 2006–2013) indicates good or high ecological status for the major basins of the Vuoksi watercourse (Manninen and Kotanen 2016). The ecological status of water bodies inhabited by *P. magnifica* range from good (n = 5) and moderate (n = 3) to poor (n = 1) whereas reference areas ranged from excellent (n = 4) and good (n = 5) to moderate (n = 1) (Syke open database).

The areas 1–9 with *P. magnifica* (Table S1), seemed to be on average more eutrophic than the reference areas (10–19), with higher mean chlorophyll *a* (P = 0.016) and total P (P = 0.003) concentrations and turbidity (P = 0.016). However, there was considerable variation in water quality within

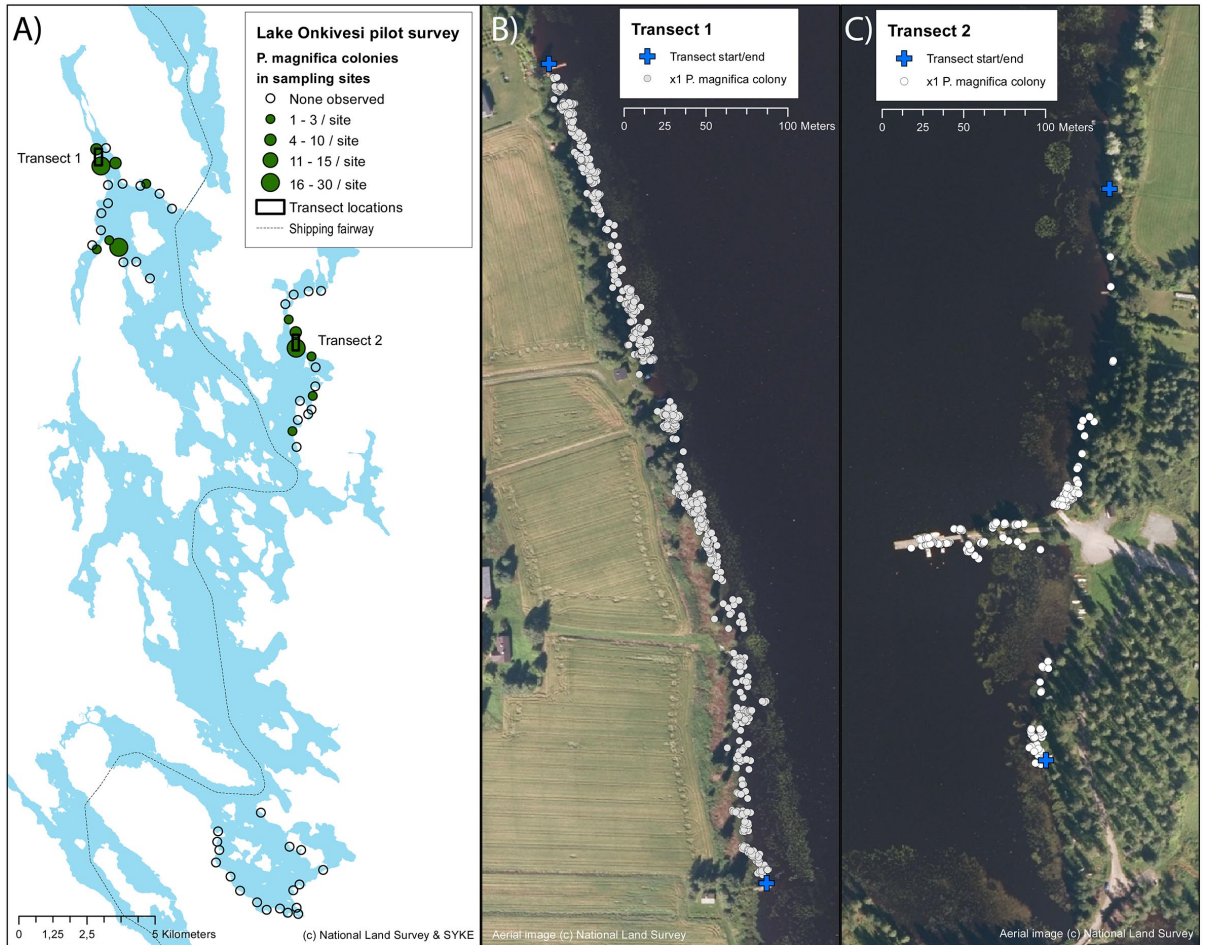


Figure 4. Records of *Pectinatella magnifica* from the pilot survey of Lake Onkivesi (area 9 in Figure 3) in August 2016, showing distributions in three sampling subareas (A) and two transects (B and C).

both groups of areas, and e.g. some reference areas like 12 in Ukonvesi (Mikkeli) had quite high nutrient (total P $28 \mu\text{gL}^{-1}$ and N $1379 \mu\text{gL}^{-1}$) and chlorophyll *a* ($28 \mu\text{gL}^{-1}$) concentrations.

The maximum epilimnetic temperature at Saimaa Lauritsala station (South Saimaa) in July–September ranged from 18 to 25 °C. There is a slight increasing trend in mean summer water temperature of Lake Saimaa from 1931–1960, through 1961–1990 to 1991–2000 (Korhonen 2002). A similar trend has been observed in Lake Kallavesi in the northern part of the Vuoksi watercourse (Korhonen 2013). In summer 2014, when the majority of *P. magnifica* observations were recorded, lake water temperature was 21–26 °C during four weeks in July–August, which was several degrees higher than the average water temperature for same period in 1971–2000 (Syke 2014).

Observations of Pectinatella magnifica

Altogether 145 records of *P. magnifica* were lodged in the IASP or reported directly to the authorities. Despite the distinctive appearance of the species, many of the sightings reported by citizens were apparently erroneous or dubious. According to the descriptions of the observations and photographs attached, other objects such as clusters of benthic algae or caddisfly eggs were sometimes erroneously reported as moss animal colonies. The first confirmed records of the species were made in 2006 close to the inlet to the Saimaa Canal. During the following years, there were few sightings and only 40 had been received by 2014. Since then, the reports have been more numerous with 46 records in 2016. There were altogether 97 confirmed records from the Vuoksi watercourse (Figure 3), but only one reliable from outside the Vuoksi watercourse, which was made in

2016 from Lake Kirkkojärvi in the River Kokemäenjoki watercourse, in the municipality of Lempäälä some 250 km from the Vuoksi watercourse. In most cases, the species was observed to foul fishing nets, or to be attached to submerged water plants, tree branches, and landing stage or quay structures.

According to the confirmed records (Figure 3), *P. magnifica* has relatively recently (ca 10 years ago) invaded the Vuoksi watercourse. Around 1000 foreign cargo vessels enter the Vuoksi watercourse annually through the Saimaa Canal. Observations were made in nine areas, seven of which were located on the Saimaa fairway near to harbours (Figure 3, Table S1) exporting paper (area 1), raw minerals (areas 2, 5 and 6), lumber and plywood (area 4), pulp (area 5), or fertilizers (area 8). Within the watershed, internal cargo, such as raw wood, is transported to Lappeenranta harbour (Area 2) according to the Statistics Finland StatFin database (2017).

In area 7 (Leppävirta Konnus) there is no harbour for international or internal cargo. However, there is a deep channel, also preferred by recreational boaters (considered as a secondary vector of the spread of *Pectinatella*), which might explain the occurrence of the species in the area. Observations made in area 3, were outside the Saimaa fairway and outside areas of internal cargo transport. Area 9 is also outside the Saimaa fairway, but on the route of internal cargo transport. Although raw wood and stoneware are transported from areas 17 (Juuka) and 18 (Nurmes), there were no reports of *P. magnifica* from those areas.

The pilot survey conducted in Lake Onkivesi revealed a sporadic distribution of *P. magnifica* (Figure 4). Consistent with the records from the public, colonies were found from the two northern sampling areas, but not from the south. Colonies were detected at 14 of the 56 sites sampled. Half of these 14 sites had fewer than 3 colonies and three sites had more than 20 colonies, with a maximum of 30. This maximum abundance observed within the sampling sites corresponds to an approximate density of one colony per 20 m². However, the two 500 m transects placed within the most populated areas showed a higher local density of colonies. Within the two transects, 954 and 285 colonies were counted (Figures 4B and 4C). Within populated areas along each transect, the average density was 4.7 (range 1–30) and 4.0 (1–39) colonies per 20 m² (calculated as the number of colonies within each populated cell of a spatial grid with cell size of 20 m²). Transect 1 (Figure 4B) had more suitable habitat and, therefore, more colonies per total length of studied shoreline than transect 2 (Figure 4C). Based on the most detailed sampling conducted at transect 1 (Figure 4B), the average depth at which colonies were attached

was 7.5 cm (range 0–40 cm; n = 270) and the corresponding total water depth at sites of occurrence was 20–50 cm. The average colony weight was 278 g (range 5–4270 g; n = 248). Most colonies were attached to submerged, relatively rigid water plant stems, such as common reed (*Phragmites australis*), horsetail (*Equisetum fluviatile*), broad-leaved pondweed (*Potamogeton natans*), and spike-rush (*Eleocharis* spp.) stems, as well as submerged willow branches, stones and quays. On the other hand, *P. magnifica* colonies seemed to avoid some plant species, such as common club-rush (*Schoenoplectus lacustris*), cattail (*Typha* spp.), yellow water-lily (*Nuphar lutea*) and white water-lily (*Nymphaea candida*). No colonies were found on extremely soft bottoms or within very dense vegetation.

Discussion

The occurrence of *Pectinatella* in the Vuoksi watercourse mainly follows the shipping waterways, and is almost exclusively confined to the vicinity of the harbours with international shipping in Lappeenranta (area 2), Varkaus (area 6), Kitee (area 4), Joensuu (area 5), Siilinjärvi (area 8) (Mäkelä 2012). Based on these observations, international shipping and ballast water transfer are likely the most important primary vectors for the *P. magnifica* invasion of the Vuoksi watercourse as previously suggested by Nehring (2005). Interestingly, the within watercourse transport of raw wood and stoneware does not seem to have spread the species into area 17 (Juuka), north of area 5, where *P. magnifica* is present. This is probably because raw wood and stoneware are mainly transported towards Lappeenranta, Joutseno and Imatra (area 10). However, bilge water from the barges transporting raw wood might be a potential vector of dispersal into area 9 in Lake Onkivesi. The vector of within-watershed dispersal into area 3 remains unclear. Our findings suggest that international shipping is the main vector, but secondary vectors, such as recreational boating within and between waters (Johnson et al. 2001; De Ventura et al. 2016) or alternatively passive transport by water birds (e.g. Wood 2002; Figuerola and Green 2002; Charalambidou et al. 2003; Reynolds et al. 2015) or fish (Markovic et al. 2009) may be potential vectors of dispersal of the species into new areas within the watercourse. *P. magnifica* was not found in some of the reference areas, such as in area 12 (Ukonvesi, Mikkeli), which is eutrophic but has no cargo harbour, or in area 14 (Savonlinna), which is oligotrophic but has a cargo harbour.

There is no international shipping to Lake Kirkkojärvi or any waterway connection to the Vuoksi

watercourse. Therefore, we consider overland transport of recreational boats or water birds to be the most likely vectors of dispersal to Lake Kirkkojärvi, which is a nutrient rich lake with high alkalinity (Table S1). As both high alkalinity (e.g. Ricciardi and Reisinger 1994) and high nutrient concentrations (Hartikainen et al. 2009) have been shown to favour bryozoans, many nutrient-enriched waters may offer potential new habitats. On the other hand, *P. magnifica* has been found from relatively oligotrophic and mesotrophic waters (Balounová et al. 2013), explaining its success in the Vuoksi watercourse (Table S1).

The high water temperature in summer 2014 probably contributed to the good growth of *P. magnifica*, the multitude of colonies and the increased notice by the general public. This attracted more attention from local and national media, which in turn likely increased the number of records made by the general public during 2014 and the following years. However, based on the record history (Figure 3), which suggests persistence and an expanding population range over time, it is most likely that the species has and will gradually become more widespread and abundant in the Vuoksi watershed and, more slowly, elsewhere in Finnish inland waters.

At the moment, the number and ecological impacts of non-indigenous species present in Lake Saimaa and other Finnish inland waters seem to be limited, even though they are still little studied. There are only two other previously known non-indigenous macroinvertebrate species present in the Lake Saimaa. The deliberately introduced and well-established signal crayfish (*Pacifastacus leniusculus*) has some documented ecosystem effects there (Ruokonen et al. 2014), whereas the occasionally encountered Chinese mitten crab (*Eriocheir sinensis*) cannot reproduce and establish in the lake (Pienimäki and Leppäkoski 2004). It is not surprising that *P. magnifica* is adding to this short array of non-native species and has been so successful in the lake. It is an ancient species as the oldest Pectinatellidae originate from the upper Triassic, ca 215 million years ago (Vinogradov 1996). The bryozoan may have been present in the area prior to the last ice age which ended around 10 000 years ago, and hence, might now be considered to be re-occupying its former native range (Koletić et al. 2015).

Invasion of *P. magnifica* may cause environmental detriment by fouling fishing gear and landing stage and quay structures, clogging water pipes, and by attaching to submerged substrata (stones, vegetation, branches) on shores used for recreation (e.g. Nakano and Strayer 2014; Choi et al. 2015). In addition to these nuisances, *P. magnifica* might pose a significant risk to fisheries and aquaculture, as it is a potential

host for the myxozoan endoparasite *Tetracapsuloides bryosalmonae* (Canning et al. 1999), the causative agent for proliferative kidney disease (PKD), which is known to be detrimental to farmed and wild salmonid fish (Sterud et al. 2007). Bryozoans, especially *Fredericella* and *Plumatella* species, have been shown to host *T. bryosalmonae* (Okamura and Wood 2002). Recently, molecular evidence has shown that *Pectinatella* may also host the parasite, and thereby, potentially transmit PKD (Tops and Okamura 2005; Hrabcová 2015).

The PKD agent has been detected in Estonia and Norway (Dash and Vasemägi 2014; Mo and Jørgensen 2017; Sterud et al. 2007). Up to now, PKD has been observed only twice in Finland, either with imported salmonid fish or otherwise in very restricted circumstances (Finnish Food Safety Authority Evira 2013). Only recently, the disease has also been detected in wild European grayling in the Koutajoki River system at the Finnish-Russian border and in wild brown trout in River Siuntionjoki in southern Finland (Vasemägi et al. 2017).

Climate change is expected to enhance the geographic range of both the bryozoan host as well as the myxozoan endoparasite (e.g. Okamura et al. 2011) causing a serious risk to both natural and cultivated salmonid fish species. Therefore, due to increasing water temperature (Korhonen 2013), it is highly likely that *Pectinatella* will to expand its spread in the near future.

T. bryosalmonae might be able to overwinter as cryptic stages in dormant statoblasts (Okamura and Wood 2002; Hartikainen et al. 2013; Abd-Elfattah et al. 2013). Symptoms of the disease in fish develop only in temperatures exceeding 15 °C (Gay et al. 2001; Bruneaux et al. 2016). Bryozoans, including *P. magnifica*, may also host other parasites (e.g. Desser et al. 2004; Stentiford et al. 2013) which increases potential risks from its invasion. Climate change and increased eutrophication are expected to increase the emergence of diseases (Tops et al. 2009), and interactions with concurrent invasion of an alternative host may be difficult to predict (Okamura et al. 2011).

Besides undesirable impacts, the invasion of *P. magnifica* may also have some positive consequences, although very little is known about its ecology and ecosystem effects. As a suspension feeder, it might remove large quantities of autotrophic and heterotrophic food items (Hartikainen et al. 2009) and influence localised nutrient cycling. Effective filtering of phytoplankton should result in increased visibility in water. Therefore, one interesting question is whether *Pectinatella* might even help to forestall initiation of algal mass occurrences. Moreover,

competitive interactions with zooplankton might alter food webs and thereby energy flow in ecosystems. *P. magnifica* may also have an antimicrobial effect on benthic algal and bacterial communities, leading to reduced biofilm formation (Pejin et al. 2015; Kollar et al. 2016).

Eradication or even prevention of further spread of *P. magnifica*, when it has been established in a watercourse, might be impossible as the statoblasts are very abundant, resistant, long lived and easily dispersed. Regardless of the vector of dispersal, potentially habitable areas for the species should be definable according to available substrata and water depth. In Lake Onkivesi, *P. magnifica* seemed to favour macrophytes with rigid, submerged stems as a substratum. Therefore, surveys of water depth and macrophyte vegetation should help in estimating potential areas of spread of the species in a lake. In favourable conditions, the species may become abundant, as shown by the pilot survey in Lake Onkivesi. Removal of preferred substrata may serve to limit the local abundance of *P. magnifica* colonies, but total eradication of the species habitats is neither technically feasible nor ecologically desirable. Monitoring the spread of the species by utilizing public observations, as well as more detailed on-site surveys, together with assessment of related risks and ecosystem effects, will be imperative in the future.

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References

- Abd-Elfattah A, Fontes I, Kumar G, Soliman H, Hartikainen H, Okamura B, El-Matbouli M (2013) Vertical transmission of *Tetracapsuloides bryosalmonae* (Myxozoa), the causative agent of salmonid proliferative kidney disease. *Parasitology* 141: 482–490, <https://doi.org/10.1017/S0031182013001650>
- Aleksandrov B, Voloshkevich O, Kurakin A, Rybalko A, Gontar V (2014) The first finding of bryozoan *Pectinatella magnifica* (Lophopodidae) in lower Danube. *Vestnik zoologii* 48: 307–312, <https://doi.org/10.2478/vzoo-2014-0036>
- Allman GJ (1856) A monograph of the fresh-water polyzoa, including all the known species, both British and foreign. London, Ray Society, 88 pp, <https://doi.org/10.5962/bhl.title.9143>
- Balounová Z, Rajchard J, Svehla J, Smahel L (2011) The onset of invasion of bryozoan *Pectinatella magnifica* in South Bohemia (Czech Republic). *Biologia* 66: 1091–1096, <https://doi.org/10.2478/s11756-011-0118-y>
- Balounová Z, Pechiousková E, Rajchard J, Joza V, Sinko J (2013) World-wide distribution of the bryozoan *Pectinatella magnifica* (Leidy, 1851). *European Journal of Environmental Sciences* 3: 96–100
- Barnes DK, Lauer TE (2003) Distribution of freshwater sponges and bryozoans in Northwest Indiana. *Proceedings of the Indiana Academy of Sciences* 112: 29–35
- Bauer C, Mildner J, Setliková I (2010) Das Moostierchen *Pectinatella magnifica* in Österreich. *Österreichs Fischereiverband und Bundesamt für Wasserwirtschaft* 63: 262–264
- Bilton DT, Freeland JR, Okamura B (2001) Dispersal in freshwater invertebrates. *Annual Review of Ecology, Evolution and Systematics* 32: 159–181, <https://doi.org/10.1146/annurev.ecolsys.32.081501.114016>
- Bruneaux M, Visse M, Gross R, Pukk L, Saks L, Vasemägi A (2016) Parasite infection and decreased thermal tolerance: impact of proliferative kidney disease on a wild salmonid fish in the context of climate change. *Functional Ecology* 31: 216–226, <https://doi.org/10.1111/1365-2435.12701>
- Canning EU, Curry A, Feist SW, Longshaw M, Okamura B (1999) *Tetracapsula bryosalmonae* n. sp. for PKX organism, the cause of PKD in salmonid fish. *Bulletin- European Association of Fish Pathologists* 19: 203–206
- Charalambidou I, Santamaria L, Figuerola J (2003) How far can the freshwater bryozoan *Cristatella mucedo* disperse in duck guts? *Archiv für Hydrobiologie* 157: 547–554, <https://doi.org/10.1127/0003-9136/2003/0157-0547>
- Choi J-Y, Joo G-J, Kim S-K, Hong D-G, Jo H (2015) Importance of substrate material for sustaining the bryozoan *Pectinatella magnifica* following summer rainfall in lotic freshwater ecosystems. *South Korea. Journal of Ecology and Environment* 38: 375–381, <https://doi.org/10.5141/ecoenv.2015.039>
- Dash M, Vasemägi A (2014) Proliferative kidney disease (PKD) agent *Tetracapsuloides bryosalmonae* in brown trout populations in Estonia. *Diseases of Aquatic Organisms* 109: 139–148, <https://doi.org/10.3354/dao02731>
- De Ventura L, Weissert N, Tobias R, Kopp K, Jokela J (2016) Overland transport of recreational boats as a spreading vector of zebra mussel *Dreissena polymorpha*. *Biological Invasions* 18: 1451–1466, <https://doi.org/10.1007/s10530-016-1094-5>
- Desser SS, Koehler A, Barta JR, Kamyab J, Ringuelet M (2004) *Trichonosema algonquinensis* n. sp. (Phylum Microsporidia) in *Pectinatella magnifica* (Bryozoa: Phylactolaemata) from Algonquin Park, Ontario, Canada. *Journal of Eukaryotic Microbiology* 51: 389–393
- Devin S, Bollache L, Noël P-Y, Beisel N (2005) Patterns of biological invasions in French freshwater systems by non-indigenous macroinvertebrates. *Hydrobiologia* 551: 137–146, <https://doi.org/10.1007/s10750-005-4456-z>
- d'Hondt J-L, Condé B (1996) Une espèce de Bryozoaires d'eau douce (Phylactolaemates) nouvelle pour la faune française: *Pectinatella magnifica* (Leidy, 1851). *Bulletin mensuel de la Société linnéenne de Lyon* 65: 322–326, <https://doi.org/10.3406/linly.1996.11143>
- Figuerola J, Green AJ (2002) Dispersal of aquatic organisms by waterbirds: a review of past research and priorities for future studies. *Freshwater Biology* 47: 483–494, <https://doi.org/10.1046/j.1365-2427.2002.00829.x>
- Finnish Food Safety Authority Evira (2013) Eläintaudit Suomessa [Animal diseases in Finland]. *Eviran julkaisu* 3/2014, 52 pp. https://www.evira.fi/globalassets/tietoa-evirasta/julkaisut/julkaisusarjat/elaimet/eviran_julkaisu_3_2014-elaintaudit-suomessa-2013.pdf
- Gay M, Okamura B, De Kinkelin P (2001) Evidence that infectious stages of *Tetracapsula bryosalmonae* for rainbow trout *Oncorhynchus mykiss* are present throughout the year. *Diseases of Aquatic Organisms* 46: 31–40, <https://doi.org/10.3354/dao46031>
- Hartikainen H, Fontes I, Okamura B (2013) Parasitism and phenotypic change in colonial hosts. *Parasitology* 140: 1403–1412, <https://doi.org/10.1017/S0031182013000899>
- Hartikainen H, Johnes P, Moncrieff C, Okamura B (2009) Bryozoan populations reflect nutrient enrichment and productivity gradients in rivers. *Freshwater Biology* 54: 2320–2334, <https://doi.org/10.1111/j.1365-2427.2009.02262.x>

- Hrabcová M (2015) Biology, life cycle and phylogeny of Malacosporeans in fish and bryozoans. Master thesis, University of South Bohemia in České Budějovice, Faculty of Science, 60 pp
- Hubschman JH (1970) Substrate discrimination in *Pectinatella magnifica* Leidy (Bryozoa). *Journal of Experimental Biology* 52: 603–607
- Jeong H, Lee K-L, Choi B-K, Kwon H, Part H-K, Jeong G-Y, Yu JJ (2015) Freshwater habitats of *Pectinatella magnifica* (Leidy, 1851) living in South Korea. *Korean Journal of Environmental Biology* 33: 352–359, <https://doi.org/10.11626/KJEB.2015.33.3.352>
- Jo H, Joo G-J, Byeon M, Hong D-G, Gim J-S, Kim J-Y, Choi J-Y (2014) Distribution pattern of *Pectinatella magnifica* (Leidy, 1851), an invasive species, in the Geum River and the Nakdong River, South Korea. *Journal of Ecology and Environment* 37: 217–223, <https://doi.org/10.5141/ecoenv.2014.026>
- Johnson LE, Ricciardi A, Carlton JT (2001) Overland dispersal of aquatic invasive species: a risk assessment of transient recreational boating. *Ecological Applications* 11: 1789–1799, [https://doi.org/10.1890/1051-0761\(2001\)011\[1789:ODOAIS\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2001)011[1789:ODOAIS]2.0.CO;2)
- Kaminski M (1984) Contributions to the knowledge of fresh-water Bryozoa of the Masurian Lake District. *Fragmenta Faunistica* 4: 73–78, <https://doi.org/10.3161/00159301FF1984.28.4.073>
- Koletić N, Novosel M, Rajević N, Franjević D (2015) Bryozoans are returning home: recolonization of freshwater ecosystems inferred from phylogenetic relationships. *Ecology and Evolution* 5: 255–264, <https://doi.org/10.1002/ece3.1352>
- Kollar P, Šmejkal K, Salmonová H, Vlková E, Lepšova-Skácelová O, Balounová Z, Rajchard J, Cvačka J, Jaša L, Babica P, Pazourek J (2016) Assessment of chemical impact of invasive bryozoan *Pectinatella magnifica* on the environment: Cytotoxicity and antimicrobial activity of *P. magnifica* extracts. *Molecules* 21: 1476, <https://doi.org/10.3390/molecules21111476>
- Korhonen J (2002) Suomen vesistöjen lämpötilaolot 1900-luvulla. (Water temperature conditions of lakes and rivers in Finland in the 20th century). Suomen ympäristö 566 (The Finnish Environment 566), 116 pp, <https://helda.helsinki.fi/handle/10138/40478>
- Korhonen J (2013) Water temperature variations in two Finnish lakes (Kallavesi and Inari) in 1981–2010. In: 19th International Northern Research Basins symposium and Workshop, Southcentral Alaska, USA. August 11–17, 2013, pp 127–136
- Kraepelin K (1887) Die Deutschen Süßwasserbryozoen. I. *Anatomisch-systematischer Teilung – Abhandlungen des naturwissenschaftlichen Vereins in Hamburg* 10: 1–168
- Leidy J (1851) On *Cristatella magnifica* n. sp. Proceedings of the Academy of Natural Sciences of Philadelphia V: 265–266
- Leuven RSEW, van der Velde G, Baijens I, Snijders J, van der Zwart C, Lenders HJR, bij de Vaate A (2009) The river Rhine: a global highway for dispersal of aquatic invasive species. *Biological Invasions* 11: 1989–2008, <https://doi.org/10.1007/s10530-009-9491-7>
- Manninen P, Kotanen J (2016) Vesien tila hyväksi yhdessä. Vuoksen vesienhoitoalueen vesienhoitosuunnitelma vuosiksi 2016–2021. Etelä-Savon elinkeino-, liikenne- ja ympäristökeskus. Raportteja 3/2016, <http://um.fi/URN:ISBN:978-952-314-391-3>
- Markovic G, Karan-Znidaric T, Simonovic P (2009) Bryozoan species *Hyalinella punctata* Hancoc in the gut content of chub *Leuciscus cephalus* L. *Polish Journal of Ecology* 57: 201–205
- Marsh T, Wood TS (2001) Results of a freshwater bryozoan survey in the Pacific Northwestern United States. *Bryozoan Studies* 2001: 207–214
- Massard JA, Geimer G (2008) Global diversity of bryozoans (Bryozoa or Ectoprocta) in freshwater. *Hydrobiologia* 595: 93–99
- Massard JA, Geimer G, Wille E (2013) Apparition de *Pectinatella magnifica* (Leidy, 1851) (Bryozoa, Phylactolaemata) dans le lac de barrage d'Esch-sur-Sûre (Luxemburg). *Bulletin de la Société des naturalists luxembourgeois* 114: 131–148
- Mawatari S (1973) New occurrence of *Pectinatella magnifica* (Leidy) in a Japanese lake. *Proceedings of Japanese Society of Systematic Zoology* 9: 41–43
- Michelene TM, Ostman C, Boylen CW, Nierzwicki-Bauer SA (2014) Records of bryozoan in the freshwater reach of the Hudson River estuary. *Northeastern Naturalist* 21: 369–379, <https://doi.org/10.1656/045.021.0305>
- Mo TA, Jørgensen A (2017) A survey of the distribution of the PKD-parasite *Tetracapsuloides bryosalmonae* (Cnidaria: Myxozoa: Malacosporea) in salmonids in Norwegian rivers – additional information gleaned from formerly collected fish. *Journal of Fish Diseases* 40: 621–627, <https://doi.org/10.1111/jfd.12542>
- Mäkelä O (2012) Itä-Suomen kuljetuskohdeselvitys. Rautatiekuorma-alueiden, vesitieterminaalien, jätekeskusten, kaivosten ja energialaitosten tieyhteydet. Pohjois-Savon elinkeino-, liikenne- ja ympäristökeskus, Raportteja 25 | 2012. https://www.doria.fi/bitstream/handle/10024/76715/Raportteja_25_2012.pdf?sequence=5
- Nakano D, Strayer DL (2014) Biofouling animals in fresh water: biology, impacts, and ecosystem engineering. *Frontiers in Ecology and the Environment* 12: 167–175, <https://doi.org/10.1890/130071>
- Nehring S (2005) International shipping – a risk for aquatic biodiversity in Germany. *Neobiota* 6: 125–143
- Notteghem P (2009) Évolution de la distribution de la Pectinatelle, *Pectinatella magnifica* (Leidy, 1851), Bryozoaire d'eau douce, en France et en Europe. *Revue Scientifique Bourgogne-Nature* 9/10: 188–197
- Okamura B, Hartikainen H, Schmidt-Posthaus H, Wahli T (2011) Life cycle complexity, environmental change and the emerging status of salmonid proliferative kidney disease. *Freshwater Biology* 56: 735–753, <https://doi.org/10.1111/j.1365-2427.2010.02465.x>
- Okamura B, Wood TS (2002) Bryozoans as hosts for *Tetracapsula bryosalmonae*, the PKX organism. *Journal of Fish Diseases* 25: 469–475, <https://doi.org/10.1046/j.1365-2761.2002.00376.x>
- Pazourek J, Šmejkal P, Kollár P, Rajchard J, Sinko J, Balounová Z, Vlková E, Salmonová H (2016) Invasion of *Pectinatella magnifica* in freshwater resources in the Czech Republic. *International Journal of Environmental, Chemical, Geological and Geophysical Engineering* 10: 314–321
- Pejin B, Ciric A, Horvatovic M, Jurca T, Glamoclija J, Nikolic M, Sokovic M (2015) An insight into antimicrobial activity to the freshwater bryozoan *Pectinatella magnifica*. *Natura Product Research* 30: 1839–1843, <https://doi.org/10.1080/14786419.2015.1068773>
- Pienimäki M, Leppäkoski E (2004) Invasion pressure on the Finnish Lake District: invasion corridors and barriers. *Biological Invasions* 6: 331–346, <https://doi.org/10.1023/B:BINV.0000034607.00490.95>
- Rassi P, Hyvärinen E, Juslén A, Mannerkoski I (2010) The 2010 Red List of Finnish Species. Ympäristöministeriö & Suomen ympäristökeskus, Helsinki, Finland, 685 pp, <http://www.ymp.fi/download/noname/%7BD978FAEA-1AEB-44AF-AD50-163D17E671A7%7D/58997> and <http://www.ymp.fi/download/noname/%7BD39E7EDA-CB3B-4E84-B15C-DEE3B269AA65%7D/58998>
- Reynolds C, Miranda NAF, Cumming GS (2015) The role of waterbirds in the dispersal of aquatic alien and invasive species. *Diversity and Distributions* 21: 744–754, <https://doi.org/10.1111/ddi.12334>
- Ricciardi A, Reisinger HM (1994) Taxonomy, distribution, and ecology of the freshwater bryozoans (Ectoprocta) of eastern Canada. *Canadian Journal of Zoology* 72: 339–359, <https://doi.org/10.1139/z94-048>
- Ruokonen TJ, Karjalainen J, Hämäläinen H (2014) Effects of an invasive crayfish on the littoral macroinvertebrates of large boreal lakes are habitat specific. *Freshwater Biology* 59: 12–25, <https://doi.org/10.1111/fwb.12242>
- Statistics Finland StatFin database (2017) http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin_lii_uvliik/010_vuulik_tau_101.px?rxid=a5ba7a1c-105f-46a2-37cf450c2SMH_2 (accessed 28 April 2017)
- Stentiford GD, Feist SW, Stone DM, Bateman KS, Dunn AM (2013) Microsporidia: diverse, dynamic and emergent pathogens in aquatic systems. *Trends in Parasitology* 29: 567–578, <https://doi.org/10.1016/j.pt.2013.08.005>

- Sterud E, Forseth T, Ugedal U, Poppe TT, Jørgensen A, Bruheim T, Fjeldstad H-P, Mo TA (2007) *Diseases of aquatic organisms* 77: 191–198, <https://doi.org/10.3354/dao01846>
- Syke (2014) Surface temperature of open waters. http://www.ymparisto.fi/en-US/Maps_and_statistics/Hydrological_observations/Monthly_hydrological_reports (accessed 28 April 2017)
- Szekeres J, Akác A, Csányi B (2013) First record of *Pectinatella magnifica* (Leidy 1851) in Hungary. *Water Research and Management* 3: 47–49
- Taticchi MI, Battoe L, Elia AC, Havens KE (2011) Freshwater byozoans (Phylactolaemata) from Central Florida lakes. *Florida Scientist* 74: 238–252
- Tops S, Hartikainen H-L, Okamura B (2009) The effects of infection by *Tetracapsuloides bryosalmonae* (Myxozoa) and temperature on *Fredericella sultana* (Bryozoa). *International Journal for Parasitology* 39: 1003–1010, <https://doi.org/10.1016/j.ijpara.2009.01.007>
- Tops S, Okamura B (2005) Malacosporean parasites (Myxozoa, Malocosporea) of freshwater bryozoans (Bryozoa, Phylactolaemata): a review. *Denisia* 16, zugleich *Kataloge der OÖ. Landesmuseen Neue Serie* 28: 287–298
- van der Waaij M (2017) http://www.microscopy-uk.org.uk/mag/artfeb10/mw-bryozo_statoblasts.html (accessed 4 September 2017)
- Vasemägi A, Nousiainen I, Saura A, Vähä J-P, Valjus J, Huusko A (2017) First record of proliferative kidney disease agent *Tetracapsuloides bryosalmonae* in wild brown trout and European grayling in Finland. *Diseases of Aquatic Organisms* 125: 73–78, <https://doi.org/10.3354/dao03126>
- Vinogradov AV (1996) New fossil freshwater bryozoans from the Asiatic part of Russia and Kazakhstan. *Paleontological Journal* 30: 284–292
- Wang B, Wang H, Cui Y (2017) *Pectinatella magnifica* (Leidy, 1851) (Bryozoa, Phylactolaemata), a biofouling bryozoan recently introduced to China. *Chinese Journal of Oceanology and Limnology* 4: 815–820
- Wilcox AW (1906) Locomotion in young colonies of *Pectinatella magnifica*. *The Biological Bulletin* 11: 245–252, <https://doi.org/10.2307/1535746>
- Williams SR (1921) Concerning “larval” colonies of *Pectinatella*. *Ohio Journal of Science* 21: 123–127
- Wood TS (2002) Freshwater bryozoans: a zoogeographical reassessment. In: Wyse Jackson PN, Buttler CJ, Spencer Jones M (eds), *Bryozoan Studies 2001: Proceedings of the 12th International Bryozoology Association*. Balkema: Rotterdam & Brookfield, pp 339–345
- Zoric K, Szekeres J, Csányi B, Kolarevic S, Markovic V, Paunovic M (2015) Distribution of the non-native Bryozoan *Pectinatella magnifica* (Leidy, 1851) in the Danube River. *Acta Zoologica Bulgarica* 67: 241–247

Supplementary material

The following supplementary material is available for this article:

Table S1. Average water quality in the Vuoksi watercourse in 2000–2016 (June–September, upper 2 metres) for 9 areas with observations of *Pectinatella magnifica* and for 10 areas, also with cargo shipping or active recreational boating, but with no observations.

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